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A numerical and experimental investigation of temperature field in place of anchors in ETICS system

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HIGHLIGHTS

- Determination of the thermal quality of recycling connectors.
- Application of infrared measurements to assess the temperature on the building envelope in ETICS system.
- Mechanical connector as a point thermal bridge in ETICS systems.
- Numerical analysis of the building envelope with mechanical connectors and the validation with measurement results.

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ABSTRACT

The aim of the paper is to determine the thermal quality of recycling connectors and to assess their application effectiveness in thermal insulation systems. Four types of connectors were used, differing in the share of the added recyclate, and two different ways of their mounting were presented. The connectors used in the work were produced on the basis of polypropylene recyclate. The initial tests determined their strength and other features required for mount connectors in the ETICS systems. The article presents the results of infrared measurements for envelopes insulated with the material of different thicknesses and mounted with the use of recycling connectors. In the numerical tests (THERM program), envelope models with a thermal connector were made for the selected variants of the connector and its mounting, treating it as a point bridge. Temperature distribution profiles were determined at the places of point thermal bridges, the thermal coupling coefficient and the value of the point thermal bridge were calculated. Throughout this work, the term 'recyclate connector' is understood by the authors as a sleeve made from recyclate and a pressure plate.

1. Introduction

The necessity and ability to precisely determine the parameters which characterize thermal insulation of building envelopes, including thermal transmittance, is of particular significance when we design energy efficient buildings, low energy, passive, zero-energy buildings or other similar structures. The above problem closely corresponds with the guidelines [1], stipulating new energy performance standards for buildings. With respect to building envelopes, their high thermal quality is ensured not only by an appropriately selected insulation type or its thickness [2]. It is also relevant at the designing stage of building envelopes to eliminate thermal bridges, which was demonstrated on the example of residential buildings in Canada [3]. Likewise, Cappelletti and his team [4] showed that the energy efficiency of buildings is not only dependant on the use of appropriate materials, but also on the connection of various building elements. It is estimated that higher demand for heat due to incorrectly designed building details and following it thermal anomalies can reach the value of 20%–35%. For example, it has been demonstrated [5] that for southern Italy it can be around 20% and in the north of Italy it is 13.5%. And in Greece [6], it was estimated that due to thermal bridges, heat losses are about 30% higher than expected. The analyses on thermal bridge led the authors of the paper [7] to the regressive model as a function of design variables. All the described works emphasize high importance of thermal bridges in the estimation of heat losses in buildings.

Point thermal bridges can be diagnosed by means of infrared measurements [8]. And the paper [9] compared the invasive and non-invasive methods for measuring the resistance of building envelopes. Using this method, we can measure the distribution of

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temperature fields on the envelope and identify possible thermal disturbances. However, it cannot be applied to determine so called linear thermal transmittance ψ [10]. And the paper [11] demonstrates that the IR thermography method can be successfully used to analyze heat losses through the building envelope. Most research studies are based on empirical relations to determine the value of linear thermal transmittance ψ [12]. In particular, Simo Ilomets with his team [13] proposed, on the basis of their measurements, the values ψ of the coefficient ψ for four types of buildings: prefabricated concrete large panel element, brick, wood (log), and autoclaved aerated concrete. And in this or similar way catalogs of typical thermal bridges are created [14].

With respect to point thermal bridges, their impact on the thermal quality of envelopes is frequently underestimated [15]. In ETICS systems [16,17], in which a mechanical connector represents the point thermal bridge, its impact should be regarded as thermal disturbance. In particular in the article [16] different connectors were tested, both polymer reinforced and steel ones.

In the present work the authors have attempted to determine the influence of point thermal bridge in the form of mechanical connector on the thermal quality of the envelope. It is important to add here that the connector was made from recycling material. The issue of an appropriate selection and application of materials used in building engineering, to maximize the recycling potential, in particular in buildings having low energy consumption, was emphasized by Thomark [18]. Also the authors of this paper described in their works [19,20] the use of recycling materials in energy-saving construction, as well as the methods for the estimation heat conduction for such materials.

But already in the last century [21] research studies were carried out on the reduction of building wastes as the main concern of the integrated management policy. Materials from recycling processes contribute to the reduction of energy consumption since the amount of energy needed to process such materials is lower than the fabrication of new materials [22]. The significance of recycling in the contemporary world can be clearly observed by the policy employed by the European Committee which is planning to totally eliminate the storage of plastic wastes at dumping sites to the year 2025, which means subjecting them to recycling in 100%. According to the requirements specified in ETAG [23,24], the application of secondary recycling materials for the fabrication of connectors is legitimate on condition that additional tests are carried out [23]. In line with the requirements specified in the documents [23,24], all required tests were carried out and presented in the work [25]. The said tests can be complemented with thermal quality data involving the proposed connectors. So far the authors have not found in literature any measuring methods which would enable the determination of thermal insulation capacity of mechanical connector itself. Most frequently, virgin material is subjected to testing for that purpose [26,27]. Yet, the experience of the authors indicates that the results of laboratory tests are often not reliable and do not reflect the real features of the component [19,20]. The information obtained by the authors show that in the case of small-sized elements, e.g. a connector or sleeve (as in the analyzed case), thermal conductivity tests are conducted for a virgin material in a plate apparatus or in a different type of apparatus in accordance with the assumptions of the Standard [28]. But in the case of a single component, thermal parameters may change, depending on its geometry or other features. Therefore, the choice of the right measuring method of thermal parameters is important to obtain the searched objectives of the carried out research. The authors treated thermal imaging as a preliminary method to assess the thermal quality of mechanical connectors. Although the method is characterized by lower accuracy, the obtained results allow us to assess the thermal quality of connectors and their performance in the envelope (their impact on temperature field distribution) The main goal was to compare the performance of the connector sleeves (or actually sleeve plates) which had a different share of recyclate. The applied measurement method does not allow us to obtain a quantitative assessment, but it answers which sleeves are better or worse in terms of the rise of heat flux at the plate location and the extent (scale) of changes in the temperature field. Due to the fact that the analysis of measurement error is still an open issue [29], the authors of the carried out research study were focusing mainly on temperature differences between individual mechanical connectors which enabled the compensation of measurement errors.

The objective of the work is to assess thermal quality of connectors (connectors' casings) on the basis of experimental and numerical research studies. The experimental studies comprised infrared diagnostics of a wall thermoinsulated in the ETICS system. Various thickness variants of the insulating material were applied (the dependence of the connector's impact on material thickness) as well as different connectors having different share of the added recycling material and diverse mounting methods. The obtained results based on field studies were complemented with numerical results obtained with the application of Therm program. For the accepted envelope variants (thickness of insulating material), mounting method of the connector and imposed boundary conditions (based on the measurement), the distribution of temperature fields on the envelope was determined. Also, the point thermal transmittance χ was determined. Numerical analyses were carried out for the connector made from virgin material. The results of numerical modeling were compared with the results of infrared tests (field of temperatures). The identified differences (temperature values) in the obtained results would indicate that the recycling material, in spite of maintained strength qualities, does not have such thermal parameters as the virgin material.

2. Method

The material used for the fabrication of connectors consisted of two raw materials:

1. Polypropylene recyclate R, which was obtained by the processing of post-production wastes. The carried out studies [25] confirmed the presence of polypropylene PP and high-density polyethylene PE-HD in the analyzed material. The weight ratios of the plastics were calculated: polypropylene ~75%, polyethylene PE-HD ~25%. Also a stabilizer in the form of *N-Ethylbenzylamine* derivative was supposedly present in the material.
2. Original polypropylene of the type EP340K, manufactured by BaselOrlenPolyolefins, marked as M.

For the studies, the mixtures of the above materials were accepted in various weight ratios:

- 100% of the raw material from recycling marked in the further part of the work as, "M_0% + R_100%" (polypropylene recyclate)
- 80% of the raw material from recycling marked in the further part of the work as M_20% + R_80%
- 60% of the raw material from recycling marked in the further part of the work as M_40% + R_60%
- 20% of the raw material from recycling marked in the further part of the work as M_80% + R_20%
- 0% of the raw material from recycling marked in the further part of the work as M_100% + R_0%

2.1. Subject of the research

In effect of the pressure exerted on the insulation through the application of a mechanical connector, friction forces increase