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Assessment of acoustic, thermal and mechanical properties of epoxy composites reinforced with expanded clay particles

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Abstract

Expanded clay particles have been used in industrial applications, such as thermal and acoustic insulation materials, and in buildings' structural elements. These materials can also be used in the manufacture of cores of sandwich materials where it is desired to have a good performance in terms of mechanical resistance, thermal insulation and sound and low weight of buildings or industrial equipment. In this study, epoxy matrix composites with different weight fractions of expanded clay particles were manufactured and characterized in terms of their physical and mechanical properties. The resulting composites were processed using the mixing techniques and casting in vacuum. The performed tests showed a decrease in the noise intensity and thermal conductivity with increasing mass fraction of expanded clay particles. In regards of mechanical behavior, it was noted that the stiffness increases, while the values of mechanical resistance in bending and compression decreases with increasing mass fraction of expanded clay particles. The fracture toughness also decreased with increasing weight fraction.

Keywords: composite materials; clay particles; fracture toughness; noise intensity; thermal conductivity.

1. Introduction

The development and manufacture of composites for specific applications in which materials have both good thermal insulation properties and acoustic, as well as lightweight is an interesting research area. One way to minimize noise intensity and thermal conductivity is to use materials like foams, cork, polymer foams micro hollow glass spheres or fiberglass, with good sound absorption and good thermal insulation characteristics, in the manufacture of composite materials and sandwich materials [1-6]. The properties of primary interest for the core materials can be summarized as: low density, high shear modulus, high shear strength, compression stiffness and both good thermal and acoustic insulation characteristics [7,8]. In comparison with traditional metallic materials, these composites present advantages such as lower weight and lower tool costs, no corrosion effects, more design freedom, etc. Castro et al [6] obtained with epoxy for agglomerated cork, 25% reduction in thermal insulation with low density. Cellular materials containing some gases (for example, air (0.026 $Wm^{-1}K^{-1}$) and CO2 gas (0.026 $Wm^{-1}K^{-1}$) are also used in the manufacture of sandwich materials to take advantage of the good insulating capacity and its low density [9]. Numerous studies are reported in literature concerning the mechanical properties and fracture toughness of filled composites on epoxy resin modified with rubber particles [10–12], thermoplastic particles [13–14] and hard particles [11,15-16]. Hard particles can contribute to the improvement of fracture toughness, while in addition

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hollow glass microspheres promote also lower density and a consequent weight reduction [2,3,6].

The expanded clay particles are lightweight ceramic honeycomb core materials produced by burning natural clay, having rounded shapes and grain sizes suited for the specific application. These materials are lightweight (density less than 1 g / cm^3) and have good sound and thermal insulation, being widely used in lightweight structural components [17]. Jun et al [18] observed that the polypropylene (PP) / clay composites are interesting because their physical and mechanical properties increase significantly with small amounts of filler clay (0.9 to 9.9 wt. %) in the PP matrix. The PP/Clay (6.5 wt. %) composites showed the best soundproofing property (about 58% higher than pure PP) when compared with the percentage of weight of other clay composites.

With this work, it is intended to process and characterize in acoustic, thermal and mechanical terms, composites with particles for specific industrial applications (eg, compressors, refrigeration units, etc.). Particularly, the main objectives were to process and evaluate the effect of weight fraction on the thermal and acoustic performance and also on the compression, flexural and fracture properties.

2. Materials and experimental procedure

2.1. Materials and physical tests

This work concerns the study of epoxy polymer composite materials processed by mixing and casting in vacuum, with different weight fractions of expanded clay particles. The resin used in this study was made from one commercial epoxy resin known as SR1500 and a hardener known as SD2505, both produced by Sicomin Composites Company (France). The formulation bases of the epoxy resin SR1500 are bisphenol A and bisphenol F; this epoxy resin has been modified to be crystallization free and to have low toxicity. In the molding of the samples, we used a steel mold having dimensions of 172x170x12 mm^3.

Table 1 shows the composition of the composites processed with different fractions of expanded clay particles (W_p) and diameters ($\varnothing_m$). The table also presents the density values, obtained by weighing the desired amounts of particles and resin and using the mixtures law [4]. Fig. 1 shows the schematic diagram for thermal analysis. The hot side temperature was measured by thermocouple, while the cold side was analysed by infrared Fluke/Ti45 IR FlexCam thermal camera. Sound intensity tests were performed using the Digital Sound Level Meter: Sound level meter NL - 31 put 1 meter from the box.

Table 1. Composites composition: weight fraction (W_p), average particles size ($\varnothing_m$) and density (d).

Material	W_p [%]	$\varnothing_m$ [mm]	d [g/cm^3]
Epoxy	-	-	1.13
Composites A	30	0.70	0.99
	40		0.96
	50		0.91
	60		0.87
	70		0.82
Composites B	30	1.88	0.96
	40		0.91
	50		0.85
	60		0.80
Composites C	30	2.58	0.95
	40		0.89
	50		0.84

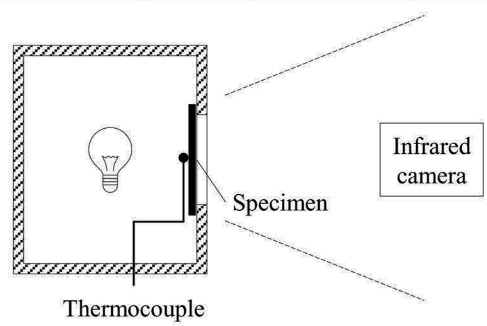

Fig. 1. Schematic diagram for thermal analysis.

2.2. Mechanical tests

Mechanical properties were evaluated on samples of neat epoxy and its composites using a Universal Testing Machine (Zwick Z100 model, German) at a crosshead displacement ratio of 2 mm/min. The following mechanical tests were performed: compressive tests, according to ASTM E399-83 standard; three points bending tests, according to ASTM D638 standard. The specimens were machined from the processed composite plates (172x170x8 mm^3), with the intended geometries. Compression specimens were parallelepiped with (16x12x6 mm^3), while 3 points bending specimens were also parallelepiped with (65x12x6 mm^3). The fracture toughness test mode I (Fig, 2a) and bending tests were performed according to the schematic representation shown in the Figure below (Fig. 2 b)).

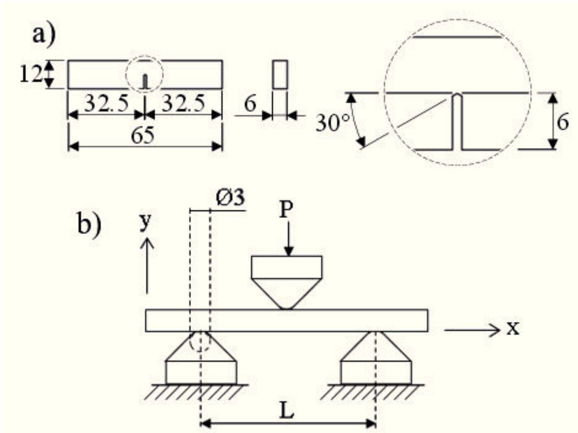

Fig. 2. Bending tests: a) geometry of the specimens for fracture toughness tests; b) schematic representation of the loading (L = 40 mm).

The compressive strength was defined as the maximum nominal compressive stress, while the flexural strength was the maximum nominal flexural stress (σ_{max}), calculated by using equation 1:

$$\sigma_{max} = \frac{3P_{max}L}{2BW^2} \quad (1)$$

where P_{max} is the maximum load from the load-displacement curve, L the span length, B the thickness and W is the width of the specimen.

The flexural stiffness modulus was calculated by linear regression of the ΔP versus Δu curve in the linear elastic region, using the linear elastic bending beam theory relationship (equation 2):

$$E=\frac{\Delta PL^3}{48\Delta uI} \quad (2)$$

where I is the second moment of the area of the transverse section ΔP and Δu are, respectively, the load range and flexural displacement range at middle span for an interval in the linear region of load versus displacement plot.

Mode-I fracture toughness (critical stress intensity factor, K_{Ic}) tests were carried out according to the specifications of the ASTM D790-93. Specimens used in the fracture toughness tests were tested in three-point bending loading with a span of 40 mm. The specimens were pre-cracked by tapping with a razor blade at the crack tip of the mechanical machined notch. The crack length was measured after the test by using a microscope mounted on an X-Y sliding base, at a minimum of 6 points along the crack front for each specimen. According to the ASTM D790-93 standard, the stress intensity factor for mode I fracture toughness in three-point bending loading is calculated by the equation 3:

$$K_{IC}=\frac{P_Q}{B\sqrt{W}}\left(\frac{6\sqrt{c}\left(1.99-c(1-c)(2.15-3.93c+2.7c^2)\right)}{(1+2c)(1-c)^{3/2}}\right) \quad (3)$$

where P_Q is the critical load (which in this case corresponds to the failure load), *c=a/W*, *a* is the crack length, *B* is the specimen thickness and *W* the specimen width. At least four specimens were tested for each test condition of the compressive strength, flexural and fracture toughness tests.

3. Results and discussion

The physical and mechanical properties before indicated were evaluated for all composite configurations. The results were normalized against the values of such properties obtained for matrix epoxy resin. The results obtained for the resin were: measured sound intensity 64.8 dB in a room with ambient sound 33.3 dB; thermal conductivity coefficient k_{ep} = 0.815 W/m.ºC; Compressive modulus 1.93 GPa; compressive strength 80.4 MPa; flexural modulus 2.87 GPa; flexural strength 118.8 MPa; fracture toughness of the resin K_{Q0}=111.9 MPa√mm.

Sound intensity was measured using plates of all composite configurations indicated in Table 1. The absolute values in dB obtained for each case were normalized to the reference value for the epoxy matrix plate. Fig. 3 shows the relative loudness values against the fraction of clay particles. The existence of an epoxy material plate (in a box with good thermal and acoustic insulation) allowed a reduction in the sound intensity of about 15.5%. When composite plates of types A, B and C were used (and W_p = 50%) as noise barriers, it was possible to obtain sound intensity reductions of 15.4%, 20.1% and 24.4%, respectively, in comparison with the epoxy plates.

Thermal conductivity was evaluated in terms of the coefficient k, according to Fourier law (equation 4):

$$q=-kA\frac{\Delta T}{\Delta x} \quad (4)$$

where q is the heat flow, A is the area, ΔT is the temperature difference between the ends and Δx is the distance between the ends.

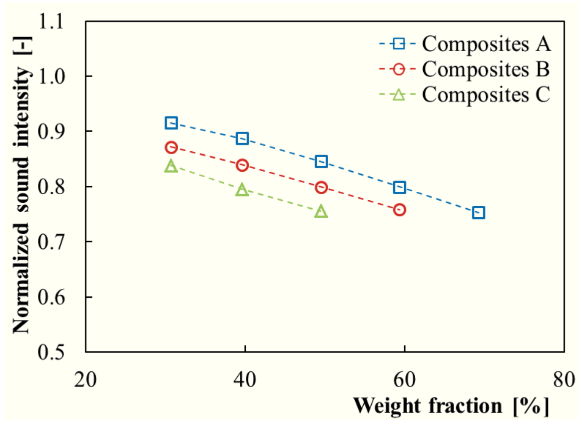

Fig. 3. Normalized sound intensity versus weight fraction.

Fig. 4 shows the normalized thermal conductivity curves (k_{comp}/k_{ep}) against the expanded particles fraction. Similarly, to acoustic insulation the thermal conductivity decreases significantly with increase of the particles fraction and of the expanded particles diameter. Composites of types A, B and C with W_p = 50% of particles exhibit thermal conductivity reductions of about 25%, 36% and 41%, respectively, and regarding to epoxy matrix.

The performance of compression testing is of interest as these materials can be subjected to compressive loads, and also because the compression resistance of the expanded clays is very low (about 0.70 MPa EN 13055-1).

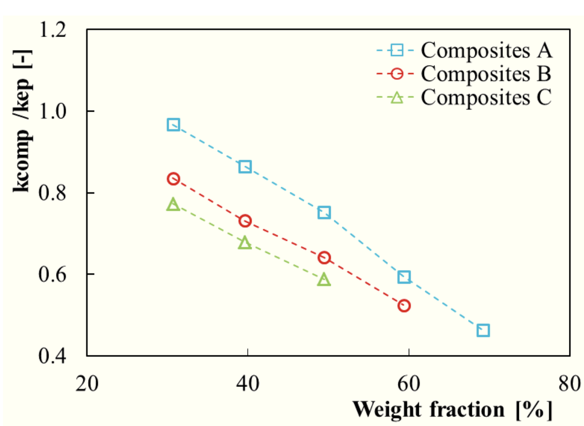

Fig. 4. Normalized thermal conductivity versus weight fraction.

Fig. 5 shows typical curves of the compressive strength tests, plotted in terms of the compressive stress *versus* extension, for composites with different weight fractions. It can be observed that the composites of type A (lower particle size) have higher stiffness values than the epoxy matrix and that they decrease with the increase of the particles fraction. On the other hand, the compressive strength values are lower than the epoxy matrix and also decrease with the increase of the fraction weight. These two trends are more effective for composites B and C, which have bigger particle sizes.

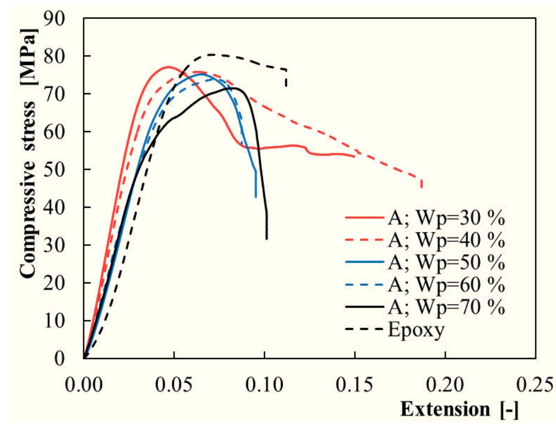

Fig. 5. Compressive stress versus extension curves.

Fig. 6 shows the normalized compressive strength versus particles fraction for the three composites. As cited before all composites have lower compressive strength than the resin. For the generality of the cases (for a given particles fraction) the compressive strength decreases with the increase of the expanded particles diameter.

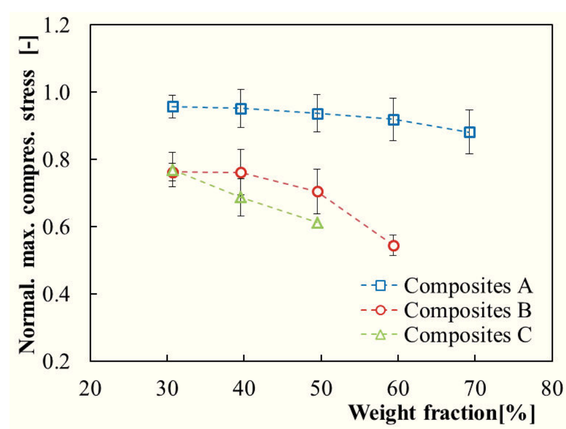

Fig. 6. Normalized maximum compressive stress versus weight fraction.

Fig. 7 shows the normalized compressive modulus versus particles fraction. Considering the universe of the analyzed cases the stiffness modulus to compression is lower than that of the matrix for the composites of type B (values greater than W_p= 40%) and for the composites of type C. On the contrary, the composites of type A exhibit clearly higher values than those of epoxy matrix (in order of 47% for W_p = 30% and 31% for W_p = 70%).

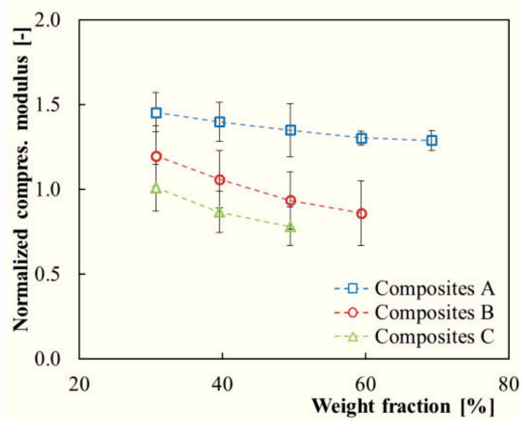

Fig. 7. Normalized compressive modulus versus weight fraction of particles.

The mechanical properties obtained in three points bending tests, flexural strength (equation 2) and flexural modulus (equation 3) are presented in Fig. 8 and Fig. 9, respectively.

Fig. 8 shows the average normalized flexural strength against the weight fraction of particles. All composites present much lower flexural strength than the matrix, and there is a losing in strength higher than 60 % in all composites. Fig. 8 shows that a significant decrease of the flexure strength with the increase of the weight fraction was obtained. Also, an important decrease of the flexure strength with the diameter of expanded particles, particularly when composites of type A are compared with composites of type B, was observed.

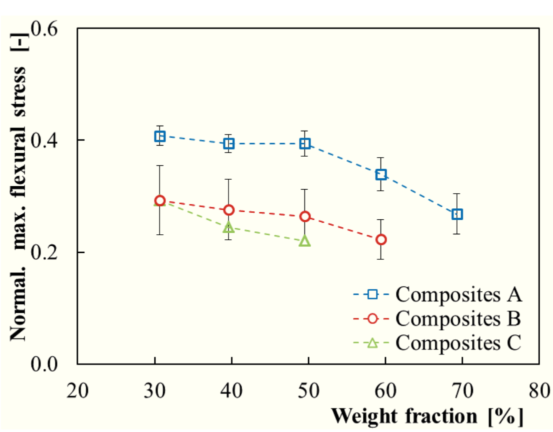

Fig. 8. Normalized maximum flexural stress versus weight fraction.

Fig. 9 presents the flexural modulus against the particles fraction. All composites show a flexural modulus significantly higher (in some cases twice as high) than the resin, and decreasing significantly with the increase of the particles fraction and also with the particles size. The highest stiffness modulus was obtained for composites W_p = 30% of particles, and these values were for the composites of types A, B and C, 94%, 47% and 36.2% higher than those of the epoxy matrix.

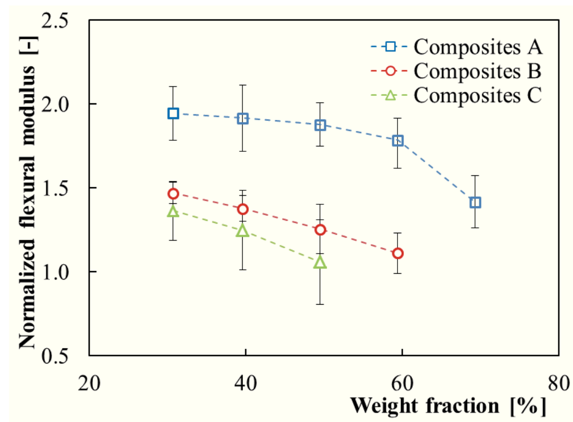

Fig. 9. Normalized flexural modulus versus weight fraction.

Fig. 10 shows the influence of the weight fraction on the average values and standard deviation of the fracture toughness (K_Q). The results were normalized relatively to the fracture toughness of the resin (K_{Q0}). All composites present much lower fracture toughness than the matrix, decreasing significantly with weight fraction, and also with the diameter of expanded particles.

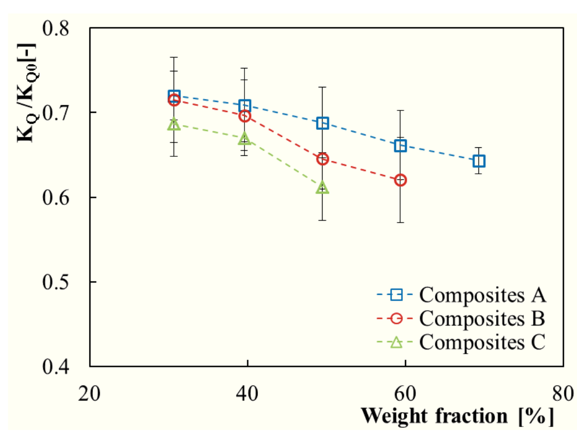

Fig. 10. Fracture toughness versus weight fraction.

4. Conclusions

This work focused on the study of the effect of weight fraction on the physical and mechanical properties of epoxy filled by expanded clay particles with different sizes. The main conclusions are:

- Sound intensity curves showed an effective intensity reduction with particle content. For Wp = 50% it was obtained a reduction in sound intensity of 15%, 20% and 24% in comparison with epoxy plates, for composites of types A, B and C, respectively;
- Thermal conductivity showed the same tendencies as sound intensity curves. For Wp = 50% it was obtained a reduction in thermal conductivity of 25%, 36% and 41% in comparison with epoxy plates, for composites of types A, B and C, respectively;
- Composites of type A show a higher compression modulus than the epoxy matrix. However, compressive strength is always lower than that of the epoxy. Both decrease with the increase of particle content.
- All composites exhibit much lower flexural strength and in many cases the flexural stiffness is higher than the epoxy matrix. On the other hand, the toughness K_Q is significantly lower than that of the matrix. The values of the three properties decrease with increased W_p.

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