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The Changes of Moisture Absorption Properties during the Service Life of External Thermal Insulation Composite System

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This paper provides initial results from experimental work on the durability of external thermal insulation composite system (ETICS). In order to predict service life of ETICS, the accelerated climatic cycle was composed on the basis of earlier scientific research and the statistic data of the Lithuanian climate. The research aims to assess the durability and service life of finishing coat by calculating the amount of moisture while measuring the 24 h water absorption of the samples during water absorption and drying testing either by measuring the changes of bond strength. 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.

Keywords: ETICS, rendering, water absorption, moisture, freezing, durability, bond strength.

1. INTRODUCTION

External thermal insulation composite system (ETICS) has been developed in Europe after World War II and initially used to retrofit solid masonry walls. Nowadays ETICS is widely used both for new construction, reconstruction and renovation of old buildings. For more than five decades, thermal insulation composite systems have been the invaluable aid reducing the heating energy need for buildings, but until now there is lack of knowledge of the system durability. In Lithuania ETICS began to be used only in the 1996. With the growth of application of ETICS the need of rapid prediction of its moisture resistance as well as durability of system arise. Therefore it is essential to study the causes of the degradation of ETICS. ETICS has a number of advantages and certain disadvantages. Due to these disadvantages – high moisture absorption, low vapour permeability, low resistance to impact – the problem of durability and efficiency of external insulation facade systems occur.

The effect of moisture plays a critical role in the service life of external finishing coat of buildings [1 – 7]. It has been estimated that heavy rains and freeze-thaw actions will increase remarkably during the following decades [8]. Therefore the main task of ETICS researches – the development of moisture-caused deformations investigation methods. The hygric properties of painted thin-layer render has been studied on the experimental basis [6, 7, 9]. But there are a lot of ETICS where the protective paint coating is not used. Thin layer of render absorbs liquid water into its pores and capillaries. It is known, that lower moisture absorption results longer service life [3]. It were performed a lot of experiments concerning ETICS service life and different results were obtained due to different test methods. Furthermore, the results from natural observations are different.

F. Stazi [10] demonstrated that the retrofitting carried out 20 years before was still effective from the point of view of thermo-hygrometric performance (guaranteeing the heat transmission rate values and the elimination of thermal bridges) and from the point of view of mechanical performance. However Mendes da Silva [11] presented three groups of defects has been observed during natural inspections of real buildings during 12 years: surface defects, cracks and local deterioration.

The durability of ETICS is outlined in Guideline for European Technical Approval ETAG 004 [12]. The requirements for water absorption amount are strictly controlled, though it does not include any dealing with significant frost attack. Instead, frost durability requirements are presented as water absorption properties. Moreover, hygrothermal tests include only heat-rain and heat-cold cycles and between these two regimes is the 48 hours of subsequent conditioning.

Daniotti [4, 13] analyzed ETICS durability referring to ETAG 004. He proposed some important conditions regarding ETAG 004 procedure. He stated, that the use of degradation factors and mechanisms analysis should be pointed out composition of the ageing cycles, order of ageing phases and maximum intensity of impacts. Furthermore, he thoroughly analysed the moisture impact on ETICS loss of thermal resistance. The difference between the values for thermal resistance calculated with the standard reference and those measured that show an evident loss in insulation performance. At the same ageing conditions, and after a rain cycle, a significant loss in thermal resistance was observed [14].

ETICS are highly susceptible to superficial condensation. Barreira [15] states, that increased surface moisture content, caused by night-time condensation, is one of the factors that influence this aesthetical degradation. Superficial condensation is caused by radiative cooling of the surface, which is more detrimental during the night due to the lack of incident solar radiation. Many authors state, that the conditions during and after

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application of ETICS (temperature, humidity, weathering) are of influence for integrity and lifetime of the system [1, 2, 10, 16].

Atmospheric exposure tests for ETICS generally include high temperature, rain imitation, cold cycles [1, 2]. Xiugin [1, 2] has studied the weatherability of ETICS by simulating heat, rain and frost conditions. He chose the adhesive strength as parameter specified the durability of ETICS. Very relevant work with extruded polystyrene foam has been carried by Topcu [3]. He determined that impact of hygrothermal ageing on the tensile bond strength properties of systems with extruded polystyrene insulation boards is rather small. The earlier experiments results show that the adhesive strength of ETICS changes a little during high temperature-spraying water cycle, but the adhesive strength decreases significantly after heating-refrigeration cycle [1, 2].

Most often, traditional standard (comparative) tests applied in durability investigation are based on the complex of extreme conditions imitating the 'universal environment' [16 – 18] and therefore are inadequate to climatic conditions of a certain locality. It is important to define the movement of water in system in order to predict the durability of the ETICS under natural ageing conditions. When modelling the environmental conditions, it is necessary to find out reasonable testing methods related with the climatic specificity of a certain locality.

It must be pointed out that the water absorption is almost always involved in all types of degradation mechanisms of mineral buildings materials which may be physical, chemical or biological in nature, or even combinations of these. There are made a lot of moisture impact testing on painted thin layer render [1, 6, 10], however, the effect of moistening – freezing – drying regimes on the water absorption of ETICS has not been adequately investigated. Especially this applies to cold climate countries, where the biggest problems occur while at the same time ambient conditions are wet and cold. In order to have more information about the durability of the ETICS, it is necessary to create cycles that comply with the terms of use. The real durability of ETICS cannot be predicted following the results of current artificial weathering tests, because they do not include the simulation of the overall impact of moisturing-drying-freezing cycling. Especially it applies to cold climate countries.

In the literature [1 – 4, 8, 17] we find some data on the physical and mechanical properties of materials intended for finishing, which predetermine the durability of such materials. However, these data are often insufficient and fragmentary. Therefore, the partial comparative investigations have been carried out. In this paper we present moisture impact on finishing layer depending on presence of glass mesh and developed test which includes heaver stress cycles than the test suggested by ETAG 004. In this test moisture, cold and heat phases are combined, which is the main difference compared to the ETAG version.

The research aims to assess the durability and service life of finishing coat with different external coatings by calculating the amount of moisture while measuring the 24 h water absorption of the samples during water absorption and drying testing either by measuring the changes of bond strength.

An attempt has been made to develop new method for ETICS durability assessment to be used in service life prediction. The data obtained from laboratory tests and analysis may also meet practical needs of the end-users.

2. EXPERIMENTAL

2.1. Materials

For the determination of the render moisture parameters, 5 samples of ETICS with different finishing coat have been treated. Specimens were made by use of the same thermal insulation material EPS 70 (produced by Lithuanian company "Ukmergės gelžbetonis" and Latvian company „Tenapors"). In order to identify the differences of base coat and finishing coat properties different finishing coatings were chosen. The authors have chosen the most popular mineral and acrylic renderings (manufacturers "Tex Color" and "Sia Sakret"). In order to find the impact of double glass mesh on ETICS water absorption rate, specimens with and without glass mesh also specimens with double glass mesh were selected. The size of specimens was 200 mm × 200 mm. The thickness of the specimens was 50 mm and 100 mm. The thickness of base coat was 2 mm – 6 mm; the thickness of finishing coat was 1.5 mm – 2 mm. The sides of each sample were sealed with several coats of epoxy resin against water (Fig. 1).

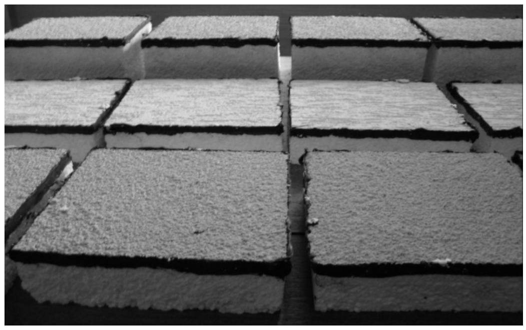

Fig. 1. Prepared specimens of ETICS (200 mm×200 mm×50 mm)

2.2. Water absorption and drying of ETICS

From all the degradation agents, moisture is particularly important to assessing the long-term performance of facades wall. An aerial water absorption content W, [kg/m^2] shows an amount of absorbed water (kg) driven by capillary suction forces by 1 m^2 of surface in contact with water surface. The transfer of the liquid moisture in a material is caused by the capillary suction, osmotic and gravitational forces. Render water absorption rate variation may provide useful information about its behaviour over the years. Therefore, the objective of the laboratory tests was to determine the changes of water absorption properties of ETICS samples in order to create laboratory cycles, adapted to cold and wet climate countries.

The percentage of water absorption in the composites was calculated by weight difference between the samples immersed in water and the dry samples using the following equation:

$$\Delta M(t) = \frac{m_t - m_0}{m_0} \times 100, \quad (1)$$

where $\Delta M(t)$ is moisture uptake, m_0 and m_t are the mass of the specimen before and during aging, respectively.

The water permeability of façade finishing coatings determines the amount of precipitation that penetrates into the deeper layers, thus, causing the water accumulation in reinforcement either the fall of frost resistance of whole system. Water absorbability of the reinforced layer and individual finishing layers specified after 0.5; 1; 2; 4; 6; 24; 48 h. The changes of finishing coat moisture properties have been compared.

Fig. 2 demonstrates the increment of water absorption intensity rates during water absorption test. All curves have similar shapes but the difference in absorption intensity rate as well as absorbed water amount.

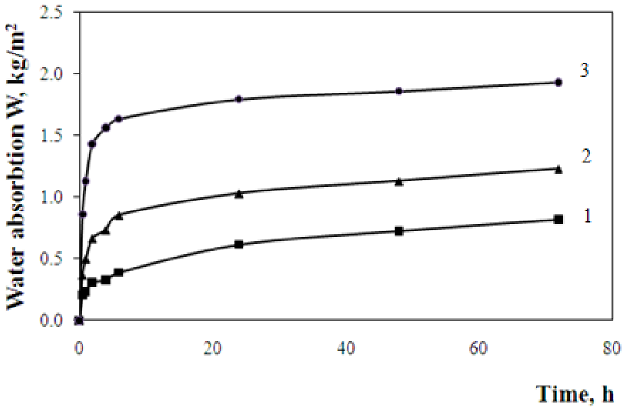

Fig. 2. Water absorption rates from water surface of ETICS samples: 1 – with mineral render; 2 – with acrylic render; 3 – with mineral render (double glass mesh)

Analyzing the curves of water absorption from water surface, the water absorption of samples after 24 h reaches 14 % – 16 % of mass and later the increasing is insignificant (0.5 % – 1 %) (Fig. 2). During water absorption test the intensity of absorption increases fast in the beginning (the first 7 hours), later the initial intensity of water absorption slows down. Thermal insulation material EPS has a small water absorption coefficient [5]; therefore the moisture hardly penetrates into it. The weaker protective properties of the finishing coating, the higher water content in base coat of ETICS during water absorption test, i. e. the ability to preserve a greater amount of water in itself decreases. Seeking to have impact resistant ETICS, the manufacturers recommend to use double fibreglass mesh for reinforcement. The second fibreglass mesh strengthens the upper surface, thereby increasing the possibility of a greater amount of water absorbed by the increased volume of base coat.

Mineral samples No. 3 (Fig. 2) have double glass mesh, the layer of reinforcement is double, and therefore its water absorption rate and water content are maximal. The sample No. 1 is also covered with mineral render but it is with one glass mesh and accordingly with one layer of reinforcement.

Table 1 represents mineral render (2 mm size grain) surface water absorption results with and without glass fibre mesh.

Fig. 3 shows that after two hours of immersion in water the half of reinforcement of sample No. 3 remains dry (the contours of absorbed water marked by white line). It follows that the mineral render completely absorbed by water within about 1 h and later the absorption continues slowly, i. e. reinforcement layer reaches almost full absorption within 7 h.

Table 1. Water absorption of ETICS with and without glass fibre mesh

Description	Water absorption, kg/m²	
	1 h	24 h
ETICS without glass fibre mesh	0.017	0.142
ETICS with glass fibre mesh	0.038	0.243

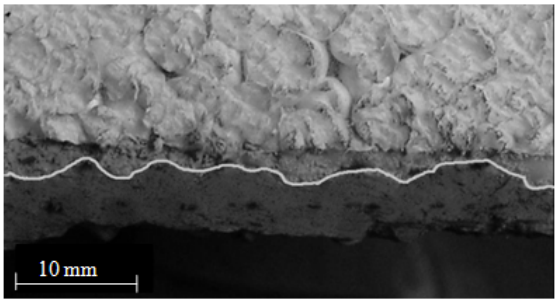

Fig. 3. The water absorption of ETICS sample after 2h (double glass mesh)

Fig. 4 indicates that ETICS samples dry out at almost the same tendencies as in the case of water absorption test. Samples No. 3 have double glass mesh, double layer of reinforcement, its drying rate is the highest. The samples dry out to the original weight within 24 h (at +40 °C).

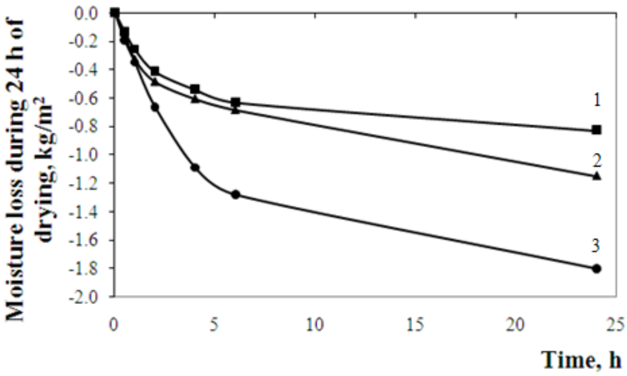

Fig. 4. Drying rate curves of ETICS samples: 1 – with mineral render; 2 – with acrylic render; 3 – with mineral render (double glass mesh)

From these findings follows, that in order to produce overall climatic impact to ETICS, it is important to cause appropriate wetting-drying-freezing effect on samples.

2.3. The modelling of laboratory climatic accelerated ageing cycle

In order to predict service life of ETICS, the accelerated climatic cycle was composed on the basis of earlier scientific research [1, 3, 6] and the statistic data of the Lithuanian climate [19], with respect to the average rain duration and the maximal outdoor temperatures in summer and winter. In order to design accelerated weathering and to find overall absorption, freezing and drying effect on the ETICS service life, was created the cycle combining these three main impacts.

On the basis of the climatic data [19], the rain duration average in Lithuania is about 7 hours and it repeats about 16 times per year. In the first part of ageing cycle the samples were immersed in water for 7 hours. Longer moisturing time is needless, as well as the intensity of absorption increase faster and reaches its full absorption in first 7 hours.

It has been found out that the –1.5 °C degrees temperature in Lithuania is repeated approximately 11.24 times, –4.5 °C degrees – 7 times and –10.5 °C degrees – 9.88 times per year [19]. Following the dismissal of cooling –1.5 °C (11,24 times) for very low impact, it was chosen the optimal variant: the impact of the annual natural frost cycles on the finishing coat should be imitated by 16 freezing cycles per year each lasting for not less than 7 hours at the ambient air temperature of −10 °C. The heating–drying step temperature +40 °C has been chosen as an effective surface temperature due to direct Sun irradiation of the surface during mean nebulosity [19]. The duration of each of heating-drying cycle has been adjusted to the need of sufficient drying out of samples during the heating-drying regime in the climatic chamber.

The natural climatic impact of moisturing-freezing-high temperature through a round year on the most unfavourable places of the building facade was imitated in the climatic test chamber within 16 days (Table 2).

Table 2. The accelerated moisturing-freezing-high temperature ageing cycle

Description	Air temperature, °C	Process	Time, h
Rain	+20	moisturing	7
Refrigeration	–10	freezing	3 decreasing
			4 keeping
Heating	+40	drying	4 increasing
			6 keeping

Every 16 moisturing-freezing-high temperature cycles, specimens were taken out and the bond strength was respectively measured. Furthermore, every 16 days it was measured the changes of water absorption.

3. DISCUSSION

The moisturing-freezing-drying laboratory tests have proven the significant impact of such accelerated ageing on the service life of ETICS.

Table 3. The bond strength, water absorption and drying comparison after ageing cycles

Samples	Bond strength, MPa after ageing cycles:			Moisture content after 24 h, kg/m^2, during accelerated ageing					
				Water absorption			Drying		
	0	16	32	0	16	32	0	16	32
1	0.10	0.06	0.08	0.62	0.70	0.70	0.83	0.70	0.42
2	0.10	0.07	0.07	1.03	1.20	1.36	1.15	1.24	1.22
3	0.11	0.06	0.09	1.79	1.28	1.42	1.80	1.00	0.86

By comparing various changing features of adhesive strength, water absorption and drying at different time period during laboratory climatic ageing cycles of each ETICS, analysis is summarized in Table 3.

Samples with double glass mesh No. 3 initially absorb a large amount of water but after 1 year simulation of natural weathering (16 moisturing-freezing-drying cycles), the 24 h water absorption decreases. In Fig. 5 we see that after 16 and 32 cycles, the 24 h water absorption slowly increases, ETICS samples accumulates water inside and do not dry up to primary weight within 24 h (Fig. 6).

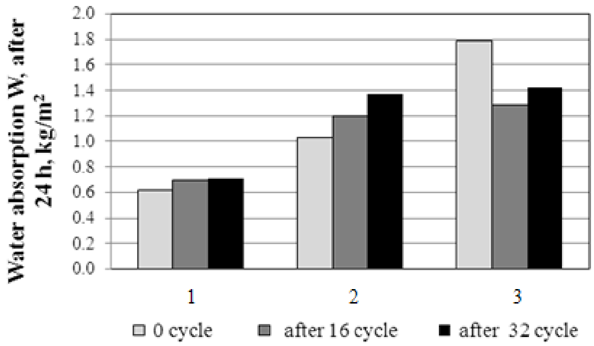

Fig. 5. Water absorption values after 24 hours of ETICS samples: 1 –with mineral render; 2 – with acrylic render; 3 – with mineral render (double glass mesh)

By analyzing drying curves we find that samples with double glass mesh accumulate moisture 2 times more than samples with one glass mesh. Moisture does not evaporate from the samples to the initial weight within 24 h. Moisture remains in reinforcement layer in sample 3, while drying curves of samples 1 and 2 stay almost similar (Fig. 6). It follows that one of the reason of moisture accumulation in external layer of ETICS – the thickness of reinforcement.

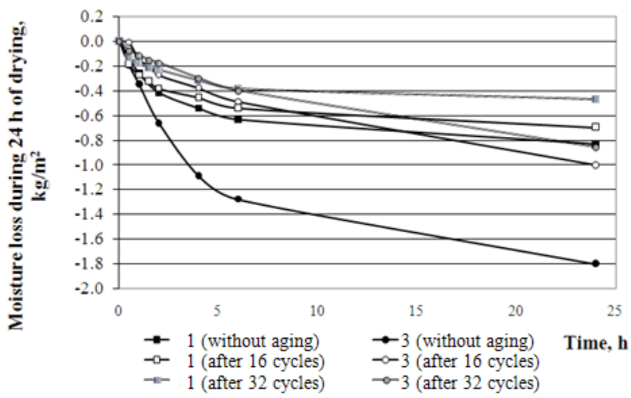

Fig. 6. Drying values after 24 hours of ETICS samples: 1 – with mineral render; 3 – with mineral render (double glass mesh)

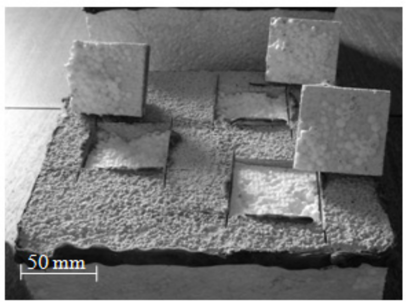

Fig. 7. The measurement of bond strength after 32 ageing cycles of ETICS samples No. 2

The bond strength after 16 ageing cycles proportionally decreases. Neglecting to the low values of the bond strength after 16 ageing cycles, the rupture have occurred in the insulation product. But later, after 32 cycles, base coat visibly separates from EPS by pulling (Fig. 7). It is evident, that accelerated moisturing-freezing-high temperature cycles affect the strength of ETICS.

It should be mentioned that in previous studies [6] the authors obtained similar results of water absorption with the plastic cement-lime rendering mixture samples.

The other authors [1, 2] got similar results of adhesive strength of ETICS, although there was no data found about the impact of double glass mesh on ETICS adhesive strength and water absorption.

4. CONCLUSIONS

1. In order to predict service life of ETICS, the accelerated climatic cycle was composed on the basis of earlier scientific research and the statistic data of the Lithuanian climate.

2. The presence of the second glass fibre mesh in the reinforcement layer increases resistance to hard body impact, thereby increasing the opportunity to absorb more water amount. Moisture does not evaporate from the samples to the initial weight within 24 h at +40 °C. One of the reasons increasing the moisture accumulation in external layer of ETICS – the thickness of reinforcement.

3. The offered methodology for the investigation of the ETICS finishing coat's durability can be employed both for the determination of the physical ageing of the coating and for the estimation of its aesthetic degradation either.

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.

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