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ScienceDirect

Procedia Technology 19 (2015) 512 – 517

Procedia Technology

8th International Conference Interdisciplinarity in Engineering, INTER-ENG 2014, 9-10 October 2014, Tirgu-Mures, Romania

Optimal technologies for external thermal insulation with polystyrene panels for different support materials

Adrian Bojan[a], Claudiu Aciu[a,*]

[a]Technical University of Cluj-Napoca, 28 Memorandumului Street, 400114, Cluj-Napoca, Romania

Abstract

In the context of the energy crisis and environmental degradation, a particular importance has the reduction of operational energy in buildings by the reduction of heat losses through exterior walls. The thermal insulation of buildings leads to operational energy savings, contributing to the reduction of environmental pollution due to current energy production systems. Given the importance of energy savings and material costs, the paper presents optimal technologies for polystyrene board thermal insulation applied on different substrates. By developing these technologies for energy saving and cost reduction, the paper falls in the category of sustainable development technologies.

Peer-review under responsibility of "Petru Maior" University of Tirgu Mures, Faculty of Engineering

Keywords: Environment; thermal insulation; polystyrene; mortar, cement

1. Introduction

In the context of the energy crisis and environmental degradation, the reduction of operational energy in buildings is particularly important.

Large scale energy efficient renovation of buildings is one of the most important instruments to realize the society's need of a more sustainable building stock [1].

* Corresponding author. Tel.: +40 748 103613.
E-mail address: claudiu.aciu@ccm.utcluj.ro

Peer-review under responsibility of "Petru Maior" University of Tirgu Mures, Faculty of Engineering
doi:10.1016/j.protcy.2015.02.073

Retrofitting of existing buildings gives significant opportunities for reducing global energy consumption and greenhouse gas emissions. This is being considered as one of main approaches to achieving sustainability in the built environment at relatively low cost and high uptake rates [2, 3].

Retrofitting the external walls always makes the largest contribution to energy conservation and emission reduction in high energy-consuming building [4].

The heating of buildings, for which the highest energy amount is consumed, is also the area where the most important savings can be achieved. Thermal insulation leads to operational energy savings, contributing at the same time to the reduction of environmental pollution due to current energy production systems, which consume high amounts of fossil fuels, the burning of which pollutes the environment.

A material that has become widely used for thermal insulation is polystyrene.

From an ecological point of view, thermal insulating materials such as polystyrene are highly energy consuming. Their high embodied energy is compensated by the advantage that their use in construction allows to significantly reduce the operational energy requirements. The energy savings obtained contribute to the reduction of environmental polluting factors.

The purpose of the paper is to streamline polystyrene panels insulation technologies, depending on the support on which the insulation is applied.

Polystyrene is a material that is frequently used in composite systems for the thermal insulation of exterior walls (ETICS – External Thermal Insulation Composite System). This is a full contact thermal insulation system, in which the thermal insulation protection is a thin decorative plaster layer, applied directly to the insulation, by means of a filling layer made from mineral mortar and reinforced with glass fiber mesh [5].

From the point of view of the design, external thermal insulation composite systems are differentiated through the way in which they are fixed to the support layer:

- bonded ETICS: this is performed over the entire surface or partially, by perimetric strips and points;
- bonded ETICS with additional mechanical fixation: the loads are completely transmitted by the adhesive layer and the anchors (dowels) ensure the stability of insulation boards until the complete drying of the adhesive. These act as a temporary connection in order to avoid the risk of detachment of the thermal insulation boards and confer stability to the thermal system in case of fire;
- mechanically fixed ETICS: the thermal insulation boards are fixed to the support only by anchors (dowels);
- mechanically fixed ETICS with supplementary adhesive: the loads are completely taken by anchors (dowels). The adhesive ensures the flatness of thermal insulation boards during the mounting [6, 7].

In order for the thermal protection obtained by the application of the thermal insulation system to meet all requirements (thermal comfort, mechanical resistance, final aspect, resistance over time, fire resistance), the system development technology is extremely important. The final result is influenced in a proportion of 40% by the quality of execution.

The research problem is to establish optimal recipes for the development of composite thermal insulation systems with polystyrene panels and to elaborate specific technologies depending on the support layer.

The most important factors in the development of an external thermal insulation system are the adhesion of the insulation material to the support layer and the bonding strength of thermal insulation composite systems.

2. Material and Method

The thermal insulation material is polystyrene EPS 80 and the studied materials used for the fixation technology of the ETICS system are:

- CT adhesive mortar for fixing Expanded Polystyrene boards – a mineral mortar composed of cement, sand with the maximal granularity 0.6 – 1 mm, resins and additives;
- cement paste – a paste obtained by the mixture of cement class 42.5R and water;
- CS II mortar– the composition for 1 m^3 of mortar is shown in Table 1.

Table 1. CS II mortar recipe.

Mortar	Cement 42,5R	Lime	Sand			
			0,08-0,16	0,16-0,50	0,50-1,00	1,00-2,00
	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]
CS II	171	260	167	333	500	500

In order to study the behavior of the fixation of thermal insulation composite systems, the following tests were performed:

- adhesive strength of hardened mortars to different substrates;
- tensile bond strength of the adhesive and of the base coat to the thermal insulation material.

2.1 Adhesive strength of hardened mortars to different substrates

The determination of the adhesive strength of hardened mortars to different substrates is required because in the thermal rehabilitation of existing buildings, the constructor encounters different substrates such as: ceramic blocks (brick), reinforced concrete (concrete diaphragms, large prefabricated panels), autoclaved cellular concrete blocks (ACC), old plaster and decorative tiling with enamel ceramic tiles.

Adhesive strength was determined according to SR EN 1015-12 – Methods of test for mortar for masonry. Determination of adhesive strength of hardened rendering and plastering mortars on substrates [8].

The tests used a CONTROLS 58-C0215/T Pull-Off tester, a dynamometer for measuring the bonding tensile strength (Fig. 1), which allowed to measure the tensile strength of the substrate of a portion of material by applying a tensile strength directly perpendicular to the test surface. The tensile strength was applied gradually, without discontinuities, using a hydraulic force multiplicator, and transmitted to a metal disc 50 mm in diameter, bonded to the test surface.

Fig. 1. CONTROLS 58-C0215/T Pull-Off tester.

The substrates included in the study were: brick, concrete, ACC, enamel ceramic tiles, and old plaster.

The test samples were made and stored according to standards in force. Five determinations for each support layer were performed and the mean value of the adhesive strength of mortars to these was calculated.

2.2 Tensile bond strength of the adhesive and of the base coat to the thermal insulation material (polystyrene)

The experimental program for the study of the tensile bond strength of adhesives to the thermal insulation material (expanded polystyrene EPS 80) was aimed at determining and comparing the results obtained in the case of the replacement of the adhesive mortar for polystyrene with CS II mortar and cement paste.

The tests were performed in the laboratory of the "URBAN-INCERC" National Institute for Research-Development in Construction, Urbanism and Sustainable Territorial Development, the Cluj-Napoca branch, and the obtained results were recorded in the Test Report.

The test used the method presented in standard SR EN 13494 – 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 [9].

The tensile bond strength of the adhesive to the thermal insulation material was determined by exerting a directly perpendicular effort to the adhesive layer. The tensile effort was exerted by means of metal plates bonded with adhesive (epoxy resin) to the test surface.

On the 200 x 200 mm test samples of expanded polystyrene EPS 80, the cement mortars (CS II, cement paste and adhesive mortar for polystyrene) were successively applied. Then, the test samples were stored for 28 days. At the end of this period, the rigid metal plates were bonded with epoxy adhesive, after which they were left to set for 24 hours (according to instructions for the use of resin).

At the end of the setting period, the test samples were tested in turn using the hydraulic press (Fig. 2).

Fig. 2. Determination of tensile bond strength with the hydraulic press.

3. Results and Discussions

The application of thermal insulation to exterior walls involves providing adhesion and stability of fixation to the support, taking the weight of the thermal insulation and of the entire system, and the continuity and flexibility of the support layer for finishing.

The thermal insulation envelope has a different dilation coefficient from that of the support layer, being subject to perceptible changes with high temperature variations, which is why it should function in a flexible way, without changing cohesion, sealing and adhesion to the support.

The technology for the development of a system that can meet the requirements presented above involves the following:

- application of mortar over the outline of the boards and in three points in the middle so that all variations in the dilation of the material are taken within the perimeter of each separate board without generating fissures at the mounting joints;
- fixation can be completed by anchorage with plastic dowels at a mean density of 6 dowels/ m^2, placed in "T" or "W" system. Dowel anchorage at the corners and in the middle of the thermal insulation boards limits the accumulation of the dilation of the material in the facade field;
- for the support of the facade finishing, a spatula mass with a composition similar or identical to that of adhesive bonding mortar is used. This is applied in a 2-3 mm thickness, in which a glass fiber reinforced mesh is incorporated in wet conditions, whose strips overlap in horizontal and vertical plane over at least 10 cm in order

to obtain a continuous, flat, shock-resistant and flexible layer, so that the exterior finishing is not subjected to deformation that may cause cracks;
- thermal insulation composite systems of facades are finished with various decorative plasters that improve the weatherability, vapor permeability and behavior of the finishing over time [5].

3.1 Determination of adhesive strength of hardened mortars to different substrates

The results obtained following the determination of the adhesive strength of hardened mortars to different substrates are shown in Table 2.

Table 2. Adhesive strength of hardened mortars to different substrates [kPa].

Mortar	Substrates				
	Brick	Concrete	ACC	Enameled ceramic tiles	Old plastering
CS II	60.62	33.93	29.95	4.98	33.11
Cement paste	8.96	3.47	25.47	0.82	8.76
CT adhesive mortar	116.05	113.6	88.33	9.68	46.56

Regarding the presented technology, as shown by the results of Table 2, the following are noted:

- CT adhesive mortar is the best from the point of view of adhesive strength to all support layer variants included in the study; it should be mentioned that for enamel ceramic and old plaster substrates, anchorage with plastic dowels is required;
- CS II mortar, although inferior to CT adhesive mortar, is good enough for the substrates included in the study, but the fixation through plastic dowel anchorage not only to the enamel ceramic and old plaster support, but also to the ACC support, is required;
- cement paste can be used only for ACC and possibly brick, in order to facilitate fixation by dowel anchorage.

3.2 Determination of the tensile bond strength of the adhesive and of the base coat to the thermal insulation material (polystyrene)

The results obtained following the determinations of the tensile bond strength of adhesives to the thermal insulation material (polystyrene) are shown in Table 3.

Table 3. Tensile bond strength of the adhesive to polystyrene EPS 80 [kPa].

Characteristics	Mortar		
	CS II	Cement paste	CT adhesive mortar
Adhesion [kPa]	19.67	63.83	83.70
Type of break	adhesive	adhesive	cohesive in polystyrene

The table shows that CT adhesive mortar has the highest tensile bond strength to polystyrene, being followed by cement paste and CS II mortar, with values ranging between 19.67 and 83.7 kPa.

The type of break of CT adhesive mortar is a cohesive break in polystyrene, which is why, in the thermal insulation composite system technology, this does not require mechanical fixation with dowels, from the point of view of the adhesion of mortar to polystyrene.

CS II mortar and cement paste have an adhesive break, which requires plastic dowel fixation.

4. Conclusions

Based on the results obtained following the tests regarding the adhesive strength of hardened mortars to the support and particularly, the results of the adhesive strength of adhesive mortar for the bonding of polystyrene to different types of substrates (brick, concrete, ACC, old plastering, enameled ceramic tiles), specific external thermal insulation technologies were developed depending on the basic material, taking into consideration the following aspects:

- based on the comparisons regarding the adhesive strength of adhesive mortar, significant adhesive strength differences were found depending on the type of support on which it was applied;
- in the case of the application of the adhesive on an enameled ceramic support, a very low mean adhesive strength was observed;
- the values of the adhesive strength of the adhesive to old plastering were rather low compared with adhesive strength to brick, concrete and ACC.

Although adhesive strength values are lower in the case of the use of CS II mortars, these can be used in the case of the application of a composite thermal insulation system mechanically fixed with compensation mortar in order to ensure the planeness of the facade. The mentioned mortars can also ensure the adhesion of polystyrene to the support until the application of mechanical fixation (dowels).

When the adhesive is replaced with the cement paste, adhesive strength to different support types varies extremely widely from one type to another; the cement paste can be used for ACC and possibly brick, in order to facilitate fixation by dowel anchorage.

The study demonstrates that the CT adhesive mortar used, has a clearly superior adhesive strength to all support materials (brick, concrete, ACC, enameled ceramic, old plastering) compared to the other mortars used. Adhesive mortar has the best adhesive strength to the brick and concrete support, with very similar values.

CS II mortar can replace CT adhesive mortar for all substrates included in the study, but fixation by plastic dowel anchorage not only to the enamel ceramic and old plaster support, but also to the ACC support is required.

The cement paste can replace CT adhesive mortar only for ACC and possibly brick, in order to facilitate fixation by dowel anchorage.

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