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Optimization of Polyurethane Panels Properties through Different Particle and Fiber Reinforcement

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Polyurethane is a highly versatile material and depending on its structure it can be applied in several application fields. One of its main applications is insulating material for the construction sector, while the most common product shape is the rigid expanded panel. This work investigates the possibility of optimizing polyurethane expanded panels for building insulating purposes by considering different particle and fiber reinforcements. Precisely, the addition of different reinforcement percentages of bentonite, phyllite, and recycled textile microfibers (both untreated and treated with NaOH) is considered in polyurethane mixes composed of isocyanate, polyol, water, silane additive, and catalysts. For fiber reinforced samples, castor oil is additionally considered as a more sustainable polyol component in polyurethane mix. Thermal conductivity is positively reduced by increasing phyllite content; indeed, these microspheres further apport porosity to the material, so a lower density, and promotes a homogeneous, fine, and closed porosity. Besides, both castor oil and NaOH fiber treatment enhance the thermal insulating too. Since insulating materials may find application also in structural elements, stress relaxation, and compression tests are performed. Polyurethanes containing phyllite display greater stiffness and mechanical improvements for specific ranges of particle percentage. On the other hand, the fiber reinforcement exceeds the particle one by an order of magnitude in improving mechanical properties in terms of maximum load and recovery. In conclusion, polyurethane reinforcements and alternative polyols are valuable solutions towards more sustainable and performant insulating building panels and product differentiation.

1. Introduction

Polyurethane is an outstanding material that finds use in several application fields, i.e., packaging, automotive, furnishing, medical equipment, construction. Indeed, the principal advantage is that both its structure and shape can be specifically modified and designed to match the desired target properties. This versatility has promoted its wide employment in the construction field, where it is mainly used as insulating material in expanded panels and foam shapes. The low density and thermal, acoustic and fire properties of polyurethane are well-established by the literature.[1] However, the addition of particles and fibers might be a feasible solution to further enhance its good properties. Indeed, it is proved that these components modify the density, so the thermal and acoustic insulating power, and improve the mechanical behavior of the matrix in which they are embedded.[2–4] Moreover, the growing sensibility to sustainability and recyclability of building materials leads to using natural components or recycled waste ones. Thus, natural and recycled reinforcements could apport benefits both in terms of performance and sustainability.

In this work, the possibility of optimizing polyurethane expanded panels for building insulating purposes is investigated by considering different percentages of particle and fiber reinforcement.

Bentonite and phyllite are considered as particle reinforcement. On the other hand, recycled textile microfibers deriving from the finishing of fabrics are considered as fiber reinforcement. As suggested by literature,[5,6] NaOH treatment is additionally considered for recycled textile fibers to increase their mechanical properties and compatibility with the matrix. Furthermore, castor oil was considered instead of polyol component to promote the sustainability of fiber reinforced polyurethanes.

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2. Results and Discussion

As displayed by ESEM micrographs (**Figure 1**a) and confirmed by optical microscopy, phyllite promoted the formation of a homogeneous, fine and close porosity in polyurethane. Conversely, the addition of bentonite involved a coarser and open porosity (Figure 1b). Bentonite also provided a heterogeneous cell size through sample thickness. This phenomenon was caused by particle exfoliation that inhibited the polyurethane polymerization and was emphasized for increasing bentonite content. Recycled

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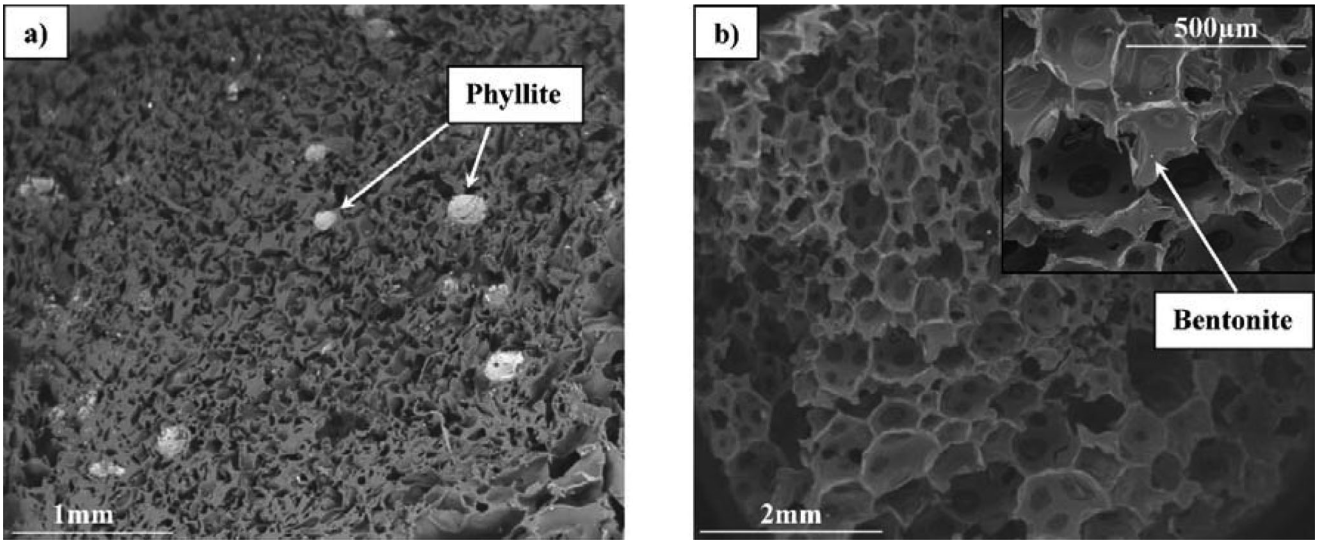

Figure 1. **Figure 1.** ESEM micrographs of polyurethanes containing phyllite (a, 70× magnification) and bentonite (b, 40× and 160× magnification).

Table 1. Density and thermal conductivity reductions of reinforced polyurethane panels in comparison with the reference one.

Particle and fiber type	Content [wt%]	Max. density reduction [%]	Content [wt%]	Max. therm cond. reduction [%]
Bentonite	3	−36	10	−6
Phyllite	2	−38	10	−9
Untreated fiber	0.5	−46	2	−3
NaOH treated fiber	0.5	−22	0.5	−5
Untreated fiber and Castor oil	0.5	−25	0.5	−2

textile fibers did not influence the polyurethane microstructure and appeared randomly oriented and distributed in the matrix.

The involved reinforcements acted as lightweight additives and significantly reduced the density of reference polyurethane (see **Table 1**), except for untreated fiber content greater than 1% (up to +15%). Precisely, the panel density decreased for increasing particle content and increased for increasing fiber content.

Higher thermal conductivity reduction was displayed for samples containing phyllite than those containing bentonite (**Table 1**). Untreated fibers improved insulating power solely for 10 wt% content, whereas NaOH treated fibers resulted in more efficiency also for reduced fiber content. Also, the substitution of polyol with castor oil decreased thermal conductivity for 0.5 wt% fiber content, even if the reduction was lower due to castor oil poor thermal stability. Greater thermal conductivity reductions were displayed at increasing particle and fiber contents.

Remarkably, phyllite addition up to 3 wt% increased the sample stiffness in the stress-relaxation test (**Figure 2**a). The best results were related to an optimum content of phyllite by 2 wt% that significantly improved the recovered load (+67.5%) and maximum load (95%) by maintaining a similar recovery time of unreinforced sample (48 s). Bentonite enhanced the maximum reference load (+76%) solely for 4 wt% content, although with a similar recovered load and worse recovery time (54 s). All fiber reinforced samples displayed great enhancement of stress-relaxation properties, especially those containing the maximum untreated fiber content of 2 wt% (Figure 2b). Notably, for 0.5 wt% fiber content, polyurethane formulations composed of castor oil promoted higher performance than those with polyol.

Phyllite also promoted stiffness and resiliency in the compression test (**Figure 3**a). Here, the maximum enhancement in terms of elastic modulus and compressive strength (74% and 79%, respectively) were allowed by adding the optimum content of 3 wt% of particle reinforcement. Greater content inhibited the correct polyurethane polymerization; thus, it led to properties loss. No benefits were provided by bentonite addition. On the other hand, increasing content of untreated fiber promoted stiffness and resiliency too, though slight enhancements to reference sample properties were observed solely for fiber content greater than 1 wt% (Figure 3b). Despite, due to their higher volume, the increasing content of treated fiber inhibited the correct polymerization and enhancements were displayed just for 0.5 wt% (+72% and +55% for elastic modulus and compressive strength, respectively). For 0.5 wt% fiber content, samples containing castor oil were more performance than those with polyol.

3. Conclusions

The properties optimization of polyurethane insulating panels was achieved by introducing particle and fiber reinforcements, whereas using recycled textile fibers and castor oil also involved sustainability. Bentonite, phyllite, recycled textile fiber (both untreated and NaOH treated) were considered in different contents. All the reinforcements reduced the reference polyurethane density and thermal conductivity. The fine and hollow phyllite microspheres better promoted a fine, homogeneous, and closed porosity that turned into better thermal and mechanical perfor-

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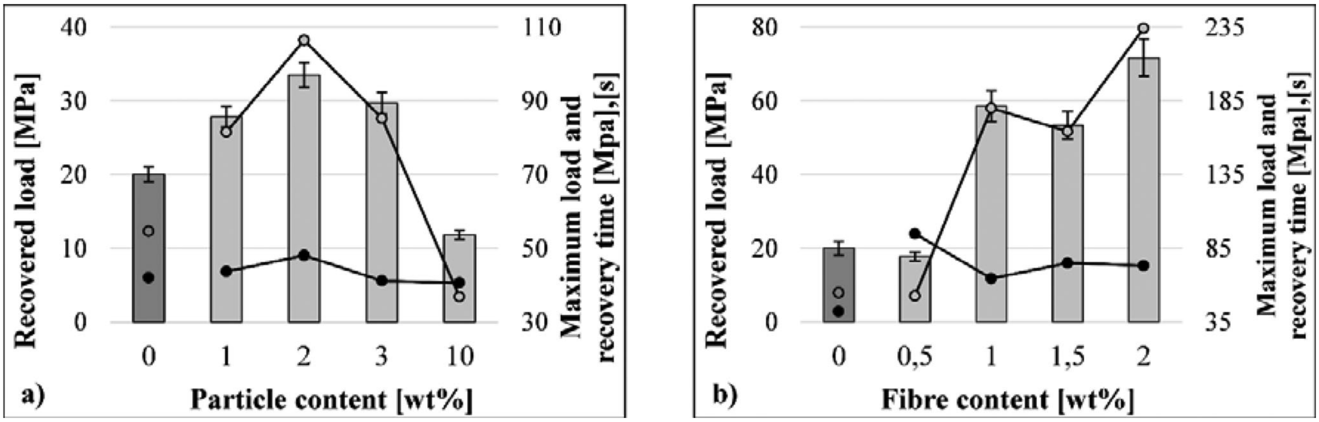

Figure 2. Stress-relaxation test results for polyurethane reinforced with phyllite a) and untreated recycled textile fibers b). Results of reinforced polyurethane (light grey) are compared to unreinforced one (dark grey) and refer to recovered load (bar chart), maximum load (lines with clear markers), and recovery time (lines with black markers).

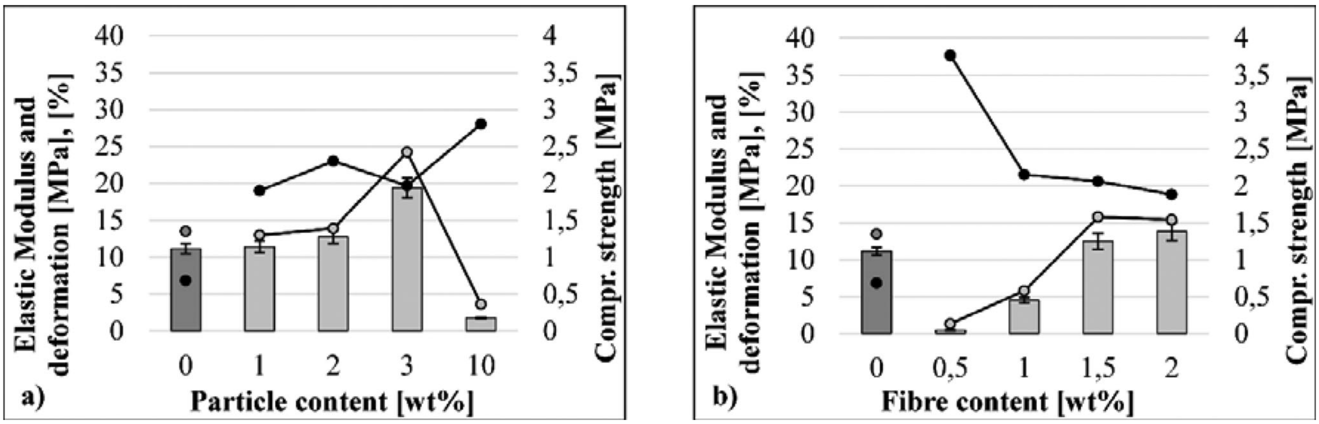

Figure 3. Compression test results for polyurethane reinforced with phyllite a) and untreated recycled textile fibers b). Results of reinforced polyurethane (light grey) are compared to unreinforced one (dark grey) and refer to elastic modulus (bar chart), compressive strength (lines with clear markers), and deformation (lines with black markers).

mances. Notably, both stress-relaxation and compression tests showed significant stiffness and resiliency enhancements for phyllite reinforced and untreated fiber reinforced polyurethane panels. Conversely, the bentonite exfoliation and the increased volume of NaOH treated recycled fibers majorly involved mechanical properties loss. Moreover, for small fiber content, castor oil resulted in better performance than polyol. Finally, these promising results suggest a feasible solution towards optimized and sustainable polyurethane panels for the construction sector.

4. Experimental Section

Particle and Fiber Reinforcement: Different particle and fiber reinforcements were investigated to enhance polyurethane insulating panel properties.

Since it was a recycled silico-aluminate composed of fine and hollow microspheres, phyllite was involved to increase sustainability and reduced the thermal conductivity and density of polyurethanes. Bentonite, characterized by lamellar crystalline structure, was also considered as particle reinforcement.

On the other hand, textile waste microfibers were involved as randomly dispersed recycled fiber reinforcement in polyurethane mix. Textile waste microfibers were generated by the fabric finishing process of a local company and were composed of pure cotton (61%), cotton blend (29%), and synthetics (10%). A mercerization treatment was considered to improve the fiber to matrix adhesion and the fibers' mechanical properties. So, fibers were soaked into a 5% NaOH water solution for 30 min, rinsed with distilled water up to neutral pH and dried at 80 °C for 24 h.[5] As a result of mercerization, treated fibers doubled their volume.

Polyurethane Panels Preparation and Characterization: Two different polyols (62.5g), water (2.5g), catalyst (0.5g), silane agents (1.44g), and particle or fiber reinforcement were pre-mixed. Then, isocyanate (62.5g) was added and mixed for few seconds with an electronic mixer. Finally, the mix was poured in a 20 × 20 × 2 cm sealed mould and maintained at 40 °C with a cryostat. Particle contents from 0 to 10 wt% were considered in the mix, whereas fibers were added up to 2 wt% due to workability issues.

Optical and Environmental Scanning Electron ("ESEM-Quanta 200 FEI") microscopy were involved to display microstructural differences; porosity assessments were also confirmed through density measurements.

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Thermal conductivity tests were performed through Heat Flow Meters (HFM 436 Lambda) and by considering a temperature gradient of 20 °C.

Compression strength tests (UNI EN ISO 604) were achieved with a 5567 Instron universal testing machine at 1 mm min^{-1} speed test. Moreover, a stress relaxation test was carried out by applying a constant deformation of 0.1 mm s^{-1} until the reach of maximum load (5% deformation), then the relaxation behavior at 10 min was studied.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

Data available on request from the authors.

Keywords

building materials, fiber reinforcement, insulating materials, particle reinforcement, polyurethane

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