Experimental Programme to Assess ETICS Cladding Durability

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ABSTRACT

The paper reports on the experimental evaluation of the durability of ETICS cladding through accelerated laboratory ageing, which is now being developed by BEST – Politechnic of Milan. The experimental programme as a whole includes accelerated laboratory ageing, long-term outdoor exposure, comparison and analysis of results. Four types of specimens have been built with masonry wall acting substrate EPS as insulation and polymeric additives incorporated in the base coat mortar. Of the additives included in the mortar, two were prepared with acrylic resin and two with vinyl resin. Additionally, for each type of specimen, one included a typical finishing coat and another one an acrylic painting. For each series of ETICS specimens, a one set will be aged and the other remains as the (cladding system reference set). There are also four pairs of sets of smaller scale samples on which disruptive tests are to be completed. The ageing cycle consists of 125 UV cycles, 125 summer thermal shock cycles and 50 winter thermal shock and freeze-thaw cycles. In order to assess performance decay on the reference specimen and on the aged specimens at the end of their service life, several disruptive tests will be carried out, including: water absorption, water vapour permeability, tensile bond strength of adhesive and of base coat to insulation, render strip tensile tests, and pull off tests. Non-disruptive tests (e.g. record of T [°C], RH [%] and heat flow) are being conducted throughout the ageing process and, at every end of test cycle, characterization tests are carried out to assess changes in thermal conductance, moisture transfer properties, dynamic effects and thermal inertia. Infrared thermography and capillarity tests are also being carried out and photos are taken in order to survey evolution of cladding degradation.

KEYWORDS

ETICS, Thermal shock, Polymer added mortar

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1 INTRODUCTION

This paper portrays structure and methodology of ETICS experimental programme, which has been developed by Durability of building components group (BEST Department – Polytechnic of Milan) since November 2003. The research programme concerns the durability assessment of ETICS (External Thermal Insulation Composite Systems with rendering) also well known as EIFS (Exterior Insulation and Finish System). This building component has been chosen due to its widespread distribution across Europe and North America and the problems concerning its durability. The study has two types of objectives: general and specific ones. General objectives are methodological ones and include: the search for innovative tools useful for Service Life assessment test design, design of methods for estimating service life, design of methods for forecasting degradation and performances decay. On the other hand, specific objectives, more closely related to the performance assessment of ETICS cladding are also sought, and include: observation and measurement of performance decay, qualitative degradation models (for ETICS), and knowledge useful for technology improvement.

This work is linked to studies concerning durability of building components developed by other research units of the Italian Durability network and it’s the development of methodologies set during the research activity brought on by BEST in collaboration with SUPSI (Italian Swiss Professional University School) about paintings durability. Main special features and innovations of ETICS experimental programme are:

- Usage of degradation factors and mechanisms analysis as a tool in designing accelerated ageing cycles (not only to find the agents to be reproduced and as preliminary analysis);
- Ageing cycles pre-design with climatic data analysis (not excluding re-scaling with outdoor specimens);
- Dynamic thermal performance decay measurement.

Future targets of research activity are outdoor exposure and time re-scaling got with degradation comparison of indoor and outdoor specimens, design of other specific tests suited for studying ETICS degradation mechanisms. First results are not to be considered as quantitative values, but as a first step in developing a method and a measurement technique suited for assess ETICS and building components durability generally. In particular, in results analysis should be considered errors and approximations due to:

- Ageing cycles not reproducing all agents (e.g. atmospheric pollution, wind and vibrations are not included);
- Limited dimensions and number of specimens;
- Limited number of sensors (iso-determined equation systems);
- Accuracy and measurement errors;
- Prototype research programme.

First results got with accelerated ageing tests concern degradation, water absorption and thermal insulation performance decay (related to water absorption).

2 SPECIMEN DESCRIPTIONS

Four kinds of specimen have been designed: two with acrylic additive in base coat (one with acrylic painting, one with finishing coat) and two with vinyl additive in base coat (one with acrylic painting, one with finishing coat). For each type one specimen to age and one not to (to test as reference for system characterization) are provided and for each type also are tested one big sample reproducing the complete wall (i.e. substrate and ETICS) and sets of small samples (only ETICS on polystyrene) suited for measuring single characteristics (thermophysical and mechanical ones). In order to study each
considered combination of ETICS, small samples are stored inside a climatic chamber and a big sample is used as door of the chamber.

Large-scale samples (100 x 100 x 22.45 cm) are comprised of three mechanically fixed and adhesively bound insulation panels (two panels 50 x 50 cm in the lower part, and one 100 x 50 cm in the upper part) are used in order to reproduce one T joint in the middle of the specimen. Polypropylene anchors are used are fixed in five positions (in four middle points and in coincidence with T joint) and aluminium profiles are used to reproduce boundary conditions and in coincidence with profiles there is a superposition for 10 cm of two sheets of glass fibre mesh. First ETICS kind tested is type A.1.

<table>
<thead>
<tr>
<th>Layer</th>
<th>s [m]</th>
<th>Specimen type</th>
<th>INTERIOR</th>
<th>A. 1</th>
<th>A. 2</th>
<th>B. 1</th>
<th>B. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior finishing</td>
<td>0,005</td>
<td>Gypsum plaster</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interior plaster</td>
<td>0,015</td>
<td>Lime cement plaster</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masonry Substrate</td>
<td>0,12</td>
<td>Non load bearing aerated clay bricks 12x25x25 cm (holes percentage 64 [%]) laid with cement bed mortar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plaster</td>
<td>0,015</td>
<td>Lime cement plaster</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adhesive</td>
<td>0,003</td>
<td>Vinyl additive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulation product</td>
<td>0,06</td>
<td>EPS 150 according to EN 13163 (density 25 kg/m³)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base coat</td>
<td>0,005</td>
<td>Vinyl additive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glass fibre mesh</td>
<td>-</td>
<td>155 g/m²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finishing coat</td>
<td>0,0015</td>
<td>Acrylic binder</td>
<td>NO</td>
<td>NO</td>
<td>Acrylic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Painting</td>
<td>-</td>
<td>NO</td>
<td>NO</td>
<td>Acrylic</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.1 Bed Mortar and Plasters

The bed mortar for the masonry brick substrate is pure cement mortar designed, according to proportions suggested by the EMPA (of Dübendorf), whereas the mix design for the lime cement plaster was carried out according to Italian National specifications for masonry construction (D.M. 20/11/87). On the other hand as binder for the polystyrene and as base coat, a pure cement mortar with polymeric additive was used.

<table>
<thead>
<tr>
<th>Mortar</th>
<th>Bed mortar: w/b = 0.56</th>
<th>Plasters: w/b = 0.67</th>
<th>Adhesive and base coat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Type</td>
<td>V/V&lt;sub&gt;C&lt;sub&gt;EM&lt;/sub&gt;</td>
<td>Type</td>
<td>V/V&lt;sub&gt;C&lt;sub&gt;EM&lt;/sub&gt;</td>
</tr>
<tr>
<td>Water</td>
<td>0.83</td>
<td>1.33</td>
<td>0.5</td>
</tr>
<tr>
<td>Cement CEM II/A-L 32.5</td>
<td>1.00</td>
<td>CEM II/A-L 32.5</td>
<td>1.00</td>
</tr>
<tr>
<td>Sand EN 196-1 normalized</td>
<td>2.84</td>
<td>EN 196-1 normalized</td>
<td>4.00</td>
</tr>
<tr>
<td>Lime No</td>
<td>-</td>
<td>Hydraulic</td>
<td>0.50</td>
</tr>
<tr>
<td>Additive No</td>
<td>-</td>
<td>No</td>
<td>Vinyl / acrylic</td>
</tr>
</tbody>
</table>

2.2 Finishings

Two kinds of finishing systems, characterized by PVC (Powder Volumetric Concentration), are compared: an acrylic painting with PVC 40 and a 1.5 mm thick finishing coat with PVC 80, that
consists of sand (0/1 mm) and an acrylic resin binder plus additives. Both finishings are red, with solar absorbance $\alpha = 0.6$. Surface emissivity is measured as $\varepsilon = 0.82$.

### 2.3 Construction and Curing Time

Specimens were fabricated inside the laboratory (spraying plaster and base coat to avoid shrinkage) and were allowed a minimum curing time of three months after the installation was completed (five months after construction of substrate) before ageing the first sample. This was done to ensure that the same initial water content for all specimens (reducing the construction water) was maintained.

![Figure 1. Sample A.1, Base coat with vinyl additive and finishing coat with acrylic resin.](image)

**Figure 2.** Location of sensors in section RH sensors are placed in the lower part of the sample.

### 2.3 Measurement Apparatus

For large-scale samples (100 x 100 cm) during the cladding fabrication process, relative humidity (RH) and temperature (T) sensors were placed in the assembly such that three T and RH data profiles could be obtained (one in section, one coincident with EPS panel joints, and one coincident with bed mortar joint). In each profile, sensors were positioned on the interior and exterior surface of the...
specimen and between the insulation and the plaster. A heat flow meter was also placed on the interior surface of the main section.

The specimen to age is placed is binded as door of the climatic chamber with a steel frame (separated from it by XPS panels) and it is insulated at boundaries (in order to get a one-dimensional heat flow). Temperature and relative humidity are recorded on the inside of the climate chamber and in the laboratory.

![Diagram of the climatic chamber and sensors positions]

**Figure 3.** On the left the sample linked to the climatic chamber; on the right sensors profiles position.

### 3 PREPARATION PHASE

#### 3.1 Degradation Factors

A wide analysis concerning degradation factors and mechanisms (see Daniotti & Paolini [2005]) has been brought on throughout the experimental programme in order to assess which environmental agents must be reproduced and their related intensity, and as well, on which characteristics of the building component are important, that means what to observe to identify the degradation and the performance decay evolution.

#### 3.2 Ageing Cycle

In order to design the accelerated cycles and assess the proportion between its parts, two ways have been pursued: standard reference (ETAG 004) and analysis of climatic data of Milan context (Test Reference Year and UNI 10349). Thanks to this study, three ageing cycles (UV cycle, winter thermal shock + freeze-thaw cycle and summer cycle) have been planned and the proportion between the summer cycles and the winter one set to 2.5. However the correct proportion between summer and winter ones must be determined with time re-scaling, studying the comparison between the degradation of the outdoor exposition specimens and the indoor accelerated ones. The value here proposed has the only intent to be a pre-design value.

Ageing sub-cycles are repeated in order to maintain the proportion 2.5. So in each complete cycle CX there are 25 UV cycles, 10 winter cycles and 25 summer cycles. Complete ageing cycles CX therefore are assembled in groups of five so to get a macro-cycle TX (its overall duration is about one month).
Table 3. Agents included and not included in the ageing cycle. Agents not included cannot be reproduced in laboratory tests or can be reproduced, but not included into an accelerated cycle.

<table>
<thead>
<tr>
<th>Agent – type of solicitation</th>
<th>Layer / component of most interest</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Included in the ageing cycle</strong></td>
<td></td>
</tr>
<tr>
<td>Summer and winter thermal shock</td>
<td>Base coat and finishing</td>
</tr>
<tr>
<td>Freeze - thaw</td>
<td>Base coat and finishing</td>
</tr>
<tr>
<td>Rain</td>
<td>Base coat and finishing</td>
</tr>
<tr>
<td>UV radiation</td>
<td>Finishing</td>
</tr>
<tr>
<td>Cyclic variations in T [°C] and RH [%]</td>
<td>Base coat and finishing, insulation</td>
</tr>
<tr>
<td><strong>Not included in the ageing cycle</strong></td>
<td></td>
</tr>
<tr>
<td>Pollution</td>
<td>Base coat and finishing</td>
</tr>
<tr>
<td>Mould</td>
<td>Base coat and finishing</td>
</tr>
<tr>
<td>Vibrations</td>
<td>Whole system</td>
</tr>
<tr>
<td>Impacts</td>
<td>Base coat and finishing</td>
</tr>
<tr>
<td>Wind</td>
<td>Anchors, whole system</td>
</tr>
</tbody>
</table>

Table 4. Basic Ageing or Ageing sub-cycles (Note: set point values in bold type).

<table>
<thead>
<tr>
<th>Basic Cycle</th>
<th>Repeat</th>
<th>Phase</th>
<th>UV</th>
<th>Winter</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV</td>
<td>25</td>
<td>1.1 UV</td>
<td>35</td>
<td>-</td>
<td>70 ± 5</td>
</tr>
<tr>
<td>Winter</td>
<td>10</td>
<td>2.1</td>
<td>5 ± 1</td>
<td>-20 ± 2</td>
<td>20</td>
</tr>
<tr>
<td>Summer</td>
<td>25</td>
<td>3.1</td>
<td>30 ± 2</td>
<td>70 ± 5</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.2</td>
<td>-</td>
<td>20</td>
<td>-</td>
</tr>
</tbody>
</table>

4 DEGRADATION AND PERFORMANCE DECAY MEASUREMENTS

In order to observe the decay in performance and the evolution of degradation, two main types of tests are taken into account: disruptive and non-disruptive.

4.1 Non-disruptive Tests

Non-disruptive tests are brought on big specimens before the accelerated exposition (not aged sample) and throughout ageing time every macro-cycle TX (that means every 5 complete cycles = 5 x (25 UV cycles + 10 winter cycles + 25 summer cycles). Two kinds of non-disruptive tests are performed (in this order):

- Qualitative degradation evolution assessment:
- Photographic degradation survey in six fixed positions (one point in the centre, four points in the half of the half of diagonals and one under the centre in coincidence with vertical joint between insulation panels). Degradation evolution is checked according to ISO 4628;
- Non-disruptive capillary absorption test (Karsten’s method according to NORMal 44-93) measurement of low-pressure absorption of water volume (in [ml]) by the surface of a porous material at fixed time steps. Results report absorption [lt/m²] versus square root of time [s⁻¹]
- Hygrothermal performances characterization cycles (record of T [°C], RH [%] and heat flow):
- SINa – Summer dynamic conditions – low wave Simulation of 21 July outdoor temperature variation in Milan context (according to UNI 10349) without solar radiation influence
Duration: 48 hours (2 sine curves with period of 24 h)
Conditions: T [°C] sine curve: max = 31.9 [°C], min = 20 [°C], amplitude = 12 [°C]
RH [%] = 50 constant
- **SINb – Summer dynamic conditions – high wave**
  Simulation of 21 July outdoor temperature variation in Milan context (according to UNI 10349) with solar radiation influence: air – sun temperature with solar absorbance $\alpha = 0.6$
  Duration: 48 hours (2 sine curves with period of 24 h)
  Conditions: $T \ [^\circ C]$ sine curve: max = 65.5 [$^\circ C$], min = 20 [$^\circ C$], amplitude = 45.5 [$^\circ C$]
  RH [%] = 50 constant
- **TI – Thermal Inertia**
  Assessment of time constants and thermal capacities.
  Duration: 72 hours (3 sine phases of 24 h)
  Conditions: $T \ [^\circ C]$ 24 h at 20 [$^\circ C$], 24 h at 70 [$^\circ C$], 24 h at 20 [$^\circ C$]
  RH [%] = 50 constant
- **CON – Thermal Conductance in steady thermal state**
  Assessment of thermal insulation performance decay
  Duration: 96 hours
  Conditions: $T \ [^\circ C] = -20$ constant
  RH [%] = 0 constant (inside the climatic chamber below 0°C must not be water or humid air for technical reasons)
  - Infrared thermography
    To capture the response of surface temperature gradients on the specimen surfaces during the CON cycle, an infrared thermographic camera is positioned for 24 hours outside the climate chamber, pointing towards the interior surface of the specimen (gypsum plaster). At the end of ageing time (end of Service Life declared) the specimen is turned round of 180° and another thermography is executed for 24 hours ($T = -20 \ [^\circ C]$ inside the climatic chamber) in order to assess the evolution of thermal bridges in coincidence with joints between insulation panels.
  - **RHst – Relative Humidity stabilization**
    Assessment of stabilization time of relative humidity (and so water content) only for the exterior layers (base coat and finishing).
    Duration: 8 hours (4 phases of 2 hours each)
    Conditions: $T \ [^\circ C] = 35 \ [^\circ C]$ constant
    RH [%]: 2 h at 20 [%], 2 h at 50 [%], 2 h at 80 [%], 2 h rain 1 [Lt/m²]
    A longer exposition (to assess moisture changes inside the whole sample) could influence the overall thermal capacity and alter ageing tests storing an excessive moisture amount.

### 4.2 Disruptive Tests

Disruptive tests are performed both on non-aged samples (characterization tests) and on aged samples when the end of Service Life is reached. Disruptive tests prepared for this experimental programme are: water absorption, water vapour permeability, tensile bond strength of adhesive and of base coat to insulation, render strip tensile test.

Other disruptive tests, such as resistance to hard body impact or resistance to perforation, could be executed, but the analysis of test methods highlighted that they do not offer numeric results and they are have to be evaluated without a precise scale.

Disruptive tests are so performed both on large samples (1m²) and on sets of selected smaller scale samples (as prescribed by the specific standards), that incorporate only the ETICS cladding component and not the masonry substrate. A set of small specimens (for all disruptive tests) is stored inside the climatic chamber and a comparison between results obtained by tests on these small aged samples and the ones obtained by tests carried on cores taken from large-scale aged samples are compared in order to help understand the influence on degradation of different position inside the chamber, different dimensions of samples and of constraints given by substrate and plastic anchors.
Table 4. Disruptive tests, dimension and number of samples and standard test method chosen.

<table>
<thead>
<tr>
<th>Test</th>
<th>Sample dimensions</th>
<th>N°</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water absorption (capillarity test)</td>
<td>200 x 200 mm</td>
<td>3</td>
<td>ETAG 004 - § 5.1.3.1</td>
</tr>
<tr>
<td>Water vapour permeability</td>
<td>Round samples: A &gt; 5000 mm²</td>
<td>5</td>
<td>EN 12086</td>
</tr>
<tr>
<td>Render strip tensile test</td>
<td>600 x 100 mm, Mesh length: 800 mm, (100 mm leaning out at boundaries)</td>
<td>3</td>
<td>ETAG 004 - § 5.5.4.1</td>
</tr>
<tr>
<td>Tensile bond strength of adhesive and base coat to insulation</td>
<td>200 x 200 mm</td>
<td>3</td>
<td>EN 13494</td>
</tr>
</tbody>
</table>

5 CONCLUDING REMARKS

Ageing tests are in progress on specimen Type A.1 that includes a vinyl resin base coat and finishing coat, the preliminary results being given in Daniotti & Paolini [2008]. Other tests related to improving knowledge of the evolution in performance decay and degradation are now being studied, whereas specific tests suited for understanding degradation mechanisms are now being designed. For example, tests methods are being devised for determining if capillary absorption properties vary more significantly in the base coat or finish coat and the phenomena that cause such variations). On the other hand, ageing tests on all specimen types in an on-going process and outdoor exposure tests will also be performed in the future.

REFERENCES


EN 196-1: 1996 – Methods of testing cement. Determination of strength

ISO 4628: 2003 – Paints and varnishes – Evaluation of degradation of coatings – Designation of quantity and size of defects, and of intensity of uniform changes in appearance


EN 12086: 1997 – Thermal insulating products for building applications – Determination of water vapour transmission properties

EN 12524: 2001 - Building materials and products - Hygrothermal properties - Tabulated design values

EN 13139: 2003 – Aggregates for mortar


EN 13494: 2003 – Thermal insulation products for building applications – Determination of the tensile bond strength of the adhesive and of the base coat to the thermal insulation material

EN 13499: 2003 – Thermal insulation products for buildings – External thermal insulation composite systems (ETICS) based on expanded polystyrene – Specification

NORMal 44 – 93 – Assorbimento d’acqua a bassa pressione