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Design and manufacture of insulation panels based on recycled lignocellulosic waste

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ABSTRACT

This paper has been focused on the properties of construction material based on cellulose. More specifically, their use as non-bearing walls, coating-panels and/or anti-humidity panels. It has been obtained from the recycling of urban waste, such as paper and paperboard.

The performance of this material has been evaluated in relation to five parameters: dimensional stability against humidity, fire action, decay resistance front fungal degradation, and, their behavior as temperature and acoustics isolation.

The performance of manufactured materials has been verified considering environmental factors, and simulating the condition of the material in service. This yielded satisfactory results in relation to all the agents mentioned, which allows concluding that the material fulfills the desired function.

It has been concluded that the designed and manufactured panels have the necessary characteristics to replace insulating materials or Gypsum plasterboard type enclosure, extending the range of materials for this function, through the incorporation of a new option based on recycled raw material, low-cost manufacture and minimal energy resources used.

1. Introduction

During the building phase, actually there is a trend towards the use of new sustainable building systems as well as new and, more environmentally friendly materials. These trends coincide with a variety of interesting methods and materials which can be used in housing construction, and thus, contribute to sustainable development under the concept of the circular economy (Herrera Troncoso et al., 2018). On the other hand, as a result of the eminent energy crisis in Argentina emerge the new law of thermal conditioning in which, specify the needed to improve the thermal conditions of the houses arises. Throughout the years, masonry construction is the most chosen than other construction systems. The lack of importance given to insulation, especially thermal insulation, is a tradition that has been ingrained along with that of brick masonry construction, almost as if the two elements cannot be considered compatible with each other, much less can be recognized as being fundamental. The low quality of thermal conditioning is found in all social classes housing but in the most precarious sectors have not possibility of acclimate the rooms and in many cases even without access to the natural gas network.

Thus, the present paper comes as the result of the analysis of two important problems: the lack or absence of conditioning of low-income housing and the non-treatment recyclable organic waste in Argentina. The first problem mentioned is given by the exponential increase of the population in recent years which is accompanied by the failure to encourage efficient use of new systems for thermal conditioning and a building with efficient energy resources and material environmentally friendly. The technological advances of materials tend to generate less energy use, less construction time and less pollution (waste and CO_2 emissions). However, traditional constructions used in Argentina have a large consumption of energy to condition due to the lack of insulation or technological enclosures but they are selected due to the low cost of these non-technological materials in the country. The second problem mentioned generates a great environmental pollution due to it accumulation without treatment, and also increased costs for their management because they were deposited in large territorial areas wasting it as a resource.

This is how the intention to achieve an accessible product becomes fundamental to solve the problem posed here.

Several research works have studied the re-use of aggregates derived

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from agricultural or industrial wastes such as glass powder as (Raut et al., 2012), (Raut et al., 2017), plastic waste aggregates (polycarbonate and polyethylene. terephthalate) investigated by (Hannawi et al., 2010), rice husks studied by (Chabannes et al., 2014), and wastepaper evaluated by (Khalid Shibib, 2015) (Aksogan et al., 2018), and (Kizinievic et al., 2018) to investigate their efficiency in manufacturing new ecological materials. These materials are light, low cost and are characterized by interesting thermal performances compared to the conventional materials of the building by (Aigbomian and Fan, 2013).

Parallelly, various ways to recycle waste have been studied (Balaž et al., 2019). eliminated environmental burden by dichlorination using polyvinyl chloride and eggshell waste (Derakhshan et al., 2017), proposed a way to reuse waste tires, and (Toledo et al., 2018) conducted a study on the process of composting sewage sludge and market waste. Many similar studies have looked at waste from several sectors to obtain sound absorbing materials by (Ma et al., 2019).

As far as waste is concerned, we are going to focus on lignin cellulosic waste. We can see that these are mostly the result of the daily use of the population (paper and cardboard) (Baillie et al., 2011), (Sternberg, 2013). The choice of these materials is justified by the contribution that they make to environmental sustainability by making use of the cellulose contained in recycled paper and cardboard, this being part of the third group of elements that are discarded in greater proportion (Parizeau, 2015). This initiative opens up the possibility of generating productive units based on waste recovery. Thus, the general objective of this project is to produce new construction materials from the cellulose of recycled paper.

The condensation moisture on the interior surfaces of the walls produces health and hygiene problems (Azqueta, 2003), loss of comfort and damage to the building heritage (Zhang et al., 2020). In addition, the thermal conductivity of the materials increases, reducing their insulating capacity (Akkurt et al., 2020).

In this way, it is necessary to provide a solution that, apart from being economical and sustainable, meets the safety conditions and improves the quality of life of the users by building a healthier living environment.

Therefore, the objective of this paper has been the design and development of insulating panels based on cellulose and water, as a new material for use in low-income or emergency housing.

2. Materials and methods

In general, the methodology has been based on the following steps: (i) characterization of the substrate; (ii) selection of the materials for the formulation of the panels; (iii) preparation of the experimental samples; (iv) mechanisms for the manufacture of the panels; (v) characterization of the final material; (vi) exposure to the degrading agents.

A series of tests have been performed to characterize the performance of four samples composed of: newspaper, white printing paper, corrugated board and egg dye cardboard (n = 20 of each one). The preparation of the different mixtures has been carried out by crushing the different materials and measuring the right proportions for a correct drying (the material is intended to be resistant). The utilized proportion has been what provides the best stability to the shelling to the touch, drying of no more than one week and which has undergone a minimum deformation (40/60% recycle material/water).

The material manufacture has been making on frames assembled in laboratory consisting in a wooden frame with a filtering system based on a sieve network. Frames of different sizes have been assembled depending on the test to be carried out, Fig. 1.

The performance of the material has been evaluated as: dimensional stability against humidity, fire action and fungal attack (frequent pathology such as dampness in homes). On the other hand, their thermal and acoustical isolation capacities have also been studied.

2.1. Dimensional stability

The material performance with respect to humidity has been evaluated by means of the water immersion method of Rowell and Ellis (1978); based on the application of dry-water-soak cycles, measuring the difference in weight and volume over time. The soaking time varies from 5 min to 2 h; first and last cycles respectively. On this occasion, the samples have been subjected to six soak-dry cycles (up to saturation point), and the data from these cycles have been detailed in Table 1.

The following coefficients have been calculated from the data provided:

Table 1
Data from dry-water-soak cycles.

WATER SOAK	DRY (103°C)
5	10 min
10	40 min
20	60 min
30	100 min
60	140 min
120	24h

Fig. 1. Samples manufacture: This is the sample preparation system in which the samples have been filtrated and cured.

$$WA = 100 \times \frac{(M_2 - M_1)}{M_2} \tag{1}$$

Water absorption coefficient (1), where WA is the water absorption (%), M1 is the weight of the dry samples and M2 is the weight of the saturated samples.

$$VS = 100 \times \frac{(V_2 - V_1)}{V_2} \tag{2}$$

Volumetric swelling coefficient (2), where VS is the volumetric swelling (%), V_1 volume of the dry samples and V_2 is the volume of the saturated samples.

$$EH = 100 \times \frac{(S_2 - S_1)}{S_2} \tag{3}$$

Coefficient of efficiency (3), where EH the water repellent efficiency (%), S_1 and S_2 are volumes of untreated and treated samples, respectively.

On the other hand, the coefficient and speed of water absorption of the different materials is calculated by calculating the resulting slope of the weight vs. time graph.

2.2. Fire resistance test

In order to evaluate the reaction of materials to fire, each sample has been exposed to the flame of a Bunsen burner to evaluate the intermittent response of the material to fire during varying periods of time under the guidelines of standard UNE 23-740-90. Tests have been conducted from 3 to 30 s. Each sample has been then classified according to the following parameters: intermittent, smoke, carbonaceous residue, presence of flame and loss of material. These have been graded on a scale of 0–3, with 0 being the absence of the manifestation of the parameter and 3 the maximum manifestation thereof. After performing a summation of each category mentioned, the result has been the performance of the material. Thus, a higher numerical result implies a more unfavorable performance.

2.3. Biological tests

The evaluation of the fungal activity has been carried out by exposing the samples to wood decay fungi, by means of using soft and brown rot fungi. These being the most aggressive, the material will be exposed to the most unfavorable conditions possible (Morrell, 2018). The exposure of the panels to the degrading agents has been done following the general guidelines of the ASTM D 2017 standard (ASTM D 2017, 2005).

2.4. Thermal and acoustic performance test

In order to carry out the tests corresponding to the evaluation of the thermal and acoustic performance of the materials, specimens of the materials have been constructed in prismatic form (Fig. 2), without the upper and lower faces, thus allowing carrying out measurements from inside them.

The thermal capacity has been evaluated under the guidelines of the IRAM 11601 standard (IRAM 11601, 2004). For this purpose, the specimen is placed in front of the flame of a Bunsen burner and the internal and external temperature is measured. With the obtained data, the following parameters have been calculated:

$$\lambda = \frac{\theta e}{2A(T_2 - T_1)} \frac{W}{mK} \tag{4}$$

Thermal conductivity (4), where: Burner power $\theta = (W)$; e: Average thickness of the plates (m); A: Area of the heating zone (m^2); T_2 - T_1: Temperatures of the hot and cold sides (K)

$$Rt = \sum \frac{e}{\lambda} \left[\frac{m^2K}{W}\right] \tag{5}$$

Thermal resistance (5), where e: material thickness (m); λ: thermal conductivity of the material (W/mK)

$$U = \frac{1}{Rt} \left[\frac{m^2K}{W}\right] \tag{6}$$

Thermal transmittance (6), where Rt is the total thermal resistance.

References to thermophysical properties of some representative materials were provided in this standard and the wall thermal resistance was accordingly calculated using the series thermal resistance of the single layer; where the amount of heat that under stationary conditions flows through the unit area of a sample of homogeneous material of infinite extension, plane and parallel faces and unit thickness in a given unit of time. It was considered that the material under study was homogeneous due to the level of high compaction and the identical primary materials; therefore, a unitary temperature difference was established between its faces taking a horizontal flow to a vertical face and as a homogeneous element.

For the acoustic evaluation has been analyzed under the guidelines of the ASTM C 423 (ASTM C 423, 2017), the frequency and unevenness have been measured for a period in which two hits are executed, one outside the test piece and the other inside it. Consequently, we have then proceeded to calculate the following parameters:

$$I_2 = I_1 e^{-\beta x} \tag{7}$$

Absorption coefficient (7), where I_1 and I_2, correspond to the sound intensity of the interior and exterior enclosure, respectively: x is the thickness and β is the insulation coefficient.

$$S = 10 \left(\log \frac{I_1}{I_0}\right) \tag{8}$$

Where S is the intensity level (8), I_1 is the sound intensity and I_0 is the minimum audible intensity.

Fig. 2. Thermal and acoustic insulation test specimens: The different types and grosser of samples allowed measuring the isolation properties of material.

3. Results

All test samples have been made with materials based on cellulose and water. These have shown a good performance as enclosure materials, similar to those which can be found at the market. In terms of the analysis of properties, there have appeared significant differences which allowed the best base material to be chosen for the manufacture of this new material.

The mechanical tests were not taken into account because it will not be a structural material: the only effort to support will be its own weight, and there was a good response since no vertical deformation was measured after 6 months estimated. This showed the capacity of this material to work as a self-supporting piece. Both the compressible stresses, typical of load-bearing elements, and bending, present in horizontal closures, were considered negligible because it was a component that serves as a vertical closure. On the other hand, when handling the material to give shape to the samples, it was subjected to a sawing with a higher resistance to MDF or Gypsum plasterboard.

3.1. Dimensional stability

Regarding the hygroscopic performance that has been analyzed, it can be observed that the results based on recycled whitepaper, cardboard and dye cardboard samples presented a high kinetic of water absorption, as can be seen in Fig. 3 and 4. On the contrary, the sample based on recycled newspaper has shown low kinetic water absorption at the initial stage of cycles (it does not absorb water during the first minutes). All the samples have reached their saturation point throughout the cycles, but all they have all shown good structural stability (in all cases, their structure has been preserved, without any resulting peeling or detachment).

Regarding capillary absorption, it can be observed that white paper and dye cardboard samples have presented high absorption (they sink immediately); while cardboard and newspaper have reduced capillary absorption in that order (they float for a few seconds).

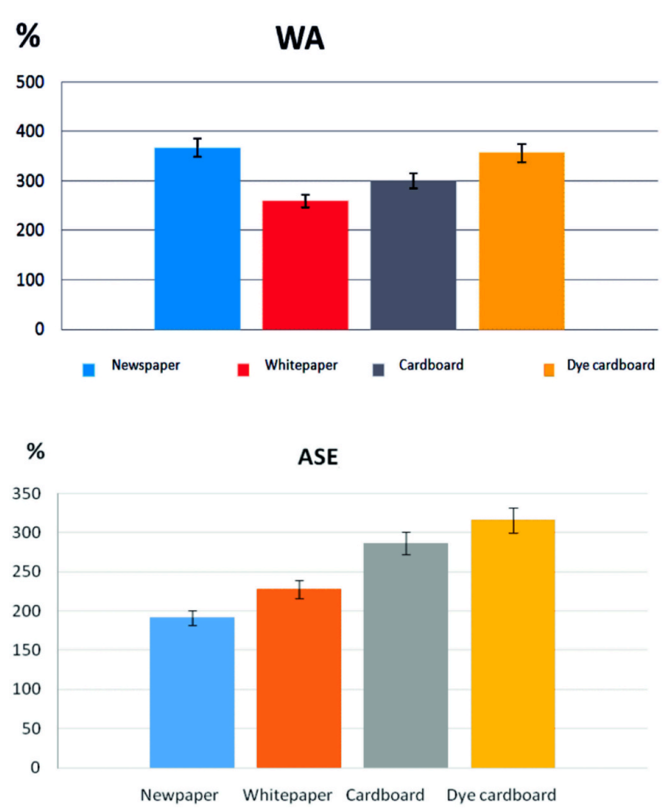

Fig. 3. Graph of WA, %, and Anti-shrink Efficiency (ASE, %) after soaking and drying cycles according to Rowell.

The water absorption coefficient has shown a weight increase of up to 370% in newspaper, compared to 46% increase in untreated wood, taking this as a reference of known material. The other materials have lower rates, but relatively considerable in relation to the behavior of wood. These coefficients show an important trend of loss of dimensional stability.

As for the volumetric swelling coefficient, a newspaper has increased its volume by 10%, white paper by 7%, cardboard by 5% and dyes cardboard by 12%. An important difference in behavior is observed between the materials analyzed. While white paper, cardboard and dye cardboard absorb water to a large extent, newspaper gradually increases and takes time to reach its saturation point.

The absorption coefficients (derived from the polynomial equations of the curves in the graph in Fig. 4), as well as water absorption rates (coefficient divided by the time where the curve behaves as a straight line) are presented in Table 2.

Here we can see that the absorption coefficients of the various materials used are very dissimilar from each other. Taking as reference the wood as a known material, we can observe that all of them have a higher order of magnitude of absorption (higher initial slope in Fig. 4) so it shows the already mentioned and expected, since these are based on absorbent materials by nature. As for the best behavior we can see that the best was the cardboard followed by paper, maple and newspaper, in that order (the last two have a higher porosity due to its manufacturing process). The increase in humidity in 15 min in dye cardboard come from the treatment that this material has been had in its molded (it has a high temperature molding which makes it more porous than the rest). It is because it also has the highest percentage of WA% and ASE%

It can then be concluded that the samples of white paper, cardboard and dye cardboard have not had a good behavior against water absorption, nor have they maintained their dimensional stability, otherwise, the newspaper has presented favorable results in relation to water repellent behaving similar to a waterproof wood, yet it has not had good dimensional stability, so it could be classified as a behavior type I of Rowell and Elis (1978) classification.

The high-water absorption presented in all cases is what gives the material its mechanical stability: the evolution of the absorption rate is divided into two phases: the first is characterized by high-water absorption after 5 min, followed by a slowing down of the absorption (Mai, 2018). This ability to absorb a high quantity of water in a short time could have an effect on the water dosage to be used in the making of the composites (Belakroum et al., 2018) in order to ensure a good adhesion between the lignocellulosic particles (Mandili et al., 2019)

3.2. Fire resistance test

In order to evaluate the performance against fire action, each sample has been exposed to the flame of a Bunsen burner over varying periods of time. Tests have been conducted from 3 to 30 s, as can be seen in Fig. 5.

Performance has been measured by means of a rating of each sample according to its behavior, as it has been mentioned above. All materials have shown the presence of flame before 3 s (5 in cardboard, 10 in newspaper and 20 in white paper), but in all cases the flame has been extinguished without spreading, as it can be seen in Fig. 5. Newspaper, cardboard and dye cardboard board have shown low material loss, and preserved their strength, with newspaper standing out above the others.

White paper, on the other hand, has a high resistance to the initial flame, but when the exposure to fire is prolonged, it suffers a greater loss of material in comparison to the other samples.

Although in all cases it is evident that a protection system against the action of fire is necessary, this behaves like Gypsum plasterboard, or the anti-humidity panels on the market (according to the results of technical sheets).

The behavior observed is due to the base materials with lower

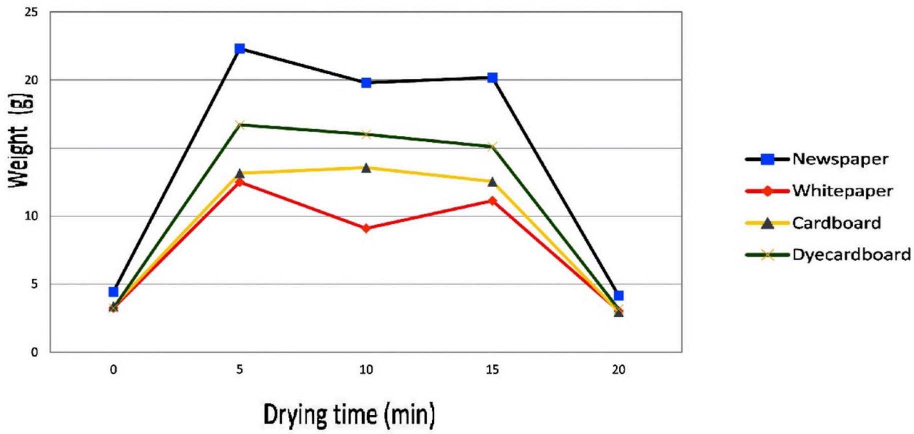

Fig. 4. Calculation of water absorption rate.

Table 2
Rates and speed of water absorption.

	Absorption coefficients	Error (R1)	Absorption speed (g/min)	Error (R1)
N	9,3	±0,9	1,86	±0,19
WP	7,3	±0,4	1,46	±0,07
CB	5,8	±0,11	1,16	±0,04
DCB	4,2	±0,17	0,84	±0,25

density (more porous) showed a better performance with respect to fire, due to a higher level of compaction in its preparation given by this more open molecular structure which allows the final result to be more compact. This implies that there is less oxygen circulation through the material, decreasing combustion; unlike the less compacted samples in which the material is already in its almost maximum state of compaction, and so the preparation system does not change its behavior with respect to this agent.

3.3. Biological tests

As for the biological tests, specimens have been assembled in Petri dishes, and kept permanently moistened, as can be seen in Fig. 6.

At the end of the test, the performance evaluation will be determined gravimetrically by weight loss (Fig. 7).

The control shows a weight loss in all cases, except for the diary,

Fig. 5. Fire behavior test of a Bunsen burner.

Fig. 6. It pictures panels without fungal inoculation (control) and inoculated for the study of biodegradation.

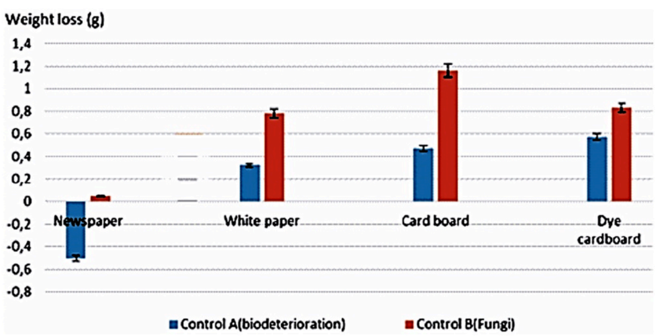

Fig. 7. A) Weight loss (g) after 4 months of fungal exposure B) Coefficient of weight loss.

possibly due to the lower desorption of the latter compared to the other materials. The source of absorption is given by the amount added to the test (approximately 200 cm^3 every 2 weeks).

As a result of an analysis on this matter, it may be observed that in the biodegradation ones there is a decrease of weight not only by the loss of weight of the material in itself, but also by the capacity of water desorption produced by the fungal metabolism. For this reason, the values of the controls have been subtracted to obtain the real biodegradation value, Fig. 8.

After this correction, we may conclude that the material that presented the best resistance is the newspaper, followed by the dye cardboard, then the paper and finally the cardboard. These results showed that have behaved best are those that already presented ink in their original compositions. This may be justified in the chemical composition of the inks: these have in their formulation, basically, activated carbon, anilines (black) and metallic salts such as iron oxide (red), cadmium sulphide (yellow), titanium and zinc oxides (white), among other minerals (blue) (Bazza et al., 2013). They also have paraffin wax which functions as a vehicle (Kunjappu, 2001). Therefore, all these components could be acting as fungistatic biocides in the materials produced, and thus preventing them from being degraded by specific wood decay fungi. The biocides function could be explained by the presence of salts, some of which are protein chelators and others which generate an osmotic imbalance at the cellular level, and hence preventing hyphae from penetrating the material.

3.4. Thermal and acoustic performance test

In order to evaluate thermal behavior, the conductivity, resistance and thermal transmittance of each of the samples have to be calculated.

The newspaper has a low thermal conductivity, similar to wood. It is followed by dye cardboard and cardboard, and finally paper with higher levels, but equally low. It should be noted that dye cardboard and cardboard have presented very similar results. In the same way, the thermal resistance is higher in the newspaper, in comparison to other materials, and the thermal transmittance is lower, as it can be seen in Fig. 9.

This behavior could be explained that it is the molecular structure that is predominant and not the macromolecular one, since chemically they are all the same origin and the level of compaction is contrary to the results obtained. Therefore, it could be thought that the heat is transmitted through the interstitial air that remains within the microstructure of the material (Villasmil et al., 2019). Consequently, paper is the one that presents the highest amount of amorphous cellulose in comparison to the rest, probably due to the industrial whitening treatments which undergoes (Nadir et al., 2019), (Yun et al., 2020).

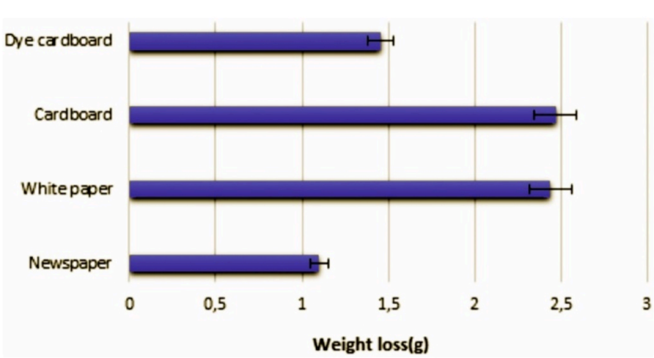

Fig. 8. Weight loss only by biodegradation (g).

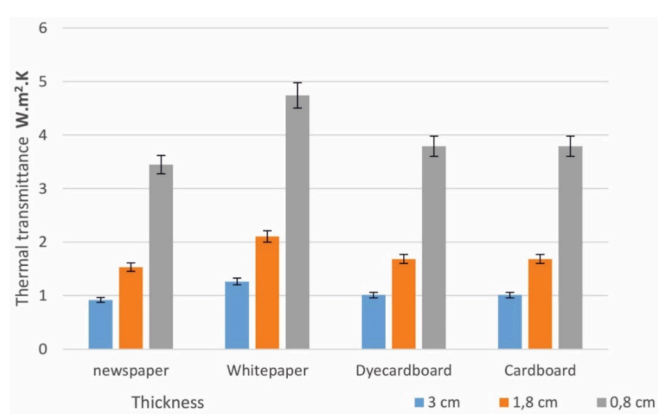

Fig. 9. Thermal transmittance (U).

Paper presents a thermal conductivity of 0.027 W/m.K, with an apparent density of 246.54 kg/m^3; which in comparison to a traditional thermal insulator, such as glass wool (apparent density: 71–150 kg/m^3; thermal conductivity: 0.038 W/m.K); or with materials of similar apparent density, such as chipboard (apparent density: 200 kg/m^3; thermal conductivity: 0.047 W/m.K) has a lower thermal conductivity, which presents it as a good thermal insulator. The other materials have similar characteristics, so the same applies to them (Pacheco-Torgal et al., 2020), (Zaman et al., 2020).

A comparison of the thermal and energetic performance between the wall with the developed and classical (i.e. Rock wool and Expanded polystyrene) insulation is conducted. It is observed that, the insulation materials based on textile waste is a competitive solution in terms of annual heating and cooling loads compared to the classical insulation (Aditya et al., 2017), (Adamczyk et al., 2018). This indicates that these new materials work as thermal insulators, not only because the values allow it to be classified in this way, but also because they present similar results to those available in the market, Table 3 (Schiavoni et al., 2016), (Ricciu et al., 2018).

As for thermal conductivity, the values obtained were 0,030; 0,024; 0,022; 0,020 W/m.K for whitepaper, dye-cardboard, newspaper and cardboard, respectively. Comparing with materials in the market we can observe that the materials have a similar conductivity to mineral wools (rock and glass wool) which range between 0.03 and 0.05 W/m.K as well as to polystyrenes which have values between 0.019 and 0.040 W/m.K. Also, comparing the materials with those of the literature, where the composition was similar, we can observe that in this one it has a close thermal behavior compared to others: for example (Raut et al., 2017), studied made-up recycled paper mill waste bricks with a cement binder to produce lightweight bricks. The results show that these bricks are characterized by high water absorption varied between 108% and 283.3% (Rajput et al., 2012). studied the bricks that are made by (Raut et al., 2012) while fixing the cement dosage and adding the cotton waste in low dosage. These bricks are characterized similar behavior of ability of water absorption and thermal conductivity ranging from 0.025 to 0.032 W/m.K (Aigbomian et al., 2018). made bricks containing sawdust in addition to wastepaper (newspaper) with a lime-based binder. The manufactured bricks have very low values of thermal conductivity (0.046–0.069W/m.K) (El Wazna et al., 2020). have studied the physical-microstructural properties of four nonwoven waste based on acrylic and wool using needle-punched technique they developed for insulation purposes. Their thermal conductivity is found between 0.037 and 0.045 W/m K.

For the acoustic evaluation, the sound absorption coefficient has been measured, which can range from 0 (not at all absorbent) to 1 (fully absorbent), Fig. 10.

It may be observed that the newspaper behaves as a good acoustic insulator, since it hardly absorbs sound waves like cardboard and dye-cardboard do. In contrast, paper turned out to be the worst acoustic insulator. The latter is consistent with the thermal insulation.

4. Discussion

In order to choose the best among the four materials designed, a system of comparative points has been prepared for each of the properties studied. For this purpose, the best score achieved has been 10 and the other scores have been compared to this, as it can be seen in Table 4.

The results show that all have obtained acceptable service behavior (all higher than 8 points). Conversely, given the high score of all the properties studied, we can say that the materials can be used as wall insulation, or else as an enclosure or cladding material.

This is important because it is low cost and easy to manufacture, facilitating the assembly of emergency or social housing. The results show that all have obtained an acceptable in-service behavior (all higher than 8 points), and as a result they fulfill the desired insulating function, as it can be seen in Table 4.

The best option which combines all the properties turned out to be paper, followed by newspaper, dye cardboard and cardboard (following that order, as it can be seen in Table 4).

In the first place the against fire behaviors is due to the base materials with lower density (more porous) as mentioned. When it comes to the case of water, the opposite performance is observed. This is due to the fact that the compaction achieved is lost in the first cycle of water absorption, and in turn becoming a porous material again, which explains the water absorption observed, fundamentally by capillarity.

In relation to biodegradation by fungal action, the materials that have behaved best (newspaper and dye cardboard) are those that already presented ink in their original compositions as has been mentioned. This also may be justified the behavior of water: the one that behaved best has been the dye cardboard which presents ink in all the material, unlike the rest in which the presence of ink is partial (newspaper and printed paper), or null (cardboard). This indicates that the dye cardboard is covered in its entirety by the dye vehicle (paraffin wax) making it completely waterproof.

As for the insulating capacity, we can conclude that the waves and heat are transmitted through the interstitial air that remains within the microstructure of the material. Consequently, paper is the one that presents the highest amount of amorphous cellulose in comparison to the rest, probably due to the industrial whitening treatments which undergoes.

In terms of water absorption, compared with other insulation materials based on recycled materials (Hannawi et al., 2010), (Chabannes et al., 2014), it was observed that all were within the expected WA coefficient (between 108 and 370%) but the fundamental difference was in the absorption kinetics achieved, since the value obtained in all the materials used here was lower, improving the dimensional stability of the existing ones (Khalid Shibib, 2015), (Kizinievic et al., 2018). On the other hand, it is observed that the material is resistant to biodeterioration, which is of great importance for its durability and for the health of the people who will live in the place where it will be implemented.

5. Conclusions

During this work, a new material has been developed from the usual recyclable waste from human activity. It allows reducing an important volume of these residues in waste. At the same time, it has been manufactured from an easy and economical process, which does not require large installations, and in particular, without the use of any organic or inorganic solvent. Only lignin cellulosic residues and water have been used.

A dimensionally stable material has been achieved, which is easy to work with, paintable and also easy to install. In the tests which have been carried out, the performance of the materials against environmental factors has been verified, simulating the situation of the material in service, which has given satisfactory results against all agents and allows us to conclude that the material fulfils the desired function.

Therefore, this material would solve the two main problems: the use of other options in materials for the conditioning of houses, generating an efficient energy use and being very low cost compared to those currently used. This is not insignificant since it is one of the fundamental variables in the choice of materials for building. Also, being low-cost, it would allow for the conditioning of low-income houses, which would be beneficial for their residents who do not have basic services such as natural gas.

The conclusion is that the panels designed and manufactured have the necessary characteristics to replace conventional insulating materials, or even Gypsum plasterboard type enclosures, being a sustainable material that fulfills both insulation and enclosure, or finishing functions. It is concluded then, that all the panels have behaved like appropriate insulators, being able to say that it has been possible to generate new thermal and acoustic insulators with good behavior in service and of low cost.

Table 3
Thermal transmittance comparative with other materials in market.

Material	Transmittance W/m^2-K
Concrete	17.20
Solid brick	15.00
Limestone	14.00
Adobe	11.00
Perforated brick	7.40
Thermoclay block	2.50
Hardwood	1.80
Coniferous wood	1.50
Particleboard	1.30
Cellular concrete	0.90
White paper	0,70
Expanded pearlite panel	0.62
Cardboard	0,58
Dyecardboard	0,58
Newspaper	0,53
Expanded cork	0.49
Mineral wool	0.40
Extruded polystyrene	0.38
Expanded polystyrene	0.37
Projected polyurethane	0.35
Polyisocyanurate foam	0.25

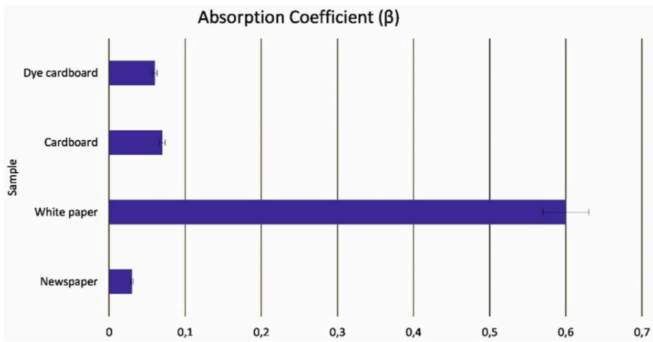

Fig. 10. Sound absorption coefficient (β).

Table 4
Global results.

	Newspaper	Printing Paper	Paperboard	Dye cardboard
Biological test score	10,0	7,8	7,8	8,7
Fire Score	10,0	10,0	8,8	8,2
Water	7,8	8,3	8,6	10,0
Thermal behavior score	7,6	6,3	7,5	7,5
Acoustic behavior score	9,6	7,7	8,8	8,8
Average	9	8,02	8,3	8,64

Finally, but not least, it is a material generated with 100% biodegradable, recyclable and recycled material, so we are contributing to reduce environmental pollution.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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