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Cellulose, Rice Husk and Polyvinyl Acetate-Based Composite: Flame Retardancy and Fungi Growth Experimental Study

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Abstract: Within the context of sustainable material development for the construction sector, this study explores the viability of panels composed of recycled newspaper-derived cellulose (9%), rice husk (14%), borax (15%), and polyvinyl acetate-based glue (62%). The methods employed involve water absorption and density tests, following ASTM C-1763 and C-303 standards. The fire resistance test conforming to the European standard UNE 23-725-90, and a mold growth test using AOAC 2002.11. The composite is prone to absorbing a significant amount of water when exposed to humid conditions. However, the incorporation of rice husk and borax can provide benefits such as improved moisture resistance compared to other cellulitic insulators, which may be advantageous in specific climates. Also, the developed composite has an intermediate density compared to other polymeric materials. This characteristic presents advantages in applications that demand a balance between strength and lightness. During the fire resistance tests, the samples with borax presented less fire propagation, and superficial damage compared with the specimens without borax. This is important, considering the fireproofing property, required in building materials. The presence of borax in the composite has an inhibitory effect on the growth of fungi and yeasts. These findings are consistent with previous research. Nevertheless, further research and testing are imperative to assess its viability and performance for commercial applications.

Keywords: recycled cellulose; rice husk waste; fire resistance; fungal growth; water absorption; density; natural fibers; resource sustainability; building sustainability

1. Introduction

Natural fiber-reinforced polymer composites are attracting the attention of researchers due to their low environmental burden imposed by their manufacture and disposal. Most of the natural fibers used in new material development are residues (waste) from agro-industrial processes [1–3]. Natural fiber reinforced composites have lower mechanical performance to glass fiber reinforced plastics (GFRP), but exhibit low thermal conductivity, biodegradation in natural environments, and high acoustic absorption [2,4].

An insulating material is defined by its high thermal resistance, which means that it limits heat exchange between two materials or environments with a temperature differential [5]. Material thermal conductivity should not exceed 0.08 W/mK for insulation applications [6]. Some other relevant parameters include resistance to water vapor diffusion, water absorption, moisture content [7], low thermal transmittance (U in W/ m^2K) [5], and adequate resistance to bending, tension [8], compression, fungal growth, and flame retardancy [9–11]; this last is referred to material's behavior

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under fire conditions or fire-proofing property, while the mold growth test verify the effectiveness of adding borax or other element, in the decrease of fungal growth [12–17].

Thermal insulation is essential for the transport and storage of temperature-sensitive products: for the prevention of overheating in certain areas of electronic devices and for indoor climate control in buildings [18–20]. Air conditioning of buildings accounts for more than 10% of global energy consumption [21]. Efficient thermal insulation based on renewable materials is an essential part of the technological change needed to mitigate climate change [7,22–27]. Renewable and bio-based materials, such as wood chips and recycled paper, were widely used for thermal insulation before the introduction of fossil fuel-based foams, but their insulating performance is relatively low [28,29]. However, looking for alternatives to reduce the environmental impact generated by the production of commercial insulators [30,31], the use of vegetable and animal origin thermal insulators have been implemented again [32].

Materials such as cellulose-containing newsprint have demonstrated good thermal properties [33–35]. Cellulose is a material that stood out for being used as a thermal insulator since the beginning of the 20th century [29], in North American and European countries. Rice husk, coconut tow and newspaper have also been presented as natural fibers with potential to be used in thermal insulation applications, due to their thermal conductivity properties [36–38]. In the study developed by Benallel et al., 2021, four different types of agricultural by-products available in the Drâa-Tafilalet region, Morocco (reed, alfa, fig branches and olive leaves) with different mass fractions of cardboard waste (20%, 30%, 40%, 50% and 60%) were analyzed separately. The lowest thermal conductivity value obtained was 0.072 W/mK and the highest value was 0.98 W/Mk [39].

A review on cellulose fiber insulation, covering its manufacturing, installation, and performance, revealed that while the typical thermal conductivity value for cellulose averages 0.040 W/mK. Its properties and performance may vary slightly based on the fabrication and installation methods [12]. The difference in where the cellulose is sourced from can affect the thermal insulation efficiency [40,41].

The water absorption test evaluated the material's ability to resist water absorption [42]. High water absorption can decrease efficiency and promote mold growth. Studies have highlighted the relevance of these tests in the characterization of insulators based on natural materials [43]. In the water absorption test performed by Penjumras et al., 2015, the results indicate that all composites showed a percentage of water absorption greater than 40% after 24 hours of water immersion. It was highlighted that water absorption of composites is a critical aspect, as it can influence the durability and stability of materials, especially in construction applications [44]. Water absorption depends on several factors, such as the chemical composition of the fibers, the size and surface area of the fibers, the density of the composites, and the intra and inter porosity characteristics [16,45]. Although all composites were observed to have water absorption above 40%, it was mentioned that rice husk composites showed the lowest water absorption (42%) after 24 hours of immersion, compared to wood fiber (63%) and textile fiber (60%) composites. This low water absorption percentage is attributed to the high level of porosity of rice husk compared to wood and textile fibers [46].

The density test can directly influence the material's thermal insulating capacity and its mechanical properties [47]. In density test performed by Muthuraj et al., 2019 [46], it was noted that all composites produced showed low densities, within the range of 378 to 488 kg/m^3. These densities are comparable to those of wheat husk-based and fully biodegradable sugarcane bagasse-based particleboard composites, according to previous studies [48–50]. The density is directly related to the porosity of the material and thus to its thermal conductivity [51]. The relationship between density and thermal conductivity in porous materials is a combination of conduction through the solid part and convection through the gaseous part (air in this case). The porous structure of the material contributes to its low thermal conductivity, which is desirable for an insulating material [52].

Composite materials based on natural fibers require the use of additives that slow down both, the material decomposition, and the speed at which the composite material burns [53]. One of the most used additives is borax [54,55]. Borax is a derivative of the element boron and the proportions to be used in the composite material vary according to the manufacturer, matrix and fibers type used

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[56]. The recommended proportion of boric salts (borax) and boric acid is between 15% to 20% composite material mass. The recommended ratio of borax to boric acid is 1/8, for a dosage of 16% to prevent combustion [12]. Boron included in cellulose was found to have a sporocidal effect on five of the most common types of fungal spores, even when subjected to a high concentration of fungi. For untreated fibers exposed to fungal samples, moisture content and relative humidity were found to have an influence on the rate of mold growth on cellulose insulation [57].

In a fire resistance study performed on hemp composites, following EN ISO 11925-2, the samples were exposed to a direct flame source inside a test chamber. The ignition time, the presence of burning droplets and whether the flames reached a specific mark within a predetermined time were recorded. It was observed that hemp composites showed higher fire resistance, while flaxseed composites exhibited better mechanical performance. Taken together, these results support the idea that bio-composites could be effectively used in the manufacture of end products for the construction sector, offering improved fire-proofing property compared to conventional materials [58,59]. Research could be oriented in materials that do not spread a fire or that they could extinguish themselves.

The building sector contributes significantly to energy consumption and greenhouse gas emissions [60]. Conventional construction insulation materials are mostly manufactured from petrochemical sources [61]. Their production and use contribute to a higher carbon footprint, pollution air, land, and water [15,62]. Natural fibers and recycled materials are increasingly attractive in construction sector, due to their sustainability and low environmental impact. Cellulose, obtained from recycled newspapers and rice husks, considered an agricultural by-product, emerge as promising elements for sustainable building materials [63]. In a previous work [20] it was found that the composite consisting of newspaper (14%), rice husk (9%), borax (15%) and polyvinyl acetate-based glue (62%), obtained a thermal conductivity of 0.042 W/mK, demonstrating promised insulation characteristics. Also, tensile, and compressive stress tests were performed, obtaining as results 1.74 and 20.5 MPa, respectively. The developed material exhibits competitive thermal conductivity and mechanical properties compared to various natural and recycled insulation materials, which could constitute a viable option for applications demanding efficient thermal insulation capacity [24,64], especially in hot-humid regions. In this context, this study focuses on determining, in laboratory-scale, water absorption percentage, density, fungal growth, and fire resistance of developed composite.

This study addresses the environmental and waste management challenges in Panama, where it is estimated that significant amounts of newsprint (15 000 tons) and rice husks (87 060 hectares) are disposed of in municipal landfills annually, causing waste accumulation and environmental deterioration. This reality highlights the need to develop innovative and sustainable solutions that take advantage of local resources and reduce dependence on conventional materials with a high environmental impact [3,4,41].

2. Materials and Methodology

2.1. Materials

The following materials were used to prepare the different specimens (see Table 1): Shredded newspaper (from Panamanian newspapers), ground rice husk (supplied by Cooperativa de Ahorro y Crédito El Avance. R. L. Los Santos, Panama), polyvinyl acetate (Grip Bond 2); borax (20 Mule Team Borax), as antiseptic and fire retardant. The instruments and equipment used include molds for the creation of density, water absorption, flammability, and fungal growth test tubes; digital balance (5000 g capacity, accuracy of 0.004 oz., Bonvoisin CO., China), vernier (Total tools CO., PTE. LTD., China), mortar mixer (16 inches in length, 2.5 inch mixing head, Ion Tool CO. China), stove (Frigilux Rim Inox, Venezuela), distilled water, chemical beaker, swabs and Simplates (Fungal and yeast counts, SIMPLATE CO., United States).

Energy dispersive X-ray fluorescence analysis was conducted at the Smithsonian Institution in Panama. Field emission scanning electron microscopy (FESEM) was performed using a ZEISS EVO

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40 from Oxford Instruments (Abingdon, United Kingdom). A thin layer of a gold-palladium alloy was sputtered onto the surfaces using an EMITECH sputter coating, SC7620, from Quorum Technologies, Ltd. (East Sussex, UK) to ensure conductivity. The elemental composition of the materials used for the new composite material was as follows:

Table 1. Energy-Dispersive X-Ray Spectroscopy (EDS).

Shredded newsprint			**Rice husk**		
Element	# at	[wt.%]	Element	# at	[wt.%]
Hydrogen	1	4.962	Hydrogen	1	3.289
Carbon	6	65.516	Carbon	6	20.048
Oxygen	8	27.363	Oxygen	8	42.807
Aluminium	13	1.400	Nitrogen	13	0.567
Calcium	20	0.759	Silicium	14	33.289
Polyvinyl acetate-based glue (Grip Bond 2)			Borax (20 Mule Team Borax)		
Hydrogen	1	5.670	Hydrogen	1	25.436
Carbon	6	63.329	Boron	5	10.079
Oxygen	8	31.001	Oxygen	8	52.792
			Sodium	11	11.692

2.2. Methodology for Composite Samples

The rice husk was ground, and the resulting material was filtered through a 0.6 mm mesh (see Figure 1). The unfiltered fractions were re-grinded to the appropriate size. The required amounts of ground husk, borax and newspaper were weighed. This mixture was combined using a mortar mixer until a uniform distribution of the components was obtained. Subsequently, the polyvinyl acetate-based glue was added, and the mixture was continued until homogenized. Once the mixture was obtained, it was transferred to a mold. After the drying period, the composite material was demolded and prepared for the corresponding tests.

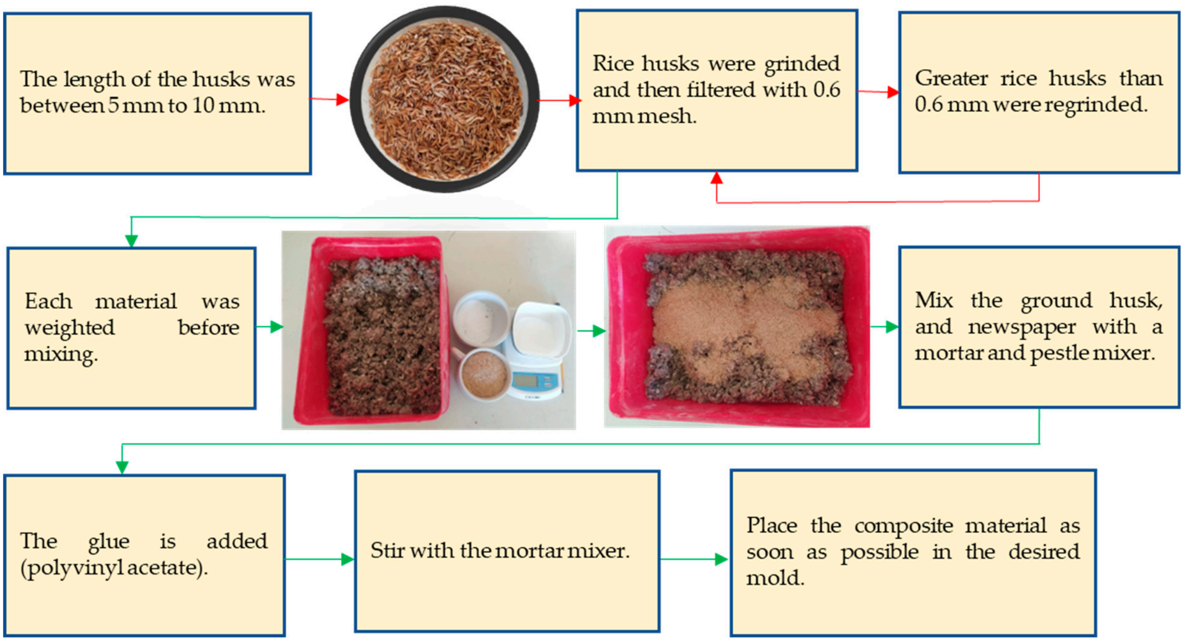

Figure 1. Steps taken to obtain the composite material.

The mass percentage in which the samples were prepared was as follows: rice husk 9%, newspaper 14%, 15% borax and 62% of polyvinyl acetate-based glue. This specific configuration was derived from a preliminary study previously conducted by our team [20]. In that study, three different percentage compositions were evaluated, and based on thermal conductivity criteria, the former composition proved to have the lowest value. This indicates that, within the compositions analyzed, the above composition presents the best properties as a thermal insulator.

2.3. Water Absorption

According to Chen et al., 2018 [65] and ASTM C 1763 [66], after the three specimens (1" high and 2" in diameter) are fabricated. The specimens must be dried in an air oven at 105 °C for 4 hours. Subsequently, the samples are weighed using a balance with an accuracy of four decimals. The samples are placed in a room with 65% of relative humidity (RH) at 25 °C. The specimens are immersed in a chemical beaker with distilled water (300 milliliters) and kept at room temperature for 24 hours. The specimens are drained for 10 minutes. The samples are reweighed. Three specimens were made to perform three water absorption tests and the mean value was calculated. After the material is submerged in water for 24 hours, part of the material dissolves, which is why replicas cannot be made on the same sample.

$$\%\ \boldsymbol{of\ water\ absorption} = \frac{\boldsymbol{Mh - Ms}}{\boldsymbol{Ms}}(\mathbf{100}\%) \tag{1}$$

Where,

Mh = mass of the sample after exposure to moisture.
Ms = mass of the dry sample

2.4. Density Test

According to ASTM C-303 [67], to obtain the density, the mass should be determined using a precision balance. Subsequently, fill a chemical beaker with water and then introduce the specimen, applying Archimedes' physical principle, and thus obtain the volume of the specimen.

To characterize the material’s density, specimens of 1" high and 2" diameter were used. This is because it complies with the adequate measures to be introduced into the chemical vessel.

2.5. Flammability Test

The fire resistance test was performed according to European standard UNE 23-725-90 [24–27]. Borax is an effective flame retardant for polymers due to its ability to form a protective layer on the material surface, release non-flammable gases during thermal decomposition and stabilize the molecular structure of the polymer, thereby inhibiting flame propagation. These mechanisms help reduce the flammability of the polymer and retard its combustion, making it a safety-enhancing agent [12,13,68]. The present test was carried out with the objective of verifying the effectiveness of borax as a flame-retardant agent in the developed composite. Three specimens (1" high and 2" diameter) were fabricated using the composite material without adding borax to the mixture, and another three specimens were created by adding borax.

In Figure 2, the methodology to be followed for performing the flammability test is shown. A "Frigilux Rim Inox" stove was used, then the burner and the metal cover were removed. Subsequently, the stove was set to the lowest power setting, the test sample is placed in the flask for five minutes. The flask is removed from the oven. Finally, a visual inspection is performed and compared with different samples with and without borax.

In addition to the European standard UNE 23-725-90, there are several other recognized standards for performing flammability tests on materials. Although these tests were not carried out in this study, it is important to mention them to provide a complete overview of the regulatory landscape in this field.

The ASTM D635 standard [69]. This standard describes a method for evaluating the flammability of polymeric materials by measuring the rate of flame spread over the surface of a material exposed to a controlled ignition source.

Another relevant standard is ISO 5660 [70]. This standard describes a procedure for determining the flammability and smoke characteristics of materials by measuring heat generation and gas production during exposure to an ignition source.

In addition, the UL 94 standard [71], developed by Underwriters Laboratories, is widely used to evaluate the flammability of plastics and composite materials. This standard classifies materials into different flammability categories according to their ability to extinguish flame and resist ignition.

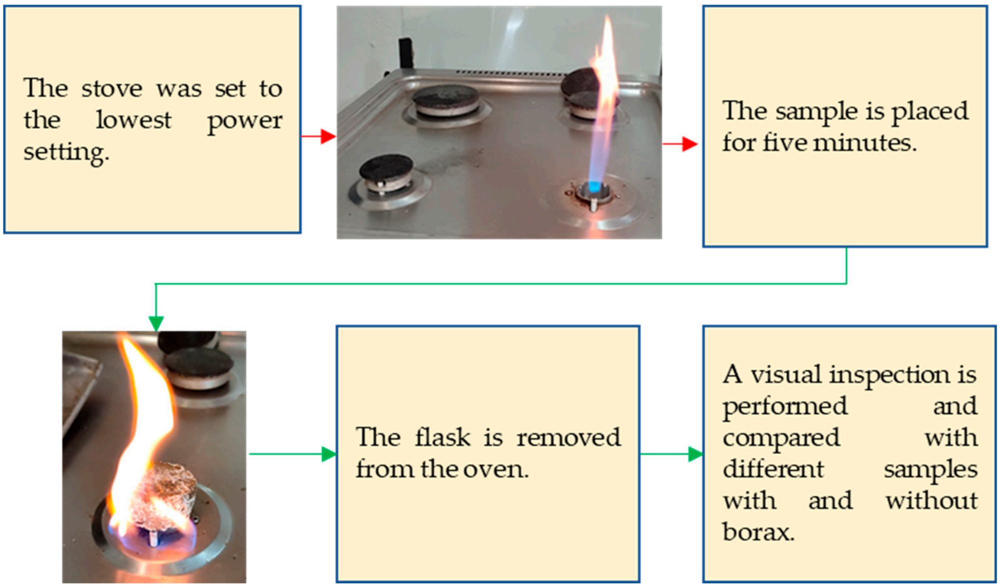

Figure 2. Methodology to be followed to perform the flammability test.

2.6. Fungi Growth Test

Similarly, three specimens were fabricated using the composite material without adding borax to the mixture, and another three specimens were created by adding borax to the mixture. All six specimens were exposed to a fungal growth solution, completely covering their surface.

The "AOAC Official Method 2002.11 - Simplate technique for enumeration of fungi and yeasts" [72] was used and the steps to be followed were as follows: A representative sample of the composite material was taken and transferred to a sterile container. Serial dilutions of the original sample were prepared to obtain manageable concentrations of microorganisms. A suitable sterile culture medium was prepared for fungal and yeast growth. A Simplate plate and a sterile swab were used to apply the diluted sample to the surface of the plate. The procedure was repeated with different dilutions and samples using fresh Simplate plates. The plates were incubated in an incubator according to the required conditions. After incubation, the fungal and yeast colonies present on each plate were examined and counted. Colony enumeration results are recorded for each sample and dilution (D, 10^{-1}, 10^{-2}) [73].

The Simplate Technique for enumeration of fungi and yeasts, according to AOAC 2002.11 method, is a total enumeration technique that does not focus on identifying specific species of fungi and yeasts. Instead, it is used to determine the presence and total amount of these microorganisms in the analyzed sample. The objective of this study was to evaluate the answer of the composite with and without borax to the general presence of fungi and yeasts.

3. Results and Discussion

3.1. Water Absorption

Table 2, presented below, compiles the dry mass and wet mass data of three replicates (S1, S2, and S3) of the composition detailed in the methodology (rice husk 9%, newspaper 14%, 15% borax

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and 62% of polyvinyl acetate). From these data, the percentage of water absorption is calculated. Additionally, an average value is provided, reflecting the average absorption of the tested samples.

Table 2. Data needed to obtain the average water absorption.

	Dry mass (g)	Wet mass (g)	Water absorption (%)
S1	23.98	39.72	65.63
S2	33.76	58.67	73.77
S3	31.00	51.08	64.79
		Average	68.06 ± 4.96

Sample S2 shows the highest percentage of water absorption (73.77%), followed by sample S1 (65.63%) and sample S3 (64.79%). This variability in the results may be due to several reasons, such as possible fluctuations in the environmental conditions during the test or variations in the internal structure of the samples.

The difference in the composition of the samples, because of the manufacturing process (small variations in the proportion of constituent materials), may have contributed to the observed disparities in water absorption levels. For example, the presence of different amounts of polyvinyl acetate, borax, or the distribution of cellulose and rice husk fibers could influence the ability of the samples to absorb water.

Comparing the water absorption capacity of the manufactured material (9% rice husk, 14% newsprint, 15% borax and 62% polyvinyl acetate), with the absorption capacity of other materials reported in the literature, such as cardboard, newsprint, egg trays, Ecovio (composites reinforced with rice and wheat husks), as well as textile and wood fibers. Ecovio emerges as a leading polymeric material in the search for sustainable alternatives to conventional plastics [46]. Ecovio's manufacturing process is based on renewable raw materials, such as corn starch and polylactic acid (PLA), making it an environmentally friendly option. The results reported in the literaure for Ecovio composites reinforced with rice husks exhibited the lowest water absorption, with an average value of 43%. On the other hand, materials reinforced with wood fibers showed the highest water absorption, with an average of 65%. These variations in water absorption can be attributed to differences in the structure and chemical composition of the raw materials used [46].

Paper-based materials, such as cardboard, wastepaper, and newsprint, exhibited extremely high levels of water absorption, with values more than 300%. This finding underlines the importance of considering moisture resistance when selecting materials for specific applications [74].

Additionally, the fabricated composite for the present study, consisting of shredded newspaper, ground rice husk, polyvinyl acetate (Grip Bond 2), and borax (20 Mule Team Borax), showed a water absorption capacity of 68.06%. This indicates an intermediate performance in terms of moisture resistance compared to other materials presented in the reviewed literature.

Comparing the percentage of water absorption in natural and recycled insulating materials mentioned in the reviewed literature [46,74] with the developed composite, it was found to have an average water absorption (68.06%). This value is higher than other materials specifically designed to prevent water absorption, such as wheat husk/Ecovio and rice husk/Ecovio, with 43% [46]. The developed composite is prone to absorb a significant amount of water when exposed to humid conditions. However, the incorporation of rice husk and borax may provide benefits such as improved moisture resistance compared to other cellulite insulators, which may be advantageous in specific climates [75]. The water absorption exhibited by the proposed composite may indicate that it is susceptible to damage and deformation when exposed to wet conditions. Although despite the aforementioned, the studied composite compared to materials such as used paper and egg tray, it absorbs 4 times less water [74].

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3.2. Density Test

Table 3 shows the results obtained from three replicates (S1, S2, and S3) of the composition mentioned in the methodology (rice husk 9%, newspaper 14%, borax 15%, and polyvinyl acetate 62%).

Table 3. Data needed to obtain the average density.

	Mass (grams)	Volume 1 (mL)	Volume 2 (mL)	Density (g/mL)
S1	38.19	200	260	0.64
S2	34.68	200	248	0.72
S3	27.59	200	245	0.61
			Average	0.66 ± 0.06

Sample S2 shows the highest density (0.82 g/cm^3), followed by sample S3 (0.79 g/cm^3) and sample S1 (0.78 g/cm^3). The differences in density between the samples could be related to the distribution and concentration of the constituent materials, as well as to the presence of possible porosities or irregularities in the structure of the composite.

Density is a fundamental property in materials characterization, especially in engineering applications where the ratio of mass to volume is crucial to the performance and functionality of the final product. In this discussion, we compare the density of a variety of polymeric and natural materials.

The results show a wide range of densities among the materials evaluated. Polymeric materials, such as low-density polyurethane (40 kg/m^3), low density polyethylene (920 kg/m^3) and high-density polyethylene (980 kg/m^3), exhibited relatively low densities compared to natural and composite materials. Among the natural materials, cork showed a density of 120 kg/m^3, while filter wool exhibited a density of 200 kg/m^3. These density values are lower compared to polymeric materials, suggesting a higher porosity and less dense structure in these natural materials. On the other hand, wood showed a significantly higher density of 840 kg/m^3, making it a denser and heavier material compared to the polymeric and other natural materials evaluated in this study. Natural rubber also showed a relatively high density of 910 kg/m^3, making it suitable for applications where strength and durability are required [76].

As for the fabricated material, which consists of a combination of shredded newsprint, ground rice husk, polyvinyl acetate, and borax, it exhibited a density of 657 kg/m^3. This intermediate density indicates a compact structure and a balanced composition among the materials used in its manufacture. The proposed material has a lower density than silicone rubber, natural rubber, PEHD and PELD. This may be advantageous in some applications where a lighter material is required. On the other hand, the density of the proposed material is higher than cork, fiberglass, wool filter, and foamed polyurethane. However, it is still lighter than wood materials [11,76].

3.3. Flammability Test

Figure 3 shows the photographs of the six specimens (3 specimens without borax and 3 specimens with borax) after performing the flammability test.

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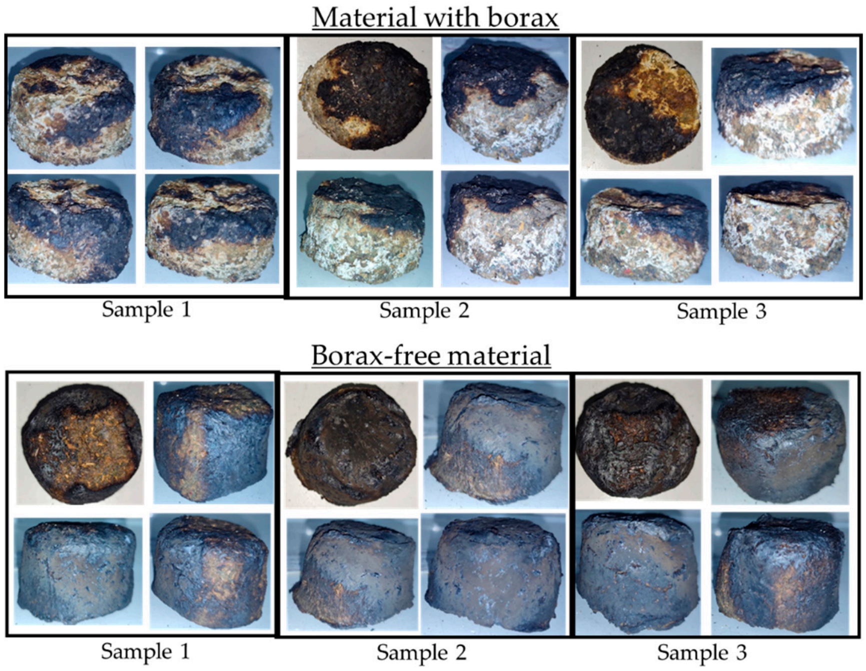

Figure 3. A. Result in the specimens of the composite material with borax. B. Result in the specimens of the composite material without borax.

The addition of borax to the composite proved to be effective in significantly improving its fire resistance compared to samples lacking borax. During the tests, it could be observed that the samples with borax presented less fire propagation, and superficial damage of the specimen. On the other hand, in the specimens without borax, the fire spread more rapidly over the entire surface and affected the specimen internally, showing a lower fire resistance capacity. These results indicate that borax in the material created is a fireproofing agent, which is why it plays a fundamental role if it is to be placed or used in a place prone to catch fire, such as buildings, vehicles, electronic devices, among others.

3.4. Fungi Growth Test

Table 4 shows the results of the Simplate technique performed on three samples with borax and three samples without borax.

Table 4. Results of the growth assay using the Simplate Technique for enumeration of fungi and yeasts.

Material with borax	P	C	D	Fungi and yeast count (UFC/mL)
Sample 1	0	<1	1	<1 *
Sample 2	0	<1	10^{-1}	<1*
Sample 3	0	<1	10^{-2}	<1*
Borax-free material				
Sample 1	84	<738	1	< 730 **
Sample 2	84	<738	10^{-1}	<7380 **
Sample 3	84	<738	10^{-2}	<73 800 **

No. of positive wells (P)
Most Probable Number of Colony Forming Units per plate (C)
Dilution Factor (D)
Colony Forming Unit (CFU)

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*There was no microbial growth in the three dilutions performed (D, 10^{-1}, 10^{-2}). **There was microbial growth in all 3 dilutions. (D, 10^{-1}, 10^{-2}); being the limit of detection of microorganisms higher than that of the technique used.

Table 4 shows the fungal and yeast counts for samples of material with borax and without borax, in different test tubes and dilutions. In the samples of mate-rial with borax, it is observed that there was no microbial growth in the three dilutions performed (D, 10^{-1}, 10^{-2}), indicated by "<1" or "<1" or "<1" Colony Forming Units (CFU) per mL. This suggests that the presence of borax in the material may have an inhibitory effect on the growth of fungi and yeasts.

In contrast, in samples of material without borax, a significant growth of fungi and yeasts was observed at all dilutions. The CFU counts per mL are higher, indicating a higher concentration of microorganisms compared to the samples of material with borax.

It is important to note that the detection limit of microorganisms for this technique is higher than the technique used in this study. This means that it is possible that the CFU counts are underestimated and that the actual presence of fungi and yeasts is higher than reported (only for the case of samples without borax).

Overall, these results suggest that the presence of borax in the composite material may have an inhibitory effect on the growth of fungi and yeasts. However, it is necessary to consider that these results were obtained using a specific technique and that there could be differences in the sensitivity and specificity of other microbiological counting techniques.

These findings are consistent with previous research that has pointed out the antimicrobial potential of borax [12,57,77]. However, additional studies are required to better understand the exact mechanisms of inhibition and to evaluate the safety and efficacy of the composite material in relation to microbial growth.

The method used, the Simplate Technique for enumeration of fungi and yeasts according to the official AOAC 2002.11 method, is a total enumeration technique that does not focus on identifying specific species of fungi and yeasts. Instead, it is used to determine the presence and total amount of these microorganisms in the analyzed sample. Since our objective was to evaluate composite behavior with and without borax to the general presence of fungi and yeasts, to obtain a total count, rather than to identify individual species.

4. Conclusions

The water absorption exhibited by the studied composite may indicate that it is susceptible to damage and deformation when exposed to wet conditions. Although this material is prone to absorb a significant amount of water when exposed to humid conditions, it absorbs 4 times less water compared to materials such as used paper and egg tray. The incorporation of rice husk and borax may provide benefits such as improved moisture resistance compared to other cellulite insulators.

The average density obtained was 0.66± 0.06 g/mL, which indicates an intermediate density compared to other polymeric and organic materials. This characteristic can be advantageous in applications where a balance between strength and lightness is required. This value is higher than other materials specifically designed to prevent water absorption.

The addition of borax provides an effective barrier against fire and holds promising behavior in terms of fire resistance. These findings support the potential application of the composite as thermal insulation of walls, for its fireproofing property. The material with borax exhibits inhibition of fungal and yeast growth, while the material without borax shows significant growth of these microorganisms. These results provide relevant information for the microbiological characterization of the composite material and may be useful in future research and industrial applications.

The developed material has an intermediate density and water absorption compared to other polymeric materials used as insulators. This characteristic presents advantages in applications that demand a balance between strength and lightness. This research aims to promote the use of materials considered as agro-industrial waste in our country, demonstrating their potential and applicability in different areas, across various engineering domains, including the production of lightweight components, construction panels, sustainable packaging, and others.

It is important to address the impact and contribution of this kind of studies, as an innovative and sustainable solutions that take advantage of local resources and reduce dependence on conventional materials with a high environmental impact.

Author Contributions: Conceptualization, SG-S; methodology, NM-C; validation, SG-S and NM-C; formal analysis, SG-S and NM-C; investigation, SG-S; resources, SG-S and NM-C; writing—original draft preparation, SG-S and NM-C; writing—review and editing, SG-S and NM-C; visualization, SG-S; supervision, NM-C; project administration, NM-C; funding acquisition, NM-C. All authors have read and agreed to the published version of the manuscript.

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