COMPARISON OF THE SOUNDPROOFING CHARACTERISTICS OF OLIVE STONE FILLED POLYPROPYLENE, GYPSUM BOARDS AND WOOD FIBER REINFORCED POLYPROPYLENE

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Noise, caused by the society and technical progress, is nowadays considered a pollutant. Noise pollution affects or could affect a great number of people. One the most concerned fields, in part by a growing law framework and by the quality expectations of the clients, is architecture. The solution to sound pollution involves eliminating it or reducing it to acceptable levels. Nowadays, one of the most recurred solutions is the use of lightweight materials such as gypsum boards, to create acoustic insulation elements. On the other hand, the environmental awareness has increased the attention towards recycled materials. In the case of composite materials, major attention has been devoted to the substitution of mineral reinforcements, such as glass fibers, by more sustainable reinforcements, as wood fibers or agroforestry wastes. In this sense, olive stones, which are a byproduct of olive oil extraction, could be used. In the present work, olive stone filled polypropylene composites were prepared. Different percentages of filler were used. The soundproofing properties of the composites were tested by means of an impedance tube. Then, the results were compared with those for gypsum boards, wood veneer and wood fiber reinforced polypropylene.

Keywords: soundproofing, natural fiber-based composite materials

INTRODUCTION

Technological developments have greatly increased the quality of life, but also have produced some side-effects, such as pollution.[1] Pollution can be understood as the sum of the components that impact the environment, and noise is one of those components.[2] Noise or more specifically noise pollution has become a major issue, as it can affect the activities of a large number of people. Medical studies show that noise could challenge selective attention processes, and must be avoided or attenuated in learning and performance environments.[3,4]

Solving the problem of noise involves eliminating it or reducing it to acceptable levels. One of the most concerned fields is the architecture. The most common methods used to address the problem are based on lightweight constructions, such as gypsum boards, which, compared to masonry, are faster to build and the sound insulation is achieved with lower surface weights.[5,6] However, lightweight constructions have limitations to low frequencies (under 100Hz), due to mass-air-mass resonance, and some weakness for frequencies above 2500Hz.[7] These low frequency limitations could cause problems with common neighbor noises, like music or talking.[8]

On the other hand, the growing awareness of the environment has opened new research directions. In the field of composite materials, the literature dwelling on the substitution of glass fibers with natural fibers is a clear example of such awareness. The natural fiber-based composites show promising mechanical properties and, nowadays, polymer reinforced composites are present in automotive, aerospace, product and construction industries. Nevertheless, there is little information about the acoustic properties of such materials.[9-11] There are studies on the soundproofing properties of inorganic filled PP composites,[12] clay and nanotube reinforced PP,[13] which show the advantages of composite materials compared to matrix-based materials. When the focus goes to natural fiber reinforced composites, the information is scarcer.[12] There are some studies on the soundproofing properties of woods, showing that different woods have different acoustic properties. Wood fibers or particles usually show a lumen and tubular morphology. The presence or absence of the lumen, due to its collapse during the composite preparation, could change dramatically the propagation velocity of sound waves, affecting the acoustic properties of the materials. Thus, as the morphology of the fibers and fillers changes from one plant or tree to another, the selection of the fibers could change the acoustic properties of the composites.[14] There is also a study on the acoustic properties of wood fiber reinforced composites, showing that increasing percentages of reinforcement increased the acoustic properties of the materials.[11] In a recent article,[10] it was found that wood fiber reinforced composites showed better acoustic properties than gypsum boards.

Sound insulation is defined by a big number of variables and there is a lack of scientific literature devoted to the problem.[15] The most essential parameters to acoustically characterize a material are its flow resistance and its absorption at normal incidence (for absorbent materials) or its flow resistance and insulation (dB) (for sound impermeable layers). There are standardized methods to obtain the flow resistance and the absorption for a given material.[16,17] Nonetheless, there are no standardized methods to obtain the value of the insulation at normal incidence. An interesting parameter is the transmission loss (TL) in an impedance tube, which informs of the soundproofing character of a sound impermeable layer against aerial noise. Though actually there are no standardized methods, some authors describe a measurement procedure by using impedance tubes.[17,18]

In this study, the PP matrix was reinforced with OSF to obtain better soundproofing properties. The objective of this work was to measure the transmission loss of olive stone reinforced polypropylene composites, and to establish the effects of sound frequencies and filler contents on the soundproofing properties of these composites.

EXPERIMENTAL

Materials

The composites were prepared using polypropylene (PP) homopolymer, Isplen PP099 G2M, with an average melt flow rate (230 ºC; 2.16 kg) of 55 g per 10 min and a density of 0.905 g/cm^3, provided by Repsol-YPF (Spain). Polypropylene functionalized with maleic anhydride (MAPP), Epolene G3015, was acquired from Eastman Chemical Products (Spain). Olive stone flour (OSF) was obtained from residues of olive oil production at Sfax (Tunisia). Diethyleneglycol dimethyl ether (diglyme) was supplied by Clariant and was used as dispersing agent. The reactants that were used for filler treatment are summarized as follows: sodium hydroxide (Merck KGaA, Darmstadt, Germany), antraquinone (Badische Anilin & Soda Fabric AG, Germany), which were used without any further purification.

Preparation of the olive stone flour (osf)

The olive oil extraction residues were dried and separated into shell and stone by means of screening ventilation. The resulting stone residue was ground into fine flour, which represented about 20-25% of the whole olive fruit.

Preparation of the composite

PP composite materials comprising 20 to 70 wt% of OSF and WF were compounded by means of a Brabender internal mixing machine. The mixing process was performed at 80 rpm rotor speed and a temperature of 190 ºC for 10 minutes. The obtained blends were ground by means of a knife mill, dried and stored for at least 24 hours before processing. The test samples were produced with a steel mould in an injection-molding machine. Ten test specimens from each obtained composite blend were used for the experiment.

Acoustic characterization

The method to measure the transmission losses, based on impedance tubes, was developed at the Polytechnic School of Gandia. The device is based on two impedance tubes used to measure the transmission losses (Figure 1).

The tube preceding the sample measures 1315 mm, and the section subsequent to the sample measures 1233 mm. Both tubes have a 40 mm interior diameter. The distance between the microphones determines the spectrum of frequencies to measure, as a plane propagation wave must be ensured in the tube.[16] In this work, a 32 mm distance was used to perform all the measurements. The loudspeaker, placed at the end of the tube, generates plane waves, measured by the microphones, two placed in the tube between the loudspeaker and the sample, and two placed at the rear end, between the sample and an anechoic termination.

The device illustrates the transference matrix, which represents the incident and reflected waves from the upper and lower parts of the sample. If the matrix coefficients are known, it is possible to obtain the TL from Eq. 1:

$$TL = 20\log_{10}\left|\frac{e^{jks} - H_{12}}{e^{jks} - H_{34}}\right| - 20\log_{10}\left|H_t\right| \quad (1)$$

where S is the distance between the microphones, H_{12} and H_{34} represent the transference function between the microphones 1 and 2 (preceding the sample), and 3 and 4 (subsequent to the sample) respectively, defined by Eq. 2:

$$H_{i,i+1} = P_{i+1} / P_i \quad (2)$$

where P_i is the complex acoustic pressure at point i, and is measured by the microphones.

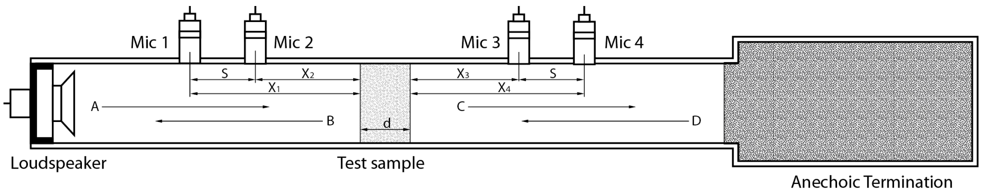

Figure 1: Impedance tubes installation used to test the materials

The relation between the auto spectrums, H_t is defined by Eq. 3:

$$H_t = \sqrt{\left|S_d / S_u\right|} \quad (3)$$

where S_u is the auto spectrum preceding the sample and S_d is the auto spectrum subsequent to the sample, which are obtained by applying Eqs. 4 and 5:

$$S_d = P_3 \cdot P_4^* \quad (4)$$

$$S_u = P_1 \cdot P_2^* \quad (5)$$

where P_2^* and P_4^* are the complex conjugates of the complex acoustic pressure at points 2 and 4.

RESULTS AND DISCUSSION

One of the properties of a material that affect its soundproofing character is its density. Table 1 shows the densities of the tested materials.

It was observed that the density of the composites increased with the addition of higher percentages of FNO. The higher is the density, the better the expected results. The results will be compared with those for laminated gypsum boards and wood veneer. The tested gypsum board was 12.1 mm thick and had a 0.71 g/cm^3 density. On the other hand, wood veneer was 4.5 mm thick and had a 0.5 g/cm^3 density.

All the specimens were tested in the impedance tubes apparatus. Figure 2 shows the outputs of the transmission loss insulation versus the frequency. It was observed that, as it was expected, the denser the material the better the insulation properties. Nonetheless, all the materials showed a parallel behavior, with similar results for low frequencies. For mid and high frequencies, the denser FNO filled materials showed superior insulation porperties. Anyhow, the range between low and mid frequencies is the most interesting and difficult to attenuate, as it is the most frequent in the case of urban and industrial noise pollution.

The most commonly used lightweight insulation solutions are gypsum boards. Figure 3 shows the outputs of the FNO based material, which showed higher TL values, compared to a gypsum board.

Figure 3 compares the TL values (dB) of the 80% FNO composite with those of a gypsum board. It must be said that the width of the gypsum board was three times that of the composite. The gypsum board was 12 mm thick, while the composite was 4 mm. It was found that the gypsum boards showed similar insulation properties for the low and half of the mid frequencies, but were better in the case of higher frequencies (>600Hz). The results showed that the use of the tested materials would be restricted to insulation conditions that include noise pollution between 0 and 630 Hz, for higher sound pollution frequencies the gypsum boards showed better insulation properties. It must be taken into account that the tested gypsum boards were thicker than the composite specimens. Thus, more research is needed to find methods to improve the soundproofing properties of the studied composite materials. Figure 4 compares the TL values (dB) of the 20 to 60% FNO composites those for a wood veneer. It must be noted that wood veneer is sligtly less dense than the FNO composites. It was found that the behavior of the materials was similar, showing the same peaks and variations of the TL against the frequency. The composites with higher FNO content showed better TL values. The weighted airborne sound insulation values are summarized in Figure 5. It was found that the airborne insulation values of the FNO-based composites were similar to that of wood veneer and slightly inferior to that of gypsum boards. The addition of increasing percentages of reinforcement allowed slight increases on the sound insulation value (0.4dB). The similarity of such values opens the door to using FNO-based composites for the manufacture soundproofing elements.

Table 1
Characterization of the tested specimens

Material	Thickness (mm)	Density (g/cm^3)
PP + 20%FNO + 5% MAPP	4.0	0.91
PP + 40%FNO + 5% MAPP	4.0	1.01
PP + 60%FNO + 5% MAPP	4.0	1.12
PP + 80%FNO + 5% MAPP	4.0	1.26

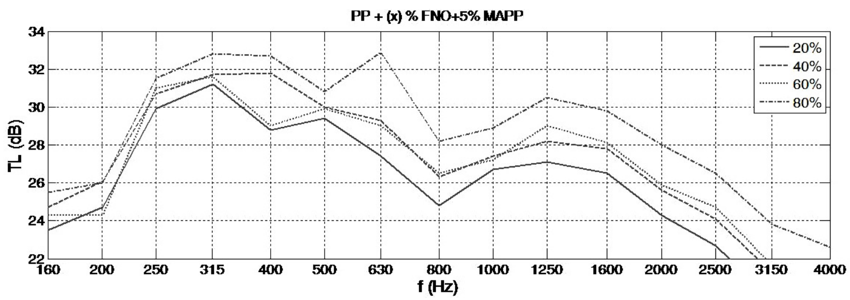

Figure 2: Transmission loss insulation against sound frequency

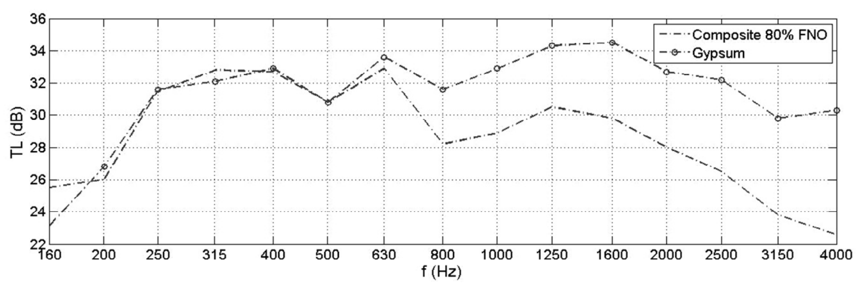

Figure 3: Comparison of the transmission loss insulation for 80% FNO composites and gypsum boards

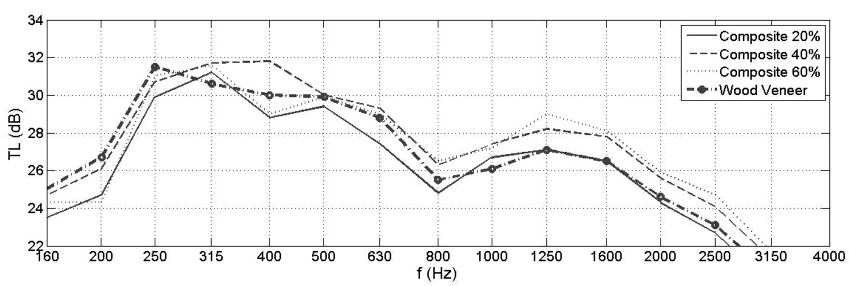

Figure 4: TL of different % of FNO versus wood veneer

The mechanical properties of the composites[19] allowed their use for semi-structural applications, such as paneling. Also, using these materials for manufacturing auxiliary materials, such as switch boxes, could be interesting, due to the possibility of mold-injecting such materials. It has been researched that installing such elements could negatively influence the soundproofing of an entire room.[6,20] Consequently, if the wall holes are covered with materials with higher sound insulation properties than the commonly used elements, usually made of pure polymer, the global insulation could be maintained.

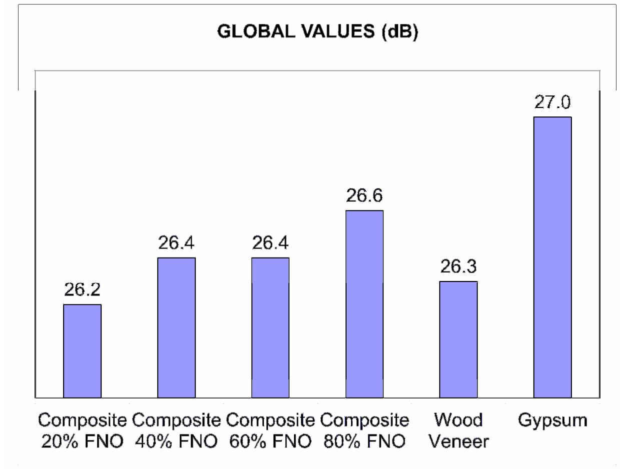

Figure 5: Comparison of acoustic insulation global values

CONCLUSION

In this work, olive stone flour reinforced polypropylene composites are presented as airborne insulation solutions. The study investigated the acoustic properties of such composites against aerial sound. The results show that their soundproofing properties were similar to those of impermeable layers, like laminated gypsum boards commonly used by builders, especially for low to mid frequencies (<630 Hz) despite the lower thickness of the composites.

The higher the amount of filler the better were the soundproofing properties of the composites. On the one hand, it could be due to the higher density of the olive stone flour compared to the density of the polypropylene, and on the other hand, it could be due to the compactness of the olive stone flour.

It was found that the global values of acoustic insulation were similar to those of wood veneer and gypsum boards, the results opening the way to using FNO-based composites to manufacture auxiliary elements, such as switch boxes.

More research is necessary to explore ways to improve the soundproofing properties of the composites for mid frequencies, from 630 to 800 Hz.

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