Sound Absorption of Recycled Gypsum Matrix Composites with Residual Cellulosic Pulp and Expanded Polystyrene

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This work aimed to study the technical feasibility of using industrial gypsum, expanded polystyrene (EPS), and cellulose solid wastes in the production of acoustic insulation panels for buildings. Five traces of acrylic gypsum matrix were produced with variations in the proportions of cellulosic pulp and EPS and always maintaining the same proportion of recycled gypsum and water. The composites produced were tested according to the ISO 10534-2 (2015) standard for the determination of the coefficient of sound absorption and ABNT NBR 14715-2 (2010) for bending tests. The results didn't show statistically significant differences in the coefficient of sound absorption with variations in the quantities of each material. However, the sonic frequency of the tests directly influenced the results, presenting a better performance at a low frequency (250 Hz). The results qualify the composite produced for use as acoustic insulation and can be used in plates for sound reflection in buildings in places where it doesn't require resistance to great stresses.

Keywords: Solid waste; Recycled gypsum; Acoustic insulation; Composites; Recycled materials

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INTRODUCTION

The constant process of development and urbanization has led to a search for a reduction in the extraction of natural resources and for an increase in the reuse of waste that is otherwise discarded in the generation of new materials. The reuse of waste not only preserves natural resources but also reduces the production costs and pleases consumers who wish to use environmentally sound materials. These new materials may be used as alternatives to those commonly used by industry.

In Brazil, the pulp and paper sector has great importance in the economy and generated a high volume of production that results in a high volume of waste that requires final disposition. This material can be incorporated into other materials, forming composites with improvements in its mechanical properties, such as tensile, flexural, acoustic, and thermal resistance (Oliveira 2012; Arenas *et al.* 2014).

Expanded polystyrene (EPS) is another residue scrapped on a worldwide scale and it consists of a rigid cellular plastic expanded by gas. This material is used for various purposes. It has been gaining prominence in civil construction because it can adapt to the needs of the work and has acoustic and thermal properties, in addition to being low cost.

Another big generator of environmental impacts in Brazil is the civil construction sector, which besides being responsible for the excessive consumption of natural resources from non-renewable sources (Levy and Helene 2007) also has alarming rates of waste generation (Halmeman *et al.* 2009).

Among the residues generated by the sector, gypsum is identified as one of the most difficult to handle and reuse. This material has the highest growth rate of use per year, a factor that can be explained by the low cost of gypsum and the dissemination of alternative construction systems like drywall. In this system, losses are high due to gypsum board cutting activities. However, this material can be recycled using a simple process, where the gypsum must be crushed and calcined (Pinheiro and Camarini 2015; Erbs *et al.* 2018).

Combining residual cellulosic pulp and EPS with a gypsum matrix, it is possible to generate a new material and to reduce the need for places and methods for an adequate final disposal of waste. It is also possible to increase the life of natural resources and minimize the environmental impacts caused by the excessive extraction of these materials (Angulo *et al*. 2011; Adamopoulos *et al*. 2015).

In the construction industry, the use of composite materials has been gaining prominence and innovation activity, seeking to cheapen and improve the properties of its components. An example of this research is done by Adamopoulos *et al.* (2015), where the properties of mechanical strength and sound absorption of gypsum matrix composites with different fractions of wood chips and rubber particles were studied. Azevedo (2017) developed a composite based on gypsum and vermiculite for use as thermal insulation material. Gencel *et al.* (2014) studied the addition of expanded vermiculite and low thermal conductivity polypropylene to light gypsum. These studies showed that there are numerous types of waste that can be used in the production of composites for use in many areas, but, on the other hand, there are still few studies in this area.

Considering this sustainable development, the present study aims to study the technical feasibility of the use of cellulosic pulp residues and EPS with a recycled gypsum matrix in the production of a composite for the acoustic treatment of buildings and to analyze their influence on sound absorption properties of the material.

EXPERIMENTAL

The residues used in this study were cellulosic pulp from eucalyptus fibers which were removed from the effluent generated in the alkaline extraction and bleaching stages, EPS, and gypsum board collected in industries of Itapeva, Brazil. For the sound absorption tests, the molding of the samples was performed according to ISO 10534-2 (2015) and for bending tests it was used the NBR 14715-2 (2010).

The recycled gypsum and water were mixed in a vessel until complete dissolution of the gypsum and then mixed with cellulosic pulp and EPS to form a homogeneous paste which was cast in the molds for 24 h. After this period, the samples were demolded and dried at atmospheric temperature for 6 days. The five recipes outlined for recycled gypsum (GR), cellulosic pulp (PC), EPS (Ip), and water (A) are presented in Table 1.

Table 1. Proportion of Components Delineated in the Manufacture of Composites

Recipe	GR (Lbs)	PC (Lbs)	Ip (Lbs)	A (Lbs)	Number of samples
1	1.0	1.0	1.0	1.0	7
2	1.0	0.5	1.5	1.0	7
3	1.0	1.5	0.5	1.0	7
4	1.0	0	1.0	1.0	7
5	1.0	1.0	0	1.0	7

The sound absorption coefficient was determined from the the impedance tube method according to the ISO 10534-2 standard. The cylindrical sample (Fig. 1a) was attached to one end of the equipment (Fig. 1b).

Fig. 1. Sample of composite (a) and test equipment ready for test (b)

The tube was excited with a random sound signal with equal intensity at different frequencies, and the sound pressure inside it was picked up by two microphones positioned at predetermined points along the length of the tube. The reading made by the microphones was transferred by a noise and vibration analyzer to the dBFA software (01dB-Metravib, Areva Company, version 4.9, Limonest, France), which performed the calculations of the transfer function to obtain the absorption coefficient sound. The samples were tested on three frequencies: 250 Hz, 500 Hz, and 1,000 Hz.

The evaluation of the bending strength was performed according to the standard NBR 14715-2 using the universal EMIC test machine. The test sample (Fig. 2a) were positioned on two parallel bases spaced apart from 350 mm. A load was applied in the sample, at a speed of 250 ± 10 N/min, until the failure of the element (Fig. 2b).

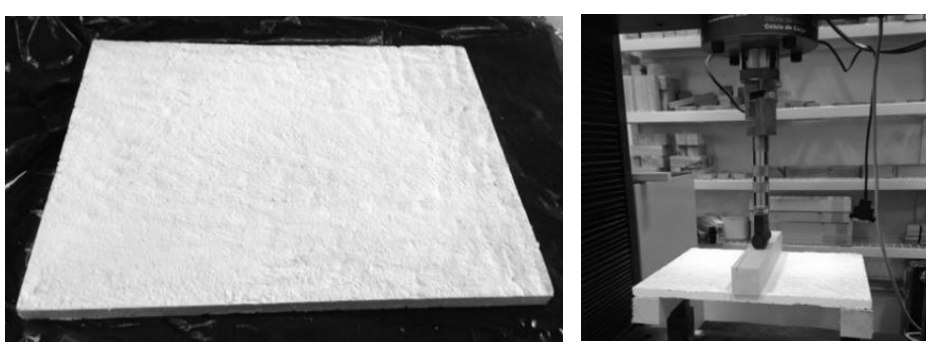

Fig. 2. Sample of composite (a) and bending test in progress (b)

For the statistical analysis, a multivariate regression model based on the aalysis of variance (ANOVA) was used to estimate the sound absorption property α (Eq. 1) and MOR

(Eq. 2), and was performed by Minitab (Minitab Inc., Version 18, State College, PA, USA) and evaluated at the 5% level of significance.

$$\alpha = \beta0+\beta1\cdot PC+\beta2\cdot Ip+\beta3\cdot Fr+\beta4\cdot PC\cdot Ip+\beta5\cdot PC\cdot Fr+\beta6\cdot Ip\cdot Fr+\beta7\cdot PC\cdot Ip\cdot Fr+\varepsilon \quad (1)$$

$$MOR= \beta0+\beta1\cdot PC+\beta2\cdot Ip+\beta3\cdot PC\cdot Ip+\varepsilon \quad (2)$$

In these equations, βi is the coefficient obtained by the least squares method, ε is the random error (%), PC is the amount of cellulosic pulp (Lbs), Fr is the measurement frequency (Lbs), R^2 is the coefficient of determination, and Ip is the amount of EPS (Lbs). The quality of the measurements was measured by the coefficient of determination, R^2. The factors GR and A are not considered to be varying in the traits studied, and the measurement frequency (Fr) was considered as a factor in this model in Eq. 1.

The Tukey's Honest Significant Difference (HSD) test was evaluated at the 5% level of significance, to compare all possible pairs of means according to Eq. 3,

$$HSD = \frac{M_i - M_j}{\sqrt{\frac{MS_w}{n_h}}} \quad (3)$$

where $Mi – Mj$ is the difference between the pair of means, MS_w is the Mean Square Within, and n is the number in the group or treatment.

RESULTS AND DISCUSSION

Figure 3 shows the mean values, the confidence intervals of the means (at the 95% confidence level), and the Tukey test results of the sound absorption for each treatment according to each of the measured frequencies considered.

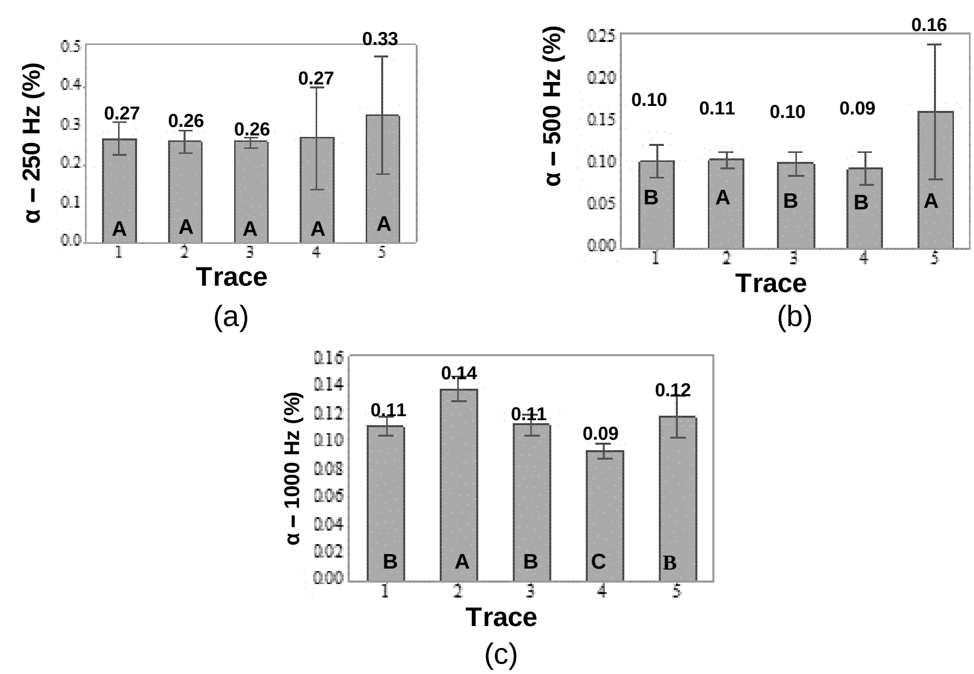

Fig. 3. Results of sound absorption for each recipe (trace) as a function of the measurement frequencies: (a) 250 Hz, (b) 500 Hz, and (c) 1000 Hz

It was observed that the recipe with the higher PC content (Tr 5) had the highest absorption coefficient for the frequencies 250 Hz (0.33) and 500 Hz (0.16) and the second highest for the frequency 1,000 Hz (0.12).

Comparing the values obtained with the Tukey test, it was found that the absorption of the materials manufactured in the five idealized recipes resulted in statistically equivalent mean values for the frequencies of 250 Hz. For the frequency of 500 Hz, the highest values of the sound absorption occurred for recipes 2 or 5, and the lowest ones occurred for recipes 1, 3, or 4. For the frequency of 1000 Hz, the highest absorption coefficient came from recipe 2, and the lowest value came from recipe 4.

Although the R^2 was 44.43%, the ANOVA indicated that the regression model (Eq. 1) was significant. This fact evidenced that the frequency had a significant impact on the values of the sound absorption, with frequency increases implying a reduction of the property. The same was found in the Tukey test, as can be observed in Fig. 3.

From the analysis of Pareto Graph in Fig. 4, it was observed that only frequency significantly influenced the values of sound absorption.

Adamopoulos *et al.* (2015) studied the sound absorption of a gypsum-based composite with wood and rubber residues and concluded that no significant differences were observed between the gypsum composites with different amounts of rubber and wood, thus showing that the frequency was the dominant factor.

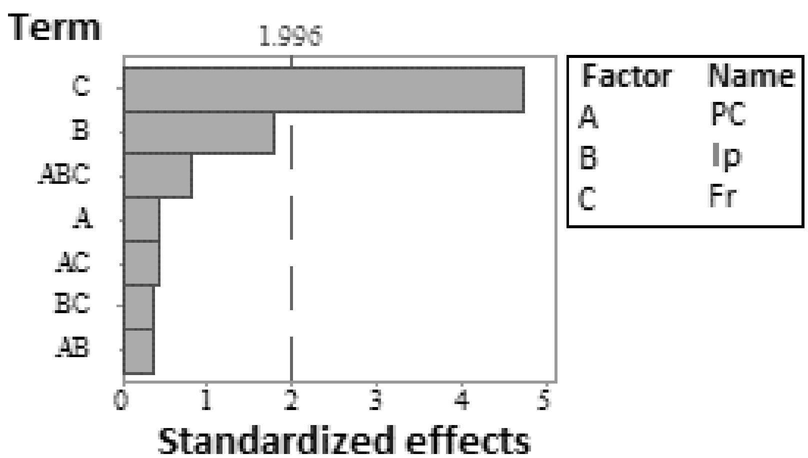

Fig. 4. Pareto graph of the analysis of the significant factors in the results of the sound absorption

Comparing the values of coefficients obtained in this study, for all recipes, with those found in literature for the gypsum board, it was observed that the composites produced presented better sound absorption in the three frequencies studied.

The studied composites presented a sound absorption coefficient higher than the wood, but their absorption capacity was much lower than that of traditional insulation materials, such as rock wool and glass wool (Table 2).

Table 2. Sound Absorption Coefficients and Density of Products

Product	250 Hz	500 Hz	1000 Hz	Density kg/m³
Rock wool *	0.66	0.73	0.74	32 to 160
Glass wool *	0.55	0.64	0.75	10 to 100
Gypsum board (13 mm) *	0.12	0.08	0.06	568
Trace 1: GR + PC + Ip (1:1:1) **	0.27	0.10	0.11	383.44
Trace 2: GR + PC + Ip (1:0,5:1,5) **	0.26	0.11	0.14	373.83
Trace 3: GR + PC + Ip (1:1,5:0,5) **	0.26	0.10	0.11	441.41
Trace 4: GR + Ip (1:1) **	0.27	0.09	0.09	372.25
Trace 5: GR + PC (1:1) **	0.33	0.16	0.12	512.67
* Taken from ABNT NBR 12179 (1992), ** this study				

According to Vimmrova *et al.* (2011) the absorption can be improved by leaving empty pores within the composites. In addition, even low to medium density (372 to 513 kg/m³) composites present surface with closed pores, making difficult the entrance and dissipation of sound waves inside it causing more reflection than absorption.

Figure 5 shows the mean values, the confidence intervals of the means (at the 95% confidence level) and the Tukey test results of the bending strength (MOR) for each trace.

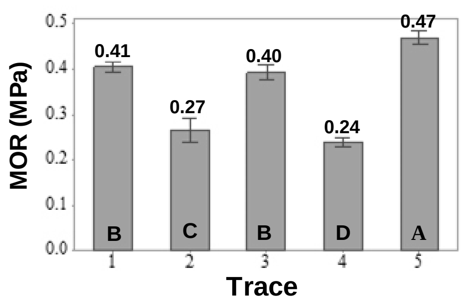

Fig. 5. Results of the bending strength of the composite for different recipes (traces)

Figure 6 illustrates the Pareto Graph evidencing factors considered significant by ANOVA. From this figure, it can be noticed that the two factors and the interaction of both were considered significant by ANOVA in the values of the MOR of the materials.

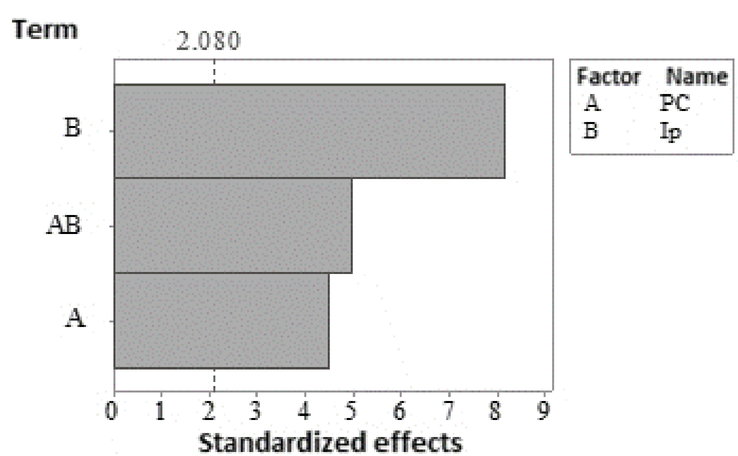

Fig. 6. Pareto graph of the analysis of the significant factors in the results of the MOR

The regression model (Eq. 2) was considered significant by ANOVA, and the R^2 was 0.9146, showing excellent accuracy of the adjustment obtained. The analysis of Fig. 6 showed that the Ip was the factor that had the greatest influence on the resistance.

From Eq. 2 it was observed that increases in PC values implied an increase in F_{max}, while that the increase in content of Ip causes reduction of the maximum failure load of the composites was observed in Fig. 5.

According to Savi (2012), the recycled plasters presented values bending strength of rupture between 0.7 and 3.5 MPa, but the cellulosic pulp and expanded polystyrene used in the composite production increased the presence of voids its interior. These pores in the gypsum have directly and negatively influence the properties of the material (Shackelford 2008) causing low resistance.

Although the frequency was the factor that had the greatest impact on the sound absorption properties of the material, it can be observed that the composite that used only cellulosic pulp (PC) in the recycled gypsum matrix (GR) presented slightly better results of sound absorption (Fig. 3) and bending strength (Fig. 5).

CONCLUSIONS

The study showed that a variation in the percentages of residues used in the composition of the final material did not cause significant statistical differences between the composites with regards to the tested parameters, and thus did not influence the sound absorption property of the composite. The frequency was the factor that had significant influence on the sound absorption results of the material. The best results were observed for the low frequency (250 Hz).

The results of the bending strength of rupture indicated that a higher amount of cellulosic pulp) improved the strength of the composite while a greater amount of Ip (expanded polystyrene) had an opposite result.

With the results obtained, it can be observed that recipe 5, with the highest amount of cellulose pulp (PC), presented the best combination of results for sound absorption and bending strength.

However, the five traces studied can be used in panels for acoustic insulation in places that does not occur the necessity of resistance to great efforts.

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