Durability of External Wall Insulation Systems with Extruded Polystyrene Insulation Boards

Durmus Topcu 1
Holger Merkel 2

T 24

ABSTRACT

External wall insulation systems (ETICS = External Thermal Insulation Composite Systems) are one of the most common insulation systems in Europe. The systems are designed to provide the appropriate thermal insulation of the wall.

An ETICS comprises the thermal insulation product and a reinforced render. The insulation boards are bonded onto the wall either by an adhesive or a mechanical fixation or a combination of both. External thermal insulation systems with extruded polystyrene boards (XPS) are widely used in Turkey and other European countries.

The paper shows results of durability tests done at laboratory scale as well as results and findings from building projects.

The durability tests were carried out using hygrothermal test facilities to simulate heat, rain and frost conditions. The results show the high tensile bond strength between the render system and the XPS insulation boards after simulated ageing of the ETICS. Due to very low water absorption of the XPS type used there is no risk of moisture accumulation within the system. This is of high importance for the durability of thermal performance of the whole construction.

The test results are in good correlation with practical experience. Examples of ETICS with XPS insulation will be provided.

KEYWORDS

Thermal insulation, Extruded polystyrene foam, Walls, ETICS

1 Dow Turkey, Istanbul, Turkey 34469, Phone +90 216 463 7744, Fax 216 3806019, dtopcu@dow.com
2 Dow Anlagenges.mbh, 65824 Schwalbach, Deutschland, Phone +49 6196 566 158, Fax +49 6196 566 426, hmerkel@dow.com
1 INTRODUCTION

Europe continues to waste at least 20% of its energy mainly due to thermal inefficiency of buildings [EC 2006].

The most cost and energy efficient measure to reduce energy consumption and CO₂-emmissions is thermal insulation of buildings, which in addition improves the indoor-air quality and the living comfort. It has a significant impact on the durability of a building by reduction of ageing of the building structure due to thermal and moisture impact.

The total ETICS (ETICS = External Thermal Insulation Composite System) market in Turkey has reached around 10MM m² in 2006 and expected to reach to 40MM m² in coming 5 years time. The average growth rate of ETICS market has been 35% in last 5 years. This growth is coming both from new buildings and also very strong renovation segment.

2 EXTRUDED POLYSTYRENE FOAM –XPS

XPS is produced by a continuous extrusion process which finally forms a homogenous closed cell foam structure.

Variations in the slot die allow board thicknesses between 20 mm and 200 mm. After passing through a cooling zone, the board edges are trimmed. The smooth foam skin resulting from the extrusion process remains on the boards or is removed mechanically (planed) for particular board types to achieve better adhesive strength in combination with e.g. concrete, mortar, or construction adhesives.

XPS foam is a standardized insulation product which complies with harmonized European Product Standard [EN 13164:2001 ] and the corresponding Turkish standard [TS 11989 EN 13164 ].

XPS insulation products have a closed-cell structure throughout the foam.

Extruded Polystyrene Boards, such as Styrofoam do not contain capillaries. This is important especially for exterior wall areas which are close to ground level. Liquid water cannot be transported within the foam behind plaster.

The typical water absorption characteristics are listed in Table 1.
Table 1. Requirements in terms of water absorption for XPS insulation products, in accordance with [EN 13164:2001].

<table>
<thead>
<tr>
<th>Water absorption characteristics</th>
<th>Thickness [mm]</th>
<th>Limit value [Vol-%]</th>
<th>EN code (EN 13164)</th>
</tr>
</thead>
<tbody>
<tr>
<td>by diffusion</td>
<td>50</td>
<td>≤ 3.0</td>
<td>WD(V)3</td>
</tr>
<tr>
<td>by diffusion</td>
<td>100</td>
<td>≤ 1.5</td>
<td>WD(V)3</td>
</tr>
<tr>
<td>by diffusion</td>
<td>200</td>
<td>≤ 0.5</td>
<td>WD(V)3</td>
</tr>
<tr>
<td>after freeze-thaw</td>
<td>40 – 200</td>
<td>≤ 1.0</td>
<td>FT2</td>
</tr>
<tr>
<td>by full immersion</td>
<td>40-200</td>
<td>≤ 0.7</td>
<td>WL(T)0.7</td>
</tr>
</tbody>
</table>

Extruded polystyrene is a thermoplastic material which demonstrates visco-elastic behaviour [Merkel 2004].

The homogeneous closed structure of XPS provides high mechanical resistance; e.g. tensile strength and shear strength [Strzepek 1990]. Additionally XPS exhibits a high resistance against forces pulling through mechanical fixations. These properties are important for the resistance of the ETICS against wind load. The robustness of an XPS product makes it ideal for handling under the tough conditions on a job-site.

The XPS products manufactured according EN 13164 are subjected to a continuous factory production control (FPC) of properties. In some European countries; e.g. France and Germany the application related product properties are certified by independent institutes (notified bodies). Thus quality and compliance of XPS products with the product standard is assured.

3 REQUIREMENTS FOR INSULATION PRODUCTS IN ETICS

The requirements for the insulation component of the system are specified in [ETAG004]. These are related to:

- Thermal resistance
- Water absorption
- Water vapour permeability
- Tensile strength
- Shear strength
- Reaction to fire

The XPS products are classified as reaction to fire class E according to the European Standard EN 13501-1. In Turkey, XPS products shall meet the requirements of German Fire Classification B1 [DIN 4102]; e.g. Styrofoam Shapemate IB.

The water absorption by partial immersion shall not exceed 1kg/m² after 24 hours.

The value has been established to cover also Mineral Wool and EPS products. For XPS the value is close to zero. Low water absorption means the performance is unaffected by moisture in this application.

The µ-value (water vapor diffusion resistance factor) shall be declared. There is however no requirement for a specific µ-value of the insulation. This is obvious, since the water vapour transport and the moisture behaviour of the wall is determined by the entire build-up with all layers and the internal and external climate conditions.

The minimum tensile strength shall not be lower than 80kPa. For XPS the declared tensile strength perpendicular to the surface is >100kPa. Actual values (provided by Dow Building Solutions) are

T24, Durability of External Wall Insulation Systems with Extruded Polystyrene Insulation Boards; D. Topcu & H. Merkel
between 400kPa and 500kPa. The shear strength is well above the required value of $\geq 0.02 \text{ N/mm}^2$ (20kPa). Actual values are about 0.20 N/mm² (200kPa).

The shear strength is very important for the mechanical resistance of bonded systems to carry the permanent weight of the system.

The surface of XPS boards for ETICS application shall be planed which allows sufficient tensile bond strength between render and insulation. Products with a smooth skin type of surface are not appropriate.

The thermal conductivity of XPS boards is sufficiently low to meet the energy savings requirements. Typical values for XPS products; e.g. Styrofoam Shapemate IB are in the range of 0.030 W/(mK) up to 60mm thickness according to Turkish Standard.

**4 TESTING OF ETIC-SYSTEMS WITH EXTRUDED POLYSTYRENE FOAM (XPS)**

It is undisputable that the hygro-thermal wall-test is most important for the determination of the durability of an ETIC-System.

The results reported in this paper were obtained from tests performed in a test facility with two walls forming the envelop of a closed climatic chamber (see Fig. 3). The test conditions were more severe than required in [ETAG004].

The two completed test walls (after 28 days drying) were assembled into the test rig. The arrangement of the test rig is shown in Figs. 2 and 3.

Hot air at 70°C was circulated into the test chamber for a period of 3 hours. After this time, the supply of hot air was terminated and a water spray of at least, 1.0 liter per square meter of wall area per minute was applied to the rendered surface of the wall. The water spray was maintained for a period of 3 hours. These conditions were maintained over 140 cycles.

After the cycles, the walls were subjected to a series of twenty 24 hour cycles consisting of exposure to a temperature of 30°C for 8 hours and exposure to a temperature of minus 20°C for 16 hours.

The water flow rate to the spray head was calibrated before the test began, which confirmed a rate of 1.25 liter per square meter of wall area per minute. Measurements of the water temperature during the test indicated that the temperature varied between 15°C to 18°C.

![Figure 2. Schematic design of “two wall” test rig.](image)
The test is halted briefly during the heating and moisture cycles for observation after 8, 20, 35, 49, 60, 81, 95, 107, 120 cycles.

![Figure 3. A look into the test chamber; two walls on the left and right side can be tested (Photo: Dow Building Solutions).](image)

The durability of a system can be characterized by determining key parameters, e.g.

- Water absorption
- Tensile bond strength between base coat and insulation after the hygrothermal test.

Figure 4 shows the water content of the insulation after hygro-thermal ageing of an ETIC-system under the above mentioned test conditions. In general the water content is rather low for the products tested. But it is obvious that the XPS insulation products contains only a negligible amount of water due to their high water resistance.

![Figure 4. Water content of the insulation after hygro-thermal ageing for XPS and EPS products.](image)

The water absorption by long-term fully immersion was tested separately according to [EN 120875]. Typical results are listed in table 2. Some values in the third column of this table were converted into kilogram water absorbed per square meter. This makes it possible to compare with water absorption values determined according EN 1609 [EN 1609]
Table 2. Water absorption (WA) after long-term (28 days) fully immersion for planed XPS.

<table>
<thead>
<tr>
<th>Thickness in mm</th>
<th>WA in m³/m³ (Vol-%) acc. [EN 1609]</th>
<th>WA in kg/m²</th>
<th>WA in kg/m² acc. [ETAG004]</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>0,52</td>
<td>~0,07</td>
<td>~0,01</td>
</tr>
<tr>
<td>50</td>
<td>0,45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>0,58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>0,61</td>
<td>~0,14</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>0,61</td>
<td>~0,13</td>
<td></td>
</tr>
</tbody>
</table>

When comparing the values it has to be taken into account that the test conditions of EN 12087 are much more severe than those of EN 1609. This is very important regarding the assessment of durability under moisture impact.

The tensile bond strength between the base coat and the XPS insulation depends on the composition of the base coat and the surface properties of the foam.

The durability of the tensile bond strength is exemplified by values given in Fig. 5. The test has been performed according to [ETAG004]. It is obvious that the adhesion between base coat and insulation significantly depends on the performance of the base coat itself, given that the surface of the insulation provides sufficient porosity.

![Figure 5. Tensile Bond Strength (TBS) after ageing between base coat and insulation for two different render Systems S1 and S2.](image)

The impact of hygrothermal ageing on the tensile bond strength properties of systems with XPS is rather small as shown in Fig. 5. The required minimum tensile bond strength of 0,08 MPa [ETAG004] is sufficiently exceeded by both systems.

5 APPLICATION OF XPS IN ETICS

From a building physics point of view the external thermal insulation is the preferred solution for wall insulation. The problem of thermal bridges can be easily solved. There is no need for internal vapor retarder (barrier) like for internal thermal insulation solutions. The water vapor resistance is decreasing from inside to the outside of the construction. This means that the construction gets the more diffusion open the more externally the layer is located. Water vapor gets not blocked at the outer layer of the wall. There is no risk of interstitial condensation.
Extruded Polystyrene Foam does not contain capillaries due to the closed cell structure. Hence there is no capillary moisture transport through the foam. This prevents moisture absorbed by the render during a rain period from penetrating into the system. The moisture will dry out to the outside.

The improved moisture resistance of XPS over other insulation materials [Merkel 2002] is of great importance in areas where the ETICS is connected to other structural parts of the building, in particular to perimeter insulation. Moisture from the ground cannot penetrate behind the render via the insulation.

The durability of XPS makes the products applicable to wall construction of highly exposed multistory buildings as shown in Figs. 6 and 7. Even under warm climate conditions XPS based systems show good long-term performance [Concesion 189]

![Figure 6. ETIC-system applied to multistory building in Istanbul/Turkey (Photo: MARDAV).](image)

![Figure 7. ETICS with XPS after ~15 years of service. No cracks nor blisters are detectable. (Photo: residential buildings in Guadalara/Span).](image)

6 SUMMARY

There is positive experience with XPS in external rendering applications for a long time. Millions of square meters were installed over the last 20 to 30 years in Europe.
The results of hygrothermal ageing tests and the practical experience demonstrate the durability of XPS based ETICS provided that the different building materials layers and their interaction were properly designed and tested.

Extruded Polystyrene Foam (XPS) is a standardized insulation product according EN 13164 and is widely and successfully used for external rendering applications in a number of countries for decades. The main advantages of XPS in ETIC-System are:

- high water resistance,
- closed cell structure of the entire foam, no capillaries, no gaps between cells,
- high shear strength, to carry the permanent load of the system,
- high tensile strength,
- high impact strength,
- appropriate vapor transport performance to avoid condensation risk in moderate and in warm climates.

Hence, extruded polystyrene foam manufactured according EN 13164 or TS 11989 EN 13164 is well suitable as insulation component in ETIC-Systems and meets the requirement of durability.

7 REFERENCES


TS 11989 EN 13164: Isı Yalıtım Mamulleri-Binalar İçin-Fabrikasyon Olarak Ekstrüzyonla İmal Edilen Polistiren Köpük (XPS)- Özellikler


EN 12087: Thermal insulating products for building application – Determination of long term water absorption by full immersion

EN 1609: Thermal insulating products for building application – Determination of short term water absorption by partial immersion


Concesion 189: Sistema de aislamiento termico exterior COTETERM ET, Instituto Eduardo Torroja Madrid 1989