Multi-layer structures with thermal and acoustic properties for building rehabilitation

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Abstract. This work compares the use of different sustainable materials in the design of multi-layer structures for the rehabilitation of buildings in terms of thermal and acoustic properties. These structures were obtained by compression moulding and thermal and acoustic tests were further carried out for the quantification of the respective insulation properties of composite materials obtained. The experimental results show that the use of polyurethane (PUR) foams and jute fabric reinforcing biocomposites promotes interesting properties of thermal and acoustic insulation. A multi-layer structure composed by PUR foam on the intermediate layer revealed thermal resistances until 0.272 m² K W⁻¹. On the other hand, the use of jute fabric reinforcing biocomposites on exterior layer promoted a noise reduction at 500 Hz until 8.3 dB. These results allow to conclude that the use of PUR foams and jute fabric reinforcing biocomposites can be used successfully in rehabilitation of buildings, when the thermal and acoustic insulation is looked for.

1. Introduction

After decades of high growth in the construction industry there is currently some stagnation and decrease in this area, due to several factors such as populational growth or the development of new materials. Although the world population continues to grow, other constraints have contributed to this overview, related to the planet’s sustainability and the natural resources consumption, which affects the people’s standard of life. In this regard, innovative approaches have emerged to rehabilitate older buildings in order to make them more functional, and also to promote energy savings through the combination of more sustainable materials.

Forty years after the introduction of compulsory thermal insulation in most European countries, insulation materials form still the main tool for the improvement of a building’s energy behaviour [1]. The use of insulation materials has increased, both in terms of buildings being insulated and in the minimum values of insulation required by national regulations [1]. By the way, one of the most important challenges of future buildings is the reduction of energy consumptions in all their life phases, from construction to demolition [2]. The United National Environment Program estimates that buildings consume about 40% of the world global energy, 25% of the global water, 40% of the global resources [2]. Besides that, buildings are also responsible of approximately 1/3 of greenhouse gas emissions of the whole planet.

Insulation materials are not independent energy production or conservation systems, but part of the complex structural elements which form a building’s shell. The energy savings can be measured by some specific intrinsic properties of the used structures such as thermal conductivity and resistance,
which are related with the characteristics of the materials. For instance, it is known that conventional materials such as gypsum block or a brick/mortar structure have thermal resistances of 0.017 m²K W⁻¹ and 0.083 m²K W⁻¹, respectively [1].

Thus, the goal of this study was to evaluate the thermal and acoustic insulation properties of multi-layer structures. These multi-layer structures were obtained from sustainable materials, focusing on the application to buildings rehabilitation.

2. Materials and Methods

2.1. Materials

The multi-layer structures were developed from the combination of three different layers, listed in Table 1. The non-woven with recycled cotton and polyether sulfone (PES) fibres, A1, had a random orientation of the fibres, and a weight of 1500 g m⁻². This material was used in the final composite with 17 mm of thickness. Cork agglomerate, B1, used had a thickness of 3.3 mm. The grey polyurethane (PUR) foam, B2, had a density between 37 – 44.9 kg m⁻³ and was used in the final composite with 1.8 mm of thickness. Jute fabric reinforcing polyvinyl chloride (PVC) membrane, C1, is used with orientation of 0°/90° and this material was used in the final composite material with thickness of 1.3 mm. Polyester fabric reinforcing PVC membrane, C2, is also used with orientation of 0°/90° and this material was used in the final composite material with 0.5 mm of thickness. Finally, a polyester fabric only, C4, was also used, with 0.2 mm of thickness.

These layers were adhered to each other through a thermoplastic adhesive web based on copolyolefin, supplied by AB-Tec, with reference XBO 013. This adhesive web had a weight of 20 – 40 g m⁻², a melt flow rate (MFR) of 11 g/10 min and a melting range of 122°C.

| Material | Position   | Reference | Composition                                      |
|----------|------------|-----------|--------------------------------------------------|
| 1        | A: interior| A1        | Non-woven with recycled cotton and PES fibres    |
| 2        | B: intermediate | B1 | Cork agglomerate                                |
| 3        | B: intermediate | B2 | Grey PUR foam                                   |
| 5        | C: exterior | C1        | Jute fabric reinforcing biocomposite             |
| 7        | C: exterior | C3        | Polyester fabric reinforcing PVC membrane       |
| 8        | C: exterior | C4        | Polyester fabric                                |

2.2. Composite Materials Production

As previously referred, the different layers were adhered to each other through a thermoplastic adhesive web based on polyolefin. The final multi-layer structures were obtained by compression moulding process in a specific equipment, showed in Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε., at 180 ºC, 1 bar, during 46 seconds. After this heating step, the samples were cooled in the same equipment, turning on the cool water circulation to hot plates, at the same pressure, during 2 minutes. Finally, the final composites were extracted after complete cooling of the final multi-layer structures.
In this study, it was intended to study the influence of use different combinations of the available materials. The compositions of different multi-layer structures produced were schematically presented in Table 2.

Table 2: Composition of Multi-layer structures.

| Multi-layer structure | Layer A | Layer B | Layer C |
|-----------------------|---------|---------|---------|
| 1                     | A1      | B1      | C1      |
| 3                     | A1      | B1      | C3      |
| 4                     | A1      | B1      | C4      |
| 5                     | A1      | B2      | C1      |
| 7                     | A1      | B2      | C3      |
| 8                     | A1      | B2      | C4      |

2.3. Thermal and acoustic insulation Tests

The thermal insulation properties of the obtained multi-layer structures were determined by Alambeta device, with samples with radius of at least 55 mm. This device measures the thermal resistance of these materials to the heat flux, and the properties of thermal conductivity and thermal resistance are obtained.

The acoustic insulation properties were obtained using an acoustic insulation chamber, Figure 2, according to E90 standard, by measuring the reduction of noise in the interior zone, emitted by a sound source in the exterior zone.
3. Results and Discussion

The summary of obtained results of thermal and acoustic tests performed with the samples of multi-layer structures are presented in Table 3, where comparative results between the different compositions of each one can be discussed. First of all, it is important to refer that the A1 material is common to all multi-layer structures, in interior position of these ones. For this reason, it is only possible to compare and discuss about the effects of the different materials used on the layers B and C, intermediate and exterior positions of the multi-layer structures, respectively. From these results, it can be observed a trend for B2 material promote better thermal resistance than B1 material. For instance, comparing the pair of samples 1 and 5, which differ only in the material of layer B, it is observed thermal resistances of 0.216 and 0.272 m² K W⁻¹, respectively. This trend is equally verified if the pairs of samples 3 and 7 or 4 and 8 were also compared. In this context, it can be concluded that the grey PUR foam has the capacity to promote better thermal insulation than cork agglomerates materials.

Relatively to the materials on layer C, the same reasoning is not possible to do totally. In samples 3 and 7, which differ only in the material of layer B, it is observed thermal resistances of 0.214 and 0.218 m² K W⁻¹, respectively. This values are the worst ones registered in these thermal tests, which allows to conclude that the C3 material, a polyester fabric reinforcing PVC membrane, is not the best choice when it looking for thermal insulation. In terms of noise reduction, it is shown a considerable influence of C1 material, a jute fabric reinforcing biocomposite, after its incorporation. Moreover, it is also possible to verify that the C3 material, a polyester fabric reinforcing PVC membrane, also promotes better acoustic insulation than C4 material, a polyester fabric. Comparing multi-layer structures 1, 3 and 4, which have the common materials on layers A and B, it is showed a noise reduction at 500 Hz of 8.3 dB, 6.6 dB and 5.4 dB, respectively. Similar trend is observed when the samples 5, 7 and 8 were compared to each other.

Table 3: Results for thermal and acoustic tests.

| Multi-layer structure | Layer A | Layer B | Layer C | Thermal Resistance, R (m² K W⁻¹) | Noise Reduction at 500 Hz (dB) |
|-----------------------|---------|---------|---------|----------------------------------|------------------------------|
| 1                     | A1      | B1      | C1      | 0.216                            | 8.3                          |
| 3                     | A1      | B1      | C3      | 0.214                            | 6.6                          |
| 4                     | A1      | B1      | C4      | 0.223                            | 5.4                          |
| 5                     | A1      | B2      | C1      | 0.272                            | 8.1                          |
| 7                     | A1      | B2      | C3      | 0.218                            | 6.1                          |
| 8                     | A1      | B2      | C4      | 0.233                            | 3.9                          |
4. Conclusions

Our planet is actually getting overloaded with buildings, threatening its sustainability. Besides that, the quality of life is also affected with this trend, due to the permanent destruction of large green areas, which are responsible to oxygen production, for buildings construction. In this context, the urban rehabilitation sector, mainly in old constructions made with traditional and already inefficient materials, is becoming more important as an alternative to the construction of new buildings. Then, the introduction of multi-layer structures capable of giving better insulation properties on buildings is a great opportunity in this sector. So, from this study, it was verified that some materials can be used in these multi-layer structures with interesting results. Thermal insulation tests of several multi-layer structures composed by different materials, showed that the use of PUR foams on intermediate layer can improve until approximately 25% of thermal resistance than other used materials. On the other hand, acoustic insulation tests performed to these multi-layer structures showed that the use of jute fabric reinforcing biocomposite on exterior layer can improve the noise reduction at 500 Hz until approximately 108%, comparing with other materials. Therefore, from this study it could be concluded that PUR foams and jute fabric reinforcing bio composites impart good thermal and acoustic properties. Furthermore, it was observed that the thermal resistances obtained with these materials are superior to conventional materials such as gypsum or brick/mortar, which is an important indicator for urban rehabilitation sector.

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