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Insulation Materials Susceptibility to Biological Degradation Agents: Molds and Subterranean Termites

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Abstract: Insulation materials are fundamental for decreasing energy losses and guaranteeing thermal and acoustic comfort in buildings, which may significantly contribute to decreasing the energy consumption related with poor thermal building conditions. These insulation materials should have a low susceptibility to biological degradation agents to decrease the risks of degradation of other construction materials, as well as decrease possible health risks related with the development of noxious biological degradation agents regarding indoor air quality, for example, or decrease possible structural risks posed by those agents. The present study aimed at evaluating the susceptibility of several insulation materials to mold growth and subterranean termites' attack. Insulation materials, including expanded polystyrene (EPS), mineral wool (MW), and expanded cork agglomerate (ICB), were tested against mold development, using maritime pine as a control. Three types of inoculations were made: (1) natural indoor inoculation; (2) artificial inoculation using *Aspergillus niger* and *Penicillium funiculosum*; and (3) artificial inoculation using *Aureobasidium pullulans*. The susceptibility of the insulation materials referred to, plus wood/glass fiber (WGF), was evaluated for two subterranean termite species: *Reticulitermes grassei* and *Reticulitermes flavipes*. The expanded cork agglomerate showed a higher susceptibility to molds than the other insulation materials tested. The remaining materials revealed a good performance, showing no growth or traces of growth of molds. All the materials tested showed susceptibility to subterranean termites, with both species being able to cross them to obtain access to the wood. However, wood/glass fiber showed a negative effect, which translated into lower survival rates and attack degrees of the wood. Some tested materials showed a good resistance to the development of biological degradation agents, namely an organic material (coconut fiber), a composite of organic and inorganic materials (WGF), and an inorganic material (EPS). These results indicate that it is possible to pursue the development of innovative and effective insulation materials with a low susceptibility to biological degradation agents, regardless of their organic or inorganic origin.

Keywords: insulation materials; biological degradation; molds; fungal growth; subterranean termites

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1. Introduction

In 2020, buildings contributed to more than 30% of global energy-related greenhouse gas (GHG) emissions [1] and about 40% of the world's energy consumption, of which approximately 27% was attributed to the residential sector [2]. To deal with this problem, several directives were delivered by the European Union (EU) aiming to minimize heating/cooling and electricity demands, and thus reducing CO_2 emissions. Among the key policies for achieving these include the Energy Performance of Building Directive (EPBD), which was launched in 2010, and the Energy Efficiency Directive (EED), which was launched in 2012. With the application of these documents, the EU estimated a reduction of 8%, 12%, and 17% on the energy required for the heating/cooling of buildings in 2020, 2030, and 2050, respectively, compared to data for 2005. Nevertheless, these decreases cannot be achieved if only new construction and new buildings are considered, and a special look at the existing and even older built heritage needs to be performed, as these buildings represent most of the European-built patrimony.

The use of proper insulation materials and design has already been proven as the best strategy to reducing energy losses and guaranteeing thermal comfort [3,4]. Additionally, the reuse of construction building materials waste has also been promoted as a sustainable practice [5].

Thermal insulation systems can be applied using three different application techniques: to the exterior—exterior insulation; to the interior—interior insulation; and via injection—cavity insulation. External thermal insulation composite systems (ETICSs) are often applied on new constructions. However, when there is a need to insulate buildings in an urban context or even built heritage, the application of an ETICS is frequently not possible (for example, due to excessive narrowing of pedestrian walkways in narrow streets), and the application of interior insulation may be the only viable solution. The application of this technique comes with some disadvantages (such as reduction in room size) and problems, such as the development of thermal bridges [6], possible occurrence of interstitial condensation [7], frost damage [8], and decay on timber beam-ends [9], among others.

It is known that air infiltration in many of the existing buildings can result in significant heat losses, with losses as high as 33% being noted in the UK [10]. As a result of these concerns about energy efficiency, along with society's desire to reduce its carbon footprint, buildings are now being designed to be increasingly airtight. This lack of unwanted ventilation can lead to dampness, moisture damage in buildings, and increased levels of indoor relative humidity. All these conditions strongly contribute to mold growth, along with several physical and environmental properties (e.g., water content, temperature, pH, and the type (i.e., organic and non-organic) and hygroscopic behavior of the materials [11,12]). Previous research has shown that organic materials, with ample nutrients in their composition, are more prone to mold growth [13]. Furthermore, the development of new insulation materials, often multi-component in nature and comprising natural materials and/or wastes as part of the composition of their matrix, seriously increases the risk of biodeterioration [14,15]. The need to evaluate the biodegradation risk of organic, inorganic, and composite insulation materials is therefore of utmost importance to enable a correct application and use of these materials in construction systems.

According to Verdier et al. [16], the most common fungal genera found in indoor environments belong to the genera *Penicillium*, *Cladosporium*, *Aspergillus*, and *Stachybotrys*. The application of antifungal additives (e.g., sodium polyborate or dichlofluanid) has been commonplace to avoid mold growth [17]. Nevertheless, such an application always raises some concerns related to the real effectiveness of the antifungal treatment over time, as well as with potential health concerns [17,18].

In addition to fungal growth, the exposure of the insulation materials to wet conditions resulting from condensation or leakage may allow for the action of other biotic degradation agents, such as subterranean termites. With regard to fungal growth, several studies have been made with the aim of evaluating the susceptibility of different construction and building materials exposed to different conditions [19–22]. Concerning the resistance to subterranean termite attacks, very few studies have been published [23,24]. Typically, termites do not use the insulation material itself as a food source, but as a means of reaching the wooden structure of the building, often present at high moisture levels. As they cross the thermal insulation layer, they create a set of tunnels that will naturally affect the thermal capacity of the insulation material and thus affect the energy efficiency of the building. Moreover, the physical properties of the insulation materials provide a considerable amount of internal temperature stability, inadvertently providing a comfortable habitat for termites [24]. A resistant thermal insulation material would contribute to the prevention of subterranean termite attacks and infestation in wooden elements of the buildings.

The present study aimed to evaluate the susceptibility of several insulation materials to mold growth and subterranean termite attacks (Blattodea: Isoptera: Rhinotermitidae) under laboratory conditions, and to consider further improvements of insulation material properties regarding biotic degradation.

2. Materials and Methods

2.1. Materials

Insulation materials, including expanded polystyrene from two different manufacturers (EPS-S and EPS-C), mineral wool (MW), and expanded cork agglomerate (Co), were tested (Figure 1), using maritime pine (*Pinus pinaster* Aiton) as a control (C). In this study, the mineral wool (MW) used consisted of either rock wool or glass wool. Glass wool is obtained by mixing natural sand and glass at a temperature between 1300 °C and 1450 °C, where the heated mass is forced through rotating nozzles, often via centrifugal force, thus creating fibers. On the other hand, rock wool is produced by melting different types of rocks (e.g., basalt, dolostone, and diabase) at 1600 °C, thus obtaining fibers that are bound together using resins (often terpolymeric mixtures) and oil (to reduce dust release). Both glass wool and rock wool are commercialized as panels, felt pipe sections, or rolls. Expanded polystyrene (EPS) is composed of small spheres of polystyrene, including an expansion agent (e.g., aliphatic alkanes, such as pentane). This method allows for the production of a rigid closed-cell foam made of approximately 98% air and 2% plastic. Insulation cork board (Co) is a natural, renewable, and recyclable material composed of natural cork that can be applied on the facade of buildings, improving their energy performance. No chemical adhesives or additives are used in the production of insulation cork boards.

(**a**) (**b**) (**c**)

Figure 1. Detailed images of the insulation materials EPS-S (**a**), MW (**b**), and Co (**c**).

For termite resistance testing, wood plus glass fibers (WGFs) and coconut fibers were also used. The WGF was of commercial origin, and the coconut fiber used was made of unprocessed coconut fibers, directly from the producer. These materials were selected due to their widespread use in Europe [25], where they are not only applied as a form of interior insulation, but also as a form of exterior insulation (i.e., ETICS). All samples were placed in a climatic room at a temperature of 20 °C ± 2 °C and a relative humidity (RH) of 65% ± 5% and were maintained in these conditions until they were required for testing. The samples that were inoculated with molds were previously steam sterilized in an autoclave at 100 °C for 20 min.

Different samples were cut from the insulation panels: a set of nine samples of each studied insulation material, with dimensions of 40 × 40 × 30 mm^3, was used to assess fungal growth; cylindrical pieces of each insulation material that were later compacted into glass tubes (see Section 2.3) were used to evaluate subterranean termites' ability to cross the materials.

2.2. Fungal Growth Tests

The samples were inoculated with three fungal species: *Aspergillus niger* Tiegh., *Penicillium funiculosum* Thom, and *Aureobasidium pullulans* (De Bary) G. Arnaud. These species were selected considering their prevalent presence in interior environments [13,16]. They are also commonly referenced to in the literature and applicable standards [13,16,26]. Three types of inoculation were applied: (1) natural indoor inoculation; (2) artificial inoculation using *A. niger* and *P. funiculosum*; and (3) artificial inoculation using *A. pullulans*, with three replicates of each insulation material being tested. A spore suspension of each fungus was used for artificial inoculations, according to the method described in ISO 846 [27], and 2 mL of fungal suspensions was applied on each insulation sample and control, using culture flasks that were previously sterilized and provided with a sterile culture medium (comprising 40 g of malt, 20 g of agar, and 1 L of distilled water). For natural indoor inoculation, samples were just left in indoor conditions at the laboratory for several days without a controlled temperature and RH.

The culture flasks with inoculated insulation materials were closed and kept inside a culture chamber at T = 22 °C ± 2 °C and 70% ± 5% RH for four weeks. The samples were visually evaluated for fungal growth weekly, considering the guidelines defined in the standard ASTM D5590-00 [26] (Table 1). After four weeks of incubation, the materials were carefully removed from the test flasks, and the fungal growth and contaminated area were visually evaluated with the help of an optical microscope.

Table 1. Guidelines for the visual assessment of fungal growth adapted from ASTM D 5590-00 [26].

Intensity of Growth	Evaluation	Covering of the Sample's Surface
0	No growth apparent under the microscope	0%
1	Traces of growth	<10%
2	Light growth	10–30%
3	Moderate growth	30–60%
4	Heavy growth (to complete surface coverage)	60–100%

2.3. Termite Attack Tests

The susceptibility of the insulation materials was evaluated for two subterranean termite species: *Reticulitermes grassei* Clément and *Reticulitermes flavipes* Kollar. The former is one of the most common species in the south of Europe, and the only one that has been identified in mainland Portugal [28,29]. *R. flavipes* is an introduced, though well-established, species in France. The termites were collected in the fields from Portugal (*R. grassei*) and France (*R. flavipes*) and were maintained under optimal conditions until testing.

The tests were performed based on an adaptation of the guidelines defined in standard EN 118 [30]. First, three cylindrical pieces of each insulation material (MW, EPS-S, EPS-C, and ECA) were cut and compacted into glass tubes. Then, the glass tubes were stacked on pine wood pieces using a contact glue, and a mixture of sand and water in a 4:1 proportion was introduced on the top of each tube. Two hundred and fifty workers, two soldiers, and two nymphs were introduced in each glass tube. The tubes were then sealed with a piece of cotton and an aluminum foil to avoid water evaporation (Figure 2). The controls were also performed without any insulation material.

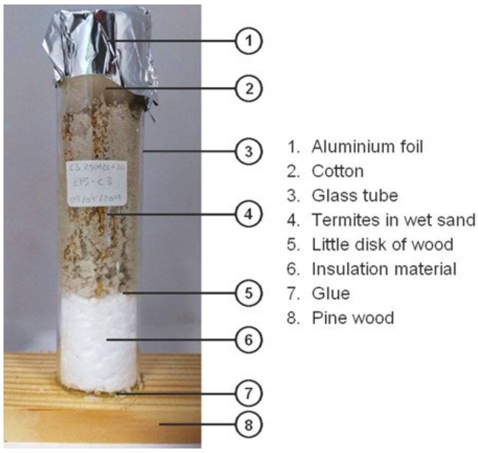

Figure 2. Termite attack test assembling, with, in this example, EPS-S as the insulation material and the termite species *Reticulitermes grassei*, after 24 h of exposure.

The test specimens were kept inside a conditioned room at 25 °C ± 2 °C and 80% ± 5% RH for four weeks. After this period, the surviving termites were removed from the glass tube and counted, and the test specimens were disassembled and cleaned. The survival rate (SR) of each test specimen was determined (Equation (1)):

$$SR\ (\%) = [(\text{nr. live workers}/250) \times 100]. \quad (1)$$

Every test specimen was visually examined, and the attack degree was classified from 1 to 4, according to the standard EN 118 [30]: 0—no attack; 1—attempted attack; 2—slight attack; 3—average attack; and 4—strong attack.

The analysis of variance (ANOVA) statistical test was performed to assess the susceptibility of the different insulation materials to termites, along with a post-hoc Tukey test, with a significance level of $p < 0.05$.

3. Results

3.1. Resistance to Fungal Attacks

Table 2 presents the average results of the visual assessment degree of fungal growth.

Table 2. Results of the visual assessment rate of fungal growth, adapted and complemented from the authors of [31].

	Natural Indoor Inoculation				Artificial Inoculation with:							
					A. niger and *P. funiculosum*				*A. pullulans*			
	Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 1**	**Week 2**	**Week 3**	**Week 4**
Control	4.0	4.0	4.0	4.0	3.7 ± 0.6	3.7 ± 0.6	3.7 ± 0.6	4.0	3.0	4.0	4.0	4.0
EPS-C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EPS-S	0.0	0.7 ± 0.6	0.7 ± 0.6	0.7 ± 0.6	0.0	0.3 ± 0.6	0.3 ± 0.6	0.3 ± 0.6	0.0	0.3 ± 0.6	0.3 ± 0.6	0.3 ± 0.6
MW	0.0	0.0	0.0	0.3 ± 0.6	0.3 ± 0.6	0.3 ± 0.6	1.0	1.0	0.0	0.0	0.0	0.0
Co	2.0	2.3 ± 0.6	3.7 ± 0.6	3.7 ± 0.6	1.7 ± 0.6	2.3 ± 0.6	2.7 ± 0.6	2.7 ± 0.6	1.0	1.3 ± 0.6	2.0	2.0

Rating scale: 0—no growth; 1—traces of growth; 2—light growth; 3—moderate growth; and 4—heavy growth.

The results obtained for the controls (Cs) allowed for the validation of the test procedure. Indeed, all controls were rated as four (heavy growth) after four weeks of incubation. Additionally, an appreciable level of fungal growth was observed for cork samples (Co) at the end of the test, with all samples presenting more than 10% of their surface contaminated and thus rated as two or more, regardless of the type of inoculation (Figure 3a). For the EPS-C samples, no growth was observed during the test (Figure 3b). However, this was not the case considering the EPS-S from a different manufacturer, where traces of growth (i.e., <10% of the contaminated surface) were detected in some samples, especially when the natural indoor inoculation method was used (Figure 3b). Furthermore, no fungal growth was observed in the MW samples for the artificial inoculation with *A. pullulans*, while there were only traces of fungal growth after the first week observations for both *A. niger* and *P. funiculosum* inoculation (Figure 3c). When considering the natural inoculation, the results showed that only one sample of MW showed traces of growth at the end of the tests for natural inoculation and was rated as one.

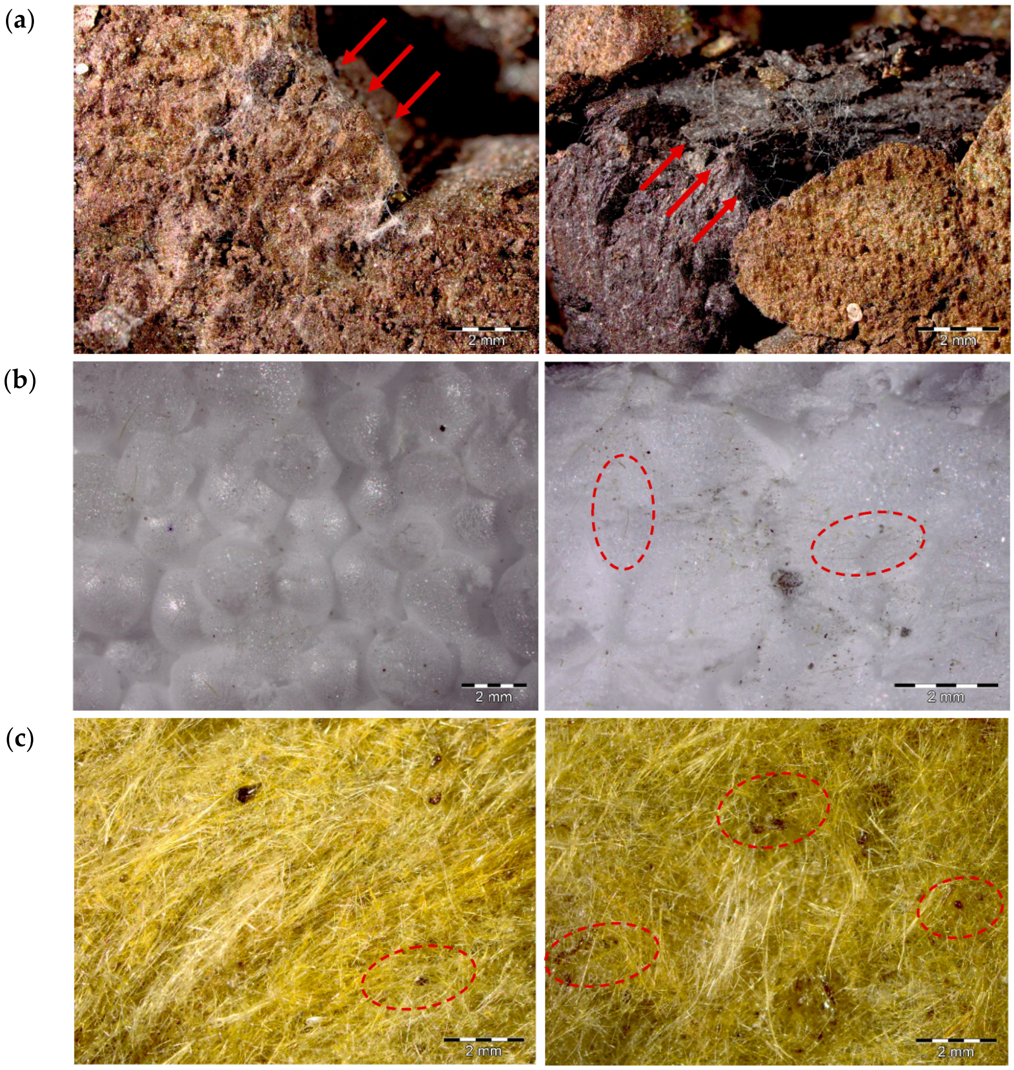

Figure 3. Aspects of some samples at the end of the fungal tests. (**a**) Expanded cork agglomerate exposed to *A. niger* and *P. funiculosum* (**left**) and to *A. pullulans* (**right**). (**b**) Expanded polystyrene EPS-C (**left**) and EPS-S (**right**) submitted to natural indoor inoculation. (**c**) Mineral wool exposed to *A. niger* and *P. funiculosum* (**left**) and to *A. pullulans* (**right**). The arrows and the dotted circles indicate fungal growth.

3.2. Termite Resistance

All controls presented a strong attack degree classified as a four (strong attack) and survival rates higher than 50%, which validated the termite attack test [32]. Both termites were able to cross all materials tested, with the wood exhibiting a high degree of attack (classified as a four; Figure 4), except for MW, that exhibited an average attack when exposed to *R. flavipes* (Table 3).

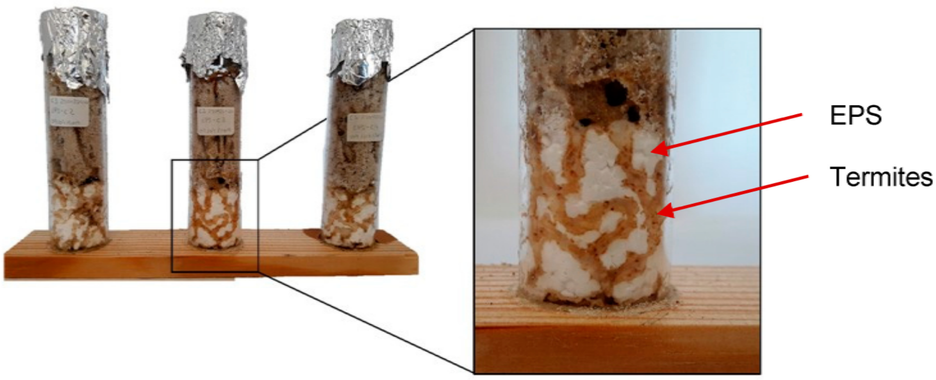

Figure 4. Test specimen of EPS-C (expanded polystyrene) with termites (*Reticulitermes grassei*) clearly crossing the insulation material.

Table 3. Results of the insulation materials' (control, coconut fiber, expanded cork (Co), EPS-C, EPS-S, WGF, and mineral wool (MW)) susceptibility to subterranean termites: *Reticulitermes grassei* and *R. flavipes*.

	Reticulitermes grassei		*Reticulitermes flavipes*	
	Survival Rate (%)	**Attack Degree**	**Survival Rate (%)**	**Attack Degree**
Control	74.0 ± 6.7 [a]	4.0 ± 0.0	56.9 ± 6.6 [a]	4.0 ± 0.0
Coconut fiber	73.3 ± 4.5 [a]	4.0 ± 0.0	24.1 ± 3.9 [bc]	4.0 ± 0.0
Co	68.5 ± 22.7 [a]	4.0 ± 0.0	58.7 ± 4.0 [a]	4.0 ± 0.0
EPS-C	75.1 ± 14.6 [a]	4.0 ± 0.0	51.3 ± 8.0 [ac]	4.0 ± 0.0
EPS-S	75.1 ± 10.5 [a]	4.0 ± 0.0	61.6 ± 7.2 [a]	4.0 ± 0.0
WGF	12.4 ± 17.2 [b]	4.0 ± 0.0	16.8 ± 12.1 [bc]	3.0 ± 1.0
MW	68.8 ± 4.5 [a]	4.0 ± 0.0	16.7 ± 21.4 [b]	4.0 ± 0.0

Note: different letters in the same column represent significant differences among survival rate values for each subterranean termite species.

Both termite species' survival rates were affected by the type of insulation material used (F = 9.063; $p < 0.001$ for *R. grassei*, and F = 11.220; $p < 0.001$ for *R. flavipes*, respectively). Both species were negatively affected by the wood/glass fiber (WGF) material, as shown in Figure 5, where the boxplots of the survival rate values of termites belonging to this species show lower values in comparison with termites in contact with other insulation materials. *R. flavipes* was not able to become established on the wood/glass fiber material, which was reflected in the lower average attack degree verified (n = 3.0 ± 1.0; Table 3). For *R. flavipes*, significantly lower survival rates, compared to the control (Figure 5), were obtained not only when in contact with the WGF ($p = 0.006$), but also with the coconut fiber ($p = 0.027$) and mineral wool ($p = 0.006$). This was the only material in which *R. grassei* showed a significantly lower performance regarding survival rate in comparison to the control ($p < 0.001$), also shown in Figure 5.

The results obtained for EPS-S and EPS-C presented no significant differences between each other for both species, leading to the conclusion that these commercially available insulation materials presented similar crossing susceptibilities for the termites in each respective test.

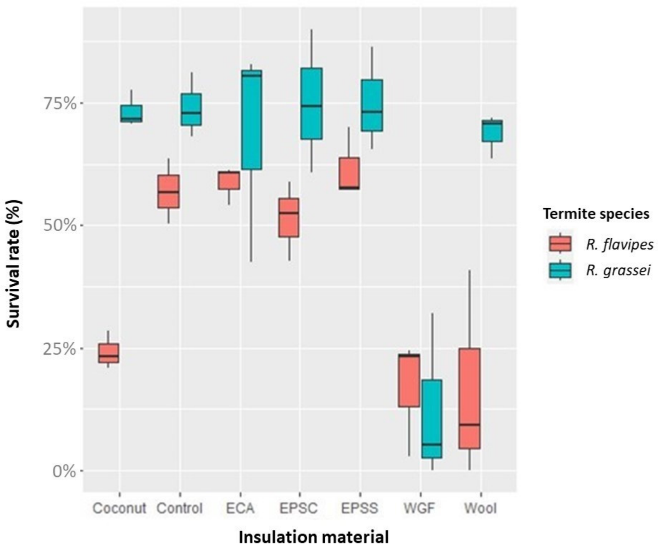

Figure 5. Boxplot of the survival rate (%) of the subterranean termites *Reticulitermes flavipes* (red boxplots) and *Reticulitermes grassei* (blue boxplots) related to the different insulation materials studied: coconut fiber (coconut), maritime pine control (control), expanded cork (ECA), expanded polystyrene: EPS-C and EPS-S, wood/glass fibers (WGF), and mineral wool (Wool).

4. Discussion

The development of new insulation materials is usually made with the objective of enhancing thermal, acoustic, or even structural features of the construction, as well as on a circular economy perspective, prioritizing the use of recycled and biobased materials in encouraging the greater use of more sustainable construction materials (for example, those suggested by the authors of [5,33]); however, the susceptibility to biological degradation agents is sometimes overlooked. Given that these insulation materials will be applied in close proximity to other construction materials, it is important that their performance, under conditions that may trigger the development of biological degradation agents (for example, leakages [19]) is appropriate; otherwise, these agents may install themselves and even act as a source of contamination to the other construction materials, thereby lowering the overall performance of the construction system.

In terms of mold development, the cork agglomerate showed a higher level of susceptibility than the other insulation materials tested, with more than 10% of the contaminated area noted at the end of the trials, either for the natural or artificial inoculation of molds (Figure 3a). The remaining materials demonstrated good performances, showing no growth or traces of growth of fungi (Figure 3b,c). All the materials showed susceptibility to subterranean termites, with both species being able to cross all materials to gain access to the wood.

In fact, cork is a natural material with an organic matrix composed of lignin, suberin, and polysaccharides (cellulose and hemicellulose) [31,34]. Indeed, organic-based materials like cork [13,20,35] are more vulnerable to fungal degradation, as they provide ample nutrients via their constituent components capable of sustaining fungal growth. Furthermore, the fungal growth for cork exposed to artificial inoculation with *A. niger* and *P. funiculosum* was higher than when cork was exposed to artificial inoculation using *A. pullulans*. In a previous study, Hyvärinen et al. [19] reported that *Penicillium* spp. was the most common fungal genera found in samples belonging to the wood group, which included natural cork (one of the building materials considered in this study) being present on 61.2% of all samples; the total prevalence of *Penicillium* sp. plus *Aspergillus* sp. was 78.1% against the 25.1% of *Aureobasidium* sp., which offers a possible justification for the results obtained in the present study. Cork was shown to be susceptible not only to molds but also to both termite species, which was expected due to the natural composition of cork regarding the nutrients available, which include components that termites thrive for in wooden food sources, such as glucose or xylose [36,37].

Coconut fiber is also a natural-based material. This material was only tested against both subterranean termite species, and their behaviors were different, as the survival rate of *R. flavipes* was significantly lower than the controls, while *R. grassei* did not show this effect (Figure 5). Coconut fibers are currently being studied for composites and for another bio-based material development, and its moisture resistance has been noted as one of their advantageous characteristics [38]. Subterranean termites are dependent on a high moisture content of the materials they thrive in, and since the behavior of coconut fibers towards moisture is contrary to the needs of the termites, its presence may negatively impact termite survival rates. However, as *R. grassei* were not affected, further investigations need to be pursued. Different termite species may exhibit a different behavior towards feeding preferences; for example, coconut wood demonstrated higher attack degrees when exposed to *Mastotermes darwiniensis* Froggatt than to *Coptotermes acinaciformis* (Froggatt) [39]. Previous studies have stated the natural durability of coconut fiber against termites as durable (*Reticulitermes santonensis* Feytaud; [40]).

Wood/glass fiber is an example of a hybrid product, using organic (wood fibers) and inorganic (glass) materials. Similar tests regarding fungal growth assessment (with *Aspergillus* sp. and *Penicillium* sp.) were previously performed in-house, and their results showed a low resistance of the material to fungal growth (Nunes, unpublished), indicating that an organic material which is favorable to fungal development will enable fungal colonization of the composite materials. Molds appear to thrive on wood and glass fibers composites, on the contrary to decay fungi and termites [41]. Indeed, subterranean termites reacted negatively against the WGFs. Termites need to construct galleries to cross the insulation materials, but doubts remain as to whether they feed on those materials or if they use it for constructing the mud tubes without ingesting them. The negative effect verified in the termite's survival rate (Figure 5), and a lower attack degree of the wood regarding *R. flavipes*, could be explained by either contact or via ingestion. The ingestion of glass may interfere with the digestive tract's integrity, which may explain the results that were obtained.

Mineral wool showed a good resistance to both molds and *R. flavipes*, although it showed traces of growth both in the naturally inoculated samples and the samples inoculated with *A. niger* and *P. funiculosum* (Figure 3c). In fact, the susceptibility to the fungal growth of an inorganic material, like MW, is expected to be naturally lower when compared with an organic material [20,31,42]. The only sample showing traces of growth for natural indoor inoculation could have been previously contaminated with some organic dust particles, thus contributing towards the increase in fungal growth susceptibility [43]. Mineral wools usually exhibit a lower water holding capacity and moisture content, and microorganisms may use dusts or water accumulated on these materials to survive, not degrading the inorganic material, as it is a poor nutrient source [20,42]. *R. flavipes* showed a lower survival rate when exposed to MW, compared to the controls, which was not verified on the other termite species (Figure 5), and this fact may be linked to feeding preferences or to the differential susceptibility of the termites when in contact with this material, and further investigations on this need to be pursued.

When considering EPS, its bio-susceptibility to fungal growth is very low, in accordance with the results published by the authors of [43]. This inorganic material was easily crossed by termites, although it has been thought that as termites are not able to feed on plastics, their contact with this material may trigger their intricate symbiotic community into processing plastic particles if ingested during the construction of their galleries. The ability of termites and its symbionts to process different kinds of plastics and wood plastics composites has been recently hypothesized, although further investigations on this are needed [44,45]. Regardless of the putatively low nutritional value of plastics, the termite holobiont (the termite together with its symbionts [46,47]) may benefit from taking some energy out of it and processing this material, even if accidentally ingested. The interest in

EPS also relies on its recycling purposes (e.g., [5,48]), and the evaluation of this material in these recycling scenarios, which include its incorporation into different materials, shall also be properly evaluated towards possible changes in its biodegradation susceptibility.

5. Conclusions

The incipient development of microorganisms on inorganic or composite insulation materials may indicate that the microorganisms may not be able to feed on those materials; however, their presence may increase other risks in indoor environments, namely health-related problems [42,49].

The insulation materials are usually not directly exposed to biological degradation agents when a good application is performed, although some resistance is expected to their development, and a plus would be to form a barrier against these agents, not enabling them to obtain another type of material. In this work, several materials showed good resistance to the development of biological degradation agents, namely an organic material (coconut fiber), a composite of organic and inorganic materials (WGF), and an inorganic material (EPS). These results indicate that it is possible to pursue the development of innovative and effective insulation materials with a low susceptibility to biological degradation agents, regardless of their organic or inorganic origin.

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