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The Durability Test Method for External Thermal Insulation Composite System (ETICS) used in Cold and Wet Climate Countries

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The paper proposes the durability prediction method for external thermal insulation composite system (ETICS), which could be applied in cold and wet climate regions. This improved method is based on the international and nowadays applicable standards for systems service life assessment (ETAG 004, ISO 15462), and completes them with other necessary impact criteria. This study examines the main climate exposures and how these impacts reproduced in the laboratories. The paper analyses the extreme air temperature and rainfall changes, the intensity of ultraviolet radiation (UV) in Lithuania. The analysis is based on evaluation of daily and yearly data recorded by meteorological stations.

The aim of the research is to compose the accelerated ageing cycle for ETICS taking into account the characteristics of building materials and identifying the potential degradation factors and indicators. In order to establish the combinations of impacts in ageing cycles, it is necessary the adequate evaluation of intensity of environmental exposures of a certain locality. The basic goal is to create the reliable accelerated ageing cycle which would be as similar as natural ageing.

Keywords: *ETICS, durability method, service life prediction, cycle, external render.*

1. Introduction

External thermal insulation composite system (ETICS) is widely used for new construction, reconstruction and renovation of old buildings. The main function of ETICS is to improve the thermal properties of enclosures and meet the requirements of the national building regulations of thermal performance of buildings. Various information about the durability of these systems we can find from the earlier researches (Daniotti and Paolini 2005, Nilica and Harmuth 2005, Daniotti and Paolini 2008, Topcu and Merkel 2008, Stazi et al. 2009).

The service life of ETICS commonly depends on the aging processes of rendering: corrosion, fatigue, loss of colour, staining, soiling, cracking, loss of adhesion, etc. Usually renders are exposed to complex atmospheric factors, such as UV radiation, moisture (rain and dew), wind, temperatures changes, which may cause surface cracks, deformations in external thin-layer (Tittarelli et al. 2007, ASHRAE 2007, Koči et al. 2012). An external layer of the system, with a typically thickness 1-3mm, must resist the biggest atmospheric effect. Thin-layer of render absorbs liquid water into its pores and capillaries. Therefore the maximum negative effect occurs in microstructure of render: changes of the internal pore radius of cylindrical pore length bend capillary (Bochen et al. 2005, Bochen and Gil 2009, Bochen 2009). It is known, that lower moisture absorption results longer service life (Topcu and Merkel 2008).

Accelerated climate ageing investigations are carried out in order to study the durability of various building materials in a substantial shorter time span than natural weather ageing would have allowed. Accelerated climate ageing could help to understand degradation processes of ETICS system. Furthermore, accelerated ageing ought to be as similar as natural ageing. Several experiments were performed concerning ETICS service life and different results were obtained due to different test methods (Shohet and Paciuk 2004, Daniotti and Paolini 2005, Bochen et al. 2005, Jelle et al. 2008, Daniotti and Paolini 2008, Bochen 2009, Bochen and Gil 2009, Koči et al. 2012, Norvaišienė et al. 2011).

The aim of the research is to develop the reliable method of accelerated ageing which could be used to predict the durability of ETICS under natural ageing conditions. The purpose of this study is to review the previous researches investigating the service life of ETICS, to examine the main climate exposures and how these may be reproduced and applied in the laboratory conditions.

2. Methods

Natural and accelerated ageing tests are extremely important for determination of the ageing characteristics of the materials and prediction of their real durability. Many different accelerated ageing tests and evaluation methods have been proposed for predicting and comparing the durability of various kinds of rendering.

The essential properties of building products and their durability with respect to climate factors were investigated within a relatively short time compared with natural outdoor climate ageing. Researchers tried to find out the correlation between natural and accelerated weathering, but chosen by them climatic impacts of accelerated tests are still different enough (Shohet and Paciuk 2004, Daniotti and Paolini 2005, Bochen et al. 2005, Jelle et al. 2008, Daniotti and Paolini 2008, Bochen 2009, Bochen and Gil 2009, Koči et al 2012). Most of these studies were based on the assumption that raised ageing temperatures and water spraying accelerates the reactions responsible for natural ageing.

One of the durability investigation methods has been created by Finnish researches (NT BUILD 495, 2000). The test method is intended for exposing materials and components used in a building envelope to UV light and heat radiation, water and frost. The results of the test were given as any changes in appearance of the specimens during the test. The description of the cycle is given in Table 1.

Another very similar ageing cycle is proposed by Polish scientists J. Bochen, S. Gil and J. Szwabowski (Bochen *et al*. 2005, Bochen 2009). The ageing test was carried out in rotational chamber with different impacts of temperatures, relative humidity, UV and rain (Table 1). The emphasis has been placed on open capillary porosity, which was examined over time.

Later on accelerated ageing test has been performed by J. Bochen in the same chamber (Bochen and Gil 2009). The influence of porosity and its structure upon the physical properties of thin-layer external render has been studied after ageing. The results showed that after weathering the changes of porosity, pore structure and chemical microstructure of plaster occurred. This, in turn, have led to thermal and shrinking cracks and weakened the render adhesion to the background. These symptoms were clearly seen on a macro level. The changes of porosity by accelerated ageing and natural weathering were compared (table 1).

Some researchers seek to find theoretical models capable of predicting rates of rendering natural ageing or

Table 1. *Accelerated climatic ageing cycle methods*

Method		Simulation of climatic impact, °C / duration				Relative humidity, %	Observation of deterioration during/after the test	Equivalence to natural ageing
		UV	Rain	Cold	Heat			
NT Built 495		+35 ± 5/1h +50 ± 5/1h +75 ± 5/1h	Spray l/ (m^2h) (suggested) 15 ± 2/1h	–20 ± 5/1h	+23 ± 5/1h	50 ± 10	Visual evaluation	Not estimated
J. Bochen[1]		+60/1h	Spray with gusts/4h	–20/4h	with UV	–	open porosity and average pore radius of render	100 cycles equivalent to 1.5–2.7 years
J. Bochen[2]		+50/1h	Spray/0.25h	–20/1h	with UV	–	open porosity and average pore radius of render	100 cycles equivalent to 2 years
B. Daniotti	Short-term	+35/1h	5 ± 2/1h Spray 1 $l/(m^2h)$	–20 ± 2/3h	+70 ± 2/1h	60 ± 5	Microscope analysis Water absorption Water vapour permeability Tensile bond strength of adhesive and base coat to insulator Render strip tensile IRT, SINa, SINb, TI CON RHst, degradation survey photos	Not estimated
	Long-term	Should be developed						
ETAG 004	Heat-rain cycles (80cycle)	–	+15 ± 5/1h Spray 1 l/ $(m^2 min)$	–	+70 ± 5/3h	30	Impact resistance Bond strength Water vapor permeability Visual evaluation	The whole service life
	Heat-cold cycles (5 cycles)	–	–	–20 ± 5/16h	+50 ± 5/8h	10		
	Freeze-thaw (30 (cycles)	–	Immersion +23 ± 2/8h	–20 ± 2/16h		–	Bond strength Visual evaluation	

their degradation rates (Daniotti et al. 2008, Daniotti and Paolini 2008). B. Daniotti suggested experimental program for ETICS render durability assessment through accelerated laboratory ageing, which is now applied in Milan. In order to design the accelerated cycles and assess the proportion between its parts, two ways have been pursued: standard reference (ETAG 004, 2000, ISO 15686-1, 2000, ISO 15686-2, 2001) and the analysis of climatic data of Milan context (Test reference Year and UNI 10349). Author compared results between long-term outdoor exposure and accelerated laboratory ageing cycle. B. Daniotti proposed some important conditions regarding ETAG 004 procedure (Daniotti and Paolini 2005, Daniotti et al. 2008) and stated, that the use of degradation factors and mechanisms should be pointed out in composition of the ageing cycles, in order of ageing phases and maximum intensity of impacts. The test method has been designed in order to compare laboratory ageing and outdoor exposure.

The shortages of existing accelerated ageing tests. Analyzing overviewed accelerated tests we can state that artificial laboratory tests have advantages and disadvantages.

Accelerated ageing test, according to NT BUILD 495, in a laboratory always carries the risk that the material might sustain degradation by other mechanisms than those which will take place by natural ageing. The results of the exposure according to this standard should as far as possible be compared with long-term tests performed with the same materials and similar constructions outdoors. The method gives no guidance how the properties of the test specimens should be measured or evaluated after exposure. Also, the method does not specify how much the climate exposure and degradation processes are accelerated.

Analyzing an accelerated cycle created by J. Bochen (J. Bochen 2009, J. Bochen and Gil 2009), it was found out that the external layer of rendering was moistened only about 15 minutes during the cycle. Is it enough 15 minutes of water spray that render could be completely absorbed by water? Also, these two methods (J. Bochen and S. Gil 2005, J. Bochen, 2009) are intended only for external render. ETICS consists of several layers and it is important to examine the durability of the entire system. The impact of the artificial accelerated cycle should affect not only external layer, but also deeper layers too.

By analyzing the durability tests of ETICS according to ETAG 004 it is important to pay attention to the few issues:

- If the water absorption of system is less than 0.5 kg/m2 after 24 hours, the system will be frost resistant and durable for its whole service life, is this subject true for all kinds of rendering and all climate conditions?
- If the defects do not occur after hydrothermal cycling, the system will be weather resistant. Is it true?
- What kind of decay UV radiation gives to the ETICS?

Is it reliable to determine the ETICS durability by the ETAG 004 procedure?

The accelerated ageing method by B. Daniotti includes UV, freeze, heat and rain impacts. After completion of ageing cycles many disruptive and non-disruptive tests are performed for the evaluation of decay (table 1). However, is it necessary to use all these test methods, moreover the earlier studies showed, that the most simple and reliable indicator of render's ageing is the change of water absorption rate during the ageing. (ASHREA 2010, Topcu and Merkel 2008, Norvaišienė et al. 2011, Koči et al. 2012)

By summarizing all above mentioned accelerated ageing methods, one matter arises: why such climate impacts, durations and amplitudes are chosen for determination of ETICS durability?

Most often, accelerated tests applied in durability investigation are based on the complex of extreme conditions imitating the 'universal environment' and therefore are inadequate to climatic conditions of a certain locality. When modeling the environmental conditions, it is necessary to find out reasonable testing methods related with the climatic specificity of a certain locality.

In order to have more information about the durability of the ETICS, it is necessary to create the ageing cycles that comply with the terms of use. Tests, which incorporate accelerated techniques, can be used when in-use conditions are known, mechanisms of deterioration are understood, key effects causing deterioration have been identified, and the range of effects (application time and severity) can be adequately simulated in a laboratory.

3. Experimental

In order to find out correlation between the results of short-term and long-term tests, the accelerated and natural weathering has been started.

3.1. Material

For the modeling of the laboratory accelerated short-term cycle, the four samples of each ETICS with dimensions 200×200×50 mm of acrylic, silicate, mineral and silicone renders have been made (Fig. 1).

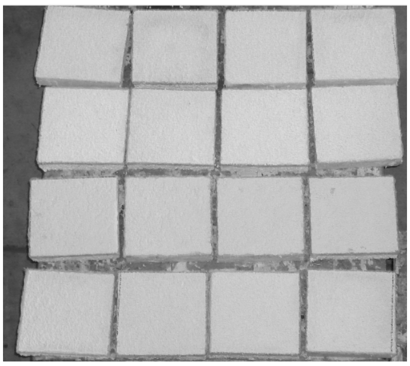

Fig. 1. *Specimens prepared of ETICS for artificial accelerated exposure (200×200×50 mm)*

For the natural ageing sample panels 1000 × 500 × 50 mm four samples of each type of rendering were exposed on a 56^{o} slope wooden south facing rack, placed on the flat roof of building (Fig. 2). During natural ageing relative humidity, UV radiation, wind velocity, temperatures changes and moisture (rain and dew) impacts were recorded by sensors at the meteorological station of Institute of Architecture and Construction.

Fig. 2. The natural exposure of ETICS panels (1000×500×50 mm) on the wooden test rack

The water absorption, bond strength and macrostructure analysis after 6, 12, 18, 24 months of natural weathering will be measured to estimate the degradation of renders.

Four samples of each types of rendering coats on plastic strip were made, in order to measure the rate of water absorption of external layer (Fig. 3).

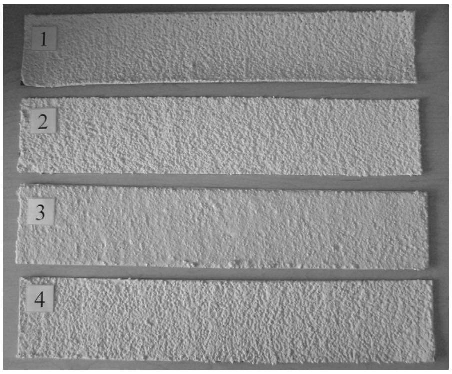

Fig. 3. The samples of external render coats on plastic strips: 1 – acrylic render, 2 – silicate render, 3 – mineral render, 4 – silicon render

It was examined the water absorption of external render layer of ETICS in order to determine what is the required duration of water impact that render could be completely saturated by water.

3.2. Modeling of climate impacts

In order to predict service life of ETICS, the accelerated climatic cycle was composed on the basis of earlier scientific research (Shohet and Paciuk 2004,Topcu and Merkel 2008, Norvaišienė et al. 2010, Jelle et al. 2008) and the statistic data of the Lithuanian climate (RSN 156-94, 1995), with respect to the average rain duration, UV radiation and the extreme outdoor temperatures in summer and winter

Modeling of rain impact. For modeling the rain impact cycle it the water absorption rate was determined (LST EN ISO 15148, 2004). Fig. 4 demonstrates the increment of water absorption intensity during water absorption test for ETICS samples.

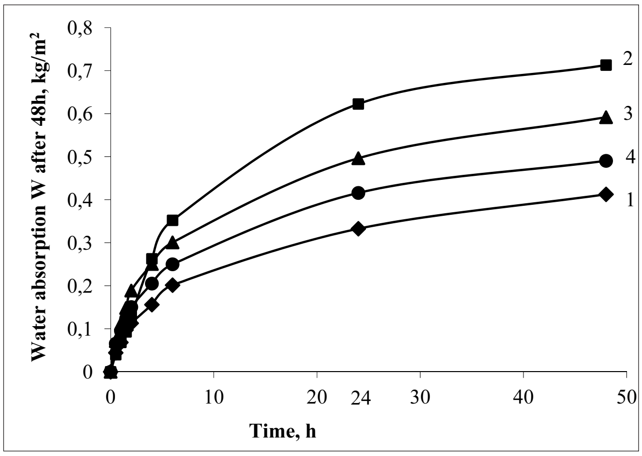

Fig. 4. Water absorption rates of ETICS samples from water surface: 1 – with acrylic render, 2 – with silicate render, 3 – with mineral render, 4 – with silicone render

Water absorption curves show, that after immersion of ETICS samples into the water, the intensity of water absorption slowdown after about 24 h.

The same water absorption test was performed with external render coats on plastic strip. The water absorption was measured every 5 minutes (Fig. 5). The water absorption slowdown after 4h and later on it continues to absorb water very slowly.

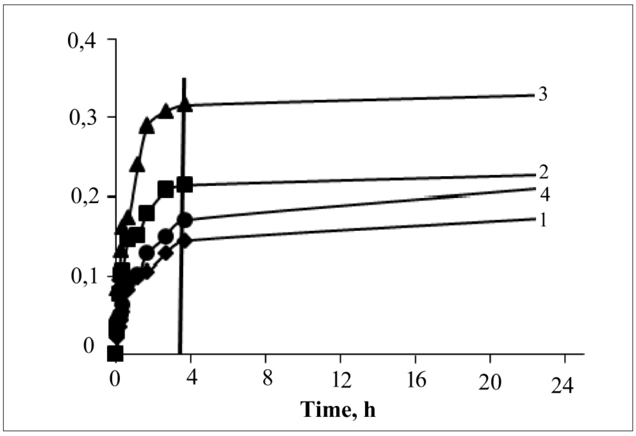

Fig. 5. Water absorption rates of external render samples on plastic strip from water surface: 1 – with acrylic render, 2 – with silicate render, 3 – with mineral render, 4 – with silicon render

These tests show that water absorption of whole ETIC system is more intensive and has higher values of water absorption than water absorption of external render of ETICS on plastic. For accelerated ageing it is important to analyze the physical changes of whole ETIC system, although the maximal negative effects of water occurs in external layer of render. From these tests it follows that the duration of rain impact we should chose not less than 4h in order to saturate by water the whole render of ETICS.

On the basis of the climatic data (RSN 156-94, 1995), the average rain duration on the vertical south-west surface in Lithuania is about 7h and it repeats about 16 times per year. In order to imitate the rain impact on ETICS samples the duration of water impact for 7h have been chosen.

Modeling of cold impact. It has been found out that the cold waves of –1.5 °C degrees temperature in Lithuania are repeated approximately 24.16 times, –4.5 °C degrees – 7.44 times, –8 °C degrees – 4.44 and –12 °C degrees – 5.72 times per year (RSN 156-94, 1995). On the basis of earlier scientific research it was estimated correlation between wave period and its amplitude: the period is growing by increasing the amplitude (Ramanauskas and Stankevičius 1998). Following that the cooling waves of –1,5 °C (24.16 times) have very low impact, the optimal variant was chosen: the impact of the annual natural frost cycles on the ETICS should be imitated by 18 freezing cycles per year each lasting for not less than 7 hours at the ambient air temperature of –12 °C.

Modeling of heat and UV radiation impacts. The +40 °C heating phase temperature has been chosen as an effective surface temperature due to direct Sun irradiation on the surface during mean nebulosity (RSN 156-94, 1995). In order to determine the necessary duration of drying during ageing cycle the drying test of samples has been performed. Fig. 6 demonstrates the drying intensity rate during drying test for ETICS samples. The samples dry out to the original weight within 24 h (at +40 °C). Therefore, the duration of heating phase has been adjusted to the need of sufficient drying out of samples during accelerated ageing of samples in the climatic chamber.

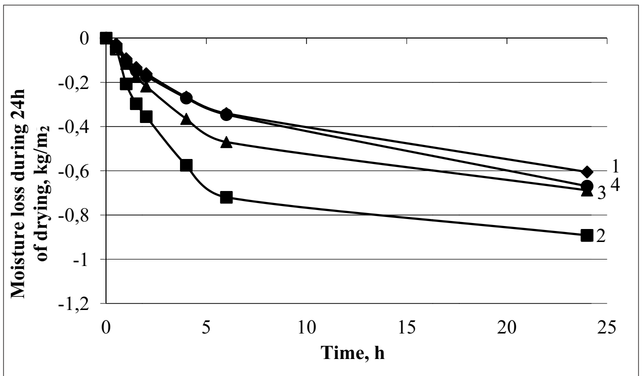

Fig. 6. Drying rates curves of ETICS samples: 1 – with acrylic render, 2 – with silicate render, 3 – with mineral render, 4 – with silicon render

At the same time the UV radiation impact was included. UV makes only 6 %, of the whole solar radiation in Lithuania; however, in the spectrum of all solar radiation waves, its impact on the finish material ageing is the most extensive (Norvaišienė et al. 2010). The intensity of UV in laboratory accelerated cycle has been calculated on the basis of the highest hourly intensity of solar radiation onto a vertical south surface. In the 290–450 mm UV wave range, under the conditions of the climatic chamber the intensity should be 35–40 W/m^2. The calculated UV radiation period embraces 448 h/year.

The laboratory accelerated ageing cycle for ETICS samples is given below (table 2).

After 16 cycles (28 days) of spraying, freezing, UV radiation and heating, the water absorption and bond strength will be respectively measured in order to determine the accelerated ageing effect to ETICS. 16 ageing cycles should be adequate to one natural year.

4. Discussion

In most the cases the accelerated aging cycles underestimate specifics of country's geographical location and prevailing climate, therefore these cycles cannot be applied in every climate zone. The intensities of weathering impacts and duration of the accelerated cycles are also not fully assessed. Our accelerated aging cycle was based on previous results (Norvaišienė et al. 2010) and Lithuanian climatological data. The most important climatic factors were selected which were involved into accelerated ageing cycle. During laboratory ageing process the most important weathering impacts and their sets, which determine the ageing and decay of ETICS are to be modelled.

Having compared the water absorption of ETICS samples and samples on plaster strips it has been observed that both cases demonstrated different results. It was experimentally proved, that water absorption rate of external layer on plastic strips increases considerably only during the first 2 h of moistening and after 4 h it fully saturates. So it is obvious that it is not enough 15 minutes to saturate the external layer of ETICS by water, as proposed in J. Bochen's method.

The analysis of water absorption of ETIC systems has shown that the silicate rendering absorbs the most of all the renderings (0.62 kg/m^2 per 24 h), and acrylic rendering –

__Table 2.__ The accelerated ageing with UV-heating-moistening-freezing impacts

Description	Air temperature, °C	Process	Total exposure period, h	Observation of deterioration during/after the test	Equivalence to natural ageing
Rain	+20	spraying	112	Macroscopic analysis Water absorption Visual evaluation Bond strength	28 days ≈ 1 year
Cold	–12	freezing	112		
UV radiation 35-40W/m^2 and heat	+40	UV lamps and heating	448		
The phases of **one** ageing cycle:					
rain	+20	spraying	7	Note: repetitions for one natural year weathering imitation – 16 times	
cold	–12	freezing	7		
UV and heat	+40	drying	28		

the less of all (0.33 kg/m^2 per 24 h). However according to water absorption rates of external layer of rendering the maximal rate of water absorption comes to mineral (0.33 kg/m^2 per 24 h) and minimal rate – to acrylic layer (0.17 kg/m^2 per 24 h). This means that the initial water absorption rate depends not only on kind of external layer, but of ETICS deeper layers too, i.e. reinforcement layer.

The offered accelerated weathering cycle could be useful for ETICS manufacturers and it could be used for testing and proof of highly frost-resistant products. The accelerated climatic testing continues and the results will be presented later. Correlation between the results obtained from artificial accelerated ageing and the natural weathering will be established.

5. Conclusions

During the creation of the accelerated ageing cycle the Lithuanian climate characteristics and results of earlier research have been taken into account. This accelerated cycle also could be applied for imitation of weathering impacts of rainy localities in middle climate zones.

In the climatic chamber the impact of UV radiation has been imitated for 28 hours with intensity of 35–40 W/m^2 and impact of summer heating – by conditioning at +40 °C temperatures. The impact of rain has been imitated by spraying for 7 hours with intensity of 1 l/ (m^2·min). The impact of winter cold has been imitated by 7 hours freezing at –12 °C temperatures. All 16 cycles takes 28 days (about 672 hours). As mentioned above, the created ageing cycle includes the main environmental impacts, however the durations and intensities of cycles are different. Our modeled cycle is calculated for certain area, i.e. for Lithuanian climate.

For determination of durability of ETICS four evaluation indicators have been chosen: macroscopic analysis, water absorption rate, mechanical adhesive strength and visual monitoring, because these are the sufficient indicators for durability evaluation of systems. These evaluation indicators are considerably simpler than evaluation techniques offered by B. Daniotti.

The whole accelerated ageing cycle lasts for 28 days which corresponds to about one natural year in the most unfavorable conditions.

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