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Research Article

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Exploring the Use of Agro Biowaste Cellulosic Fibers as a Potential Drywall Panel Board Material for Sustainable Building Use

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Abstract

This research explored the thermal conductivity (k value) and thermal resistivity (R-value) of bio-waste cellulosic fibers for potential application in drywall boards (DB) to address environmental concerns. Six (6) formulations were tested, incorporating rice and banana crop wastes, as well as paper and carton boards, mixed with plaster of Paris binder and perlite powder as fillers. Specifically, the formulations were: *P-1 (plaster of paris), P-2 (plaster of paris and perlite), WR (waste paper and rice straw), WB (waste paper and banana fiber), RB (rice straw and banana fiber),* and *lastly, WRB (waste paper, rice straw and banana fiber)*. Results showed that formulations containing rice straw and banana fiber (RB) exhibited the most promising thermal properties, with RB outperforming common commercial drywall boards in terms of R-values. RB also showed favorable moisture absorption rates. However, all formulations had higher water absorption rates than expected. The study concludes that RB has potential as an interior drywall board due to its insulation properties and recommends further research into additional properties such as acoustics and fire resistance. Despite water absorption concerns, RB remains a viable option for environmentally-friendly construction materials.

Keywords: *Thermal Conductivity; Thermal Resistivity; Drywall Boards; Cellulosic Fibers; Banana; Rice straw*

Abbreviations: DB: drywall board; P-1: plaster of Paris; P-2: plaster of Paris and Perlite; WR: waste paper and rice straw; WB: waste paper and banana fiber; RB: rice straw and banana fiber; and WRB: waste paper; Rice straw and banana fiber.

Introduction

Through the years insulation products used in the construction industry has significantly improved due to technology. This research is specific in exploring the thermal resistance and conductivity of various agro-wastes materials, which are prime agricultural products of Mindanao in order to address also the optimal use of these wastes.

In a study conducted by Gertrude in 2009 entitled "Thermal Properties of Selected Materials for Thermal Insulation Available in Uganda," they investigated thermal properties of clay, ash, sugarcane fiber, banana fiber, sawdust and charcoal dust. Results showed that all the studied samples were good insulating materials having thermal conductivities which ranged from 0.08 to 0.55 Wm-1K-1. The research had only focused on these materials as individual entities and not as an integral part when combined with building materials. As recommended by the researcher hereof, there are other thermal insulating materials which can be used and can be further researched such as paper, cotton lint, and other cellulosic materials.

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The Ecological Solid Waste Management Act of 2000 of the Department of Trade and Industry requires researches on existing markets for recycling of materials, particularly agro waste by-products. The research must include inventory of existing markets for recyclable materials, product standards for recyclables, and recycled materials. Therefore, infrastructure or the construction industry becomes the key destination for recycled materials.

This research study made use of cellulosic fibers from waste paper and agro-wastes in the production of drywall boards. These agro-wastes are extracted from rice and banana crops that are locally and highly cultivated in Mindanao. This bio-waste was found to contribute to problems related to the environment. Among the strategies to address this issue was by converting these wastes into useful products. In making that attempt on this research, the agro waste were not only utilize but even further improved into higher quality materials.

This research aims to explore the thermal insulating property and quality of bio-waste cellulosic fiber. The thermal conductivity and resistivity of the material calculated by initially conducting an experiment and calculate results. The experimental set-up made use of the Disc Lee's Method. Other physical properties such as moisture, water absorption, and sensible heat gain were also tested.

Materials and Methods or Experimental Procedures

The materials and equipment used in this experimental process for the raw materials were the ff: plaster of paris, perlite, water, rice straw fiber, banana fiber, carton and paper shreds. Followed by equipment which were the ff: 5 1/2 "dia. and ½" thk. Steel-form, Low density polyethylene (LDPE) Film, lubricant, Vernier calliper, mechanical blender and digital weighing scale.

After this preparation, the extraction of rice straw and banana fibers were done, which consisted of sun drying, disintegrating of fibers from 5mm to 25mm length using a mechanical blender and then sieved and weighed according to required percentage weight. The waste papers were also sorted, shredded, soaked and also weighed according to required percentage weight. The proposed formulation sample for the bio waste dry wall panel of the experiment were then prepared according to the ff percentage:

Formulation Sample (Coded as follows)	Ratio of Bio Waste Drywall Material Composition
P-1 (only plaster of paris)	100% Plaster of Paris
P-2 (only plaster of paris and perlite)	70% Plaster of Paris 30% Perlite
WR (with waste paper and rice straw fiber only)	70% Plaster of Paris 15% Perlite 7.5% Waste Paper 7.5% Rice Straw Fiber
WB (with waste paper and banana fiber)	70% Plaster of Paris 15% Perlite 7.5% Waste Paper 7.5% Banana Fiber
RB (with rice straw and banana fiber)	70% Plaster of Paris 15% Perlite 7.5% Rice Straw Fiber 7.5% Banana Fiber
WRB (with waste paper, rice straw and banana fiber)	70% Plaster of Paris 15% Perlite 5% Waste Paper 5% Rice Straw Fiber 5% Banana Fiber

Table 1: *Percentage Formulation of Cellulosic Fibers.*

Following the percentage mixture as shown in Table 1, the ingredients were then mixed accordingly with water. After achieving a fine thick slurry mixture was achieved for each of the formulation, each of this was poured and formed into a steel-form with 5 1/2 inches diameter and ½ inch thk. depth.

Lubricant was first applied on the steel form before all the formulation were poured and then covered with LDPE film then levelled plain.

Determination of moisture content and water absorption

The material samples were weighed and then placed to a circulated oven at a temperature of 90±2°C for 1 hour and cooled to room temperature in a desiccator for 30 minutes. Oven drying was repeated until mass was constant to 0.01 differences. The percentage of moisture content of the material samples when conditioned at 50±5% relative humidity and a temperature of 23±2°C was determined. Moisture percent was calculated using the ff formula:

$$M\% = \frac{|Initial\ Weight - Final\ Weight|}{|Final\ Weight|} \times 100$$

Following the determination of percentage of moisture content was the water absorption test to determine the tendency of the material to absorb at a certain span of time. The increase in mass of the material sample expressed in percentage of its dry mass after immersion in water for a specified period time was taken. Each material sample was submerged for 24 hours in clean water at room temperature and then removed from the water, wiped with a damp cloth and weighed. Water absorption percentage was calculated using the ff formula:

$$M\% = \frac{|W_2 - W_d|}{|W_d|} x\, 100$$

Where: W_s is the weight of saturated samples in grams and; W_d is the weight of dry samples in grams

Determination of Thermal Conductivity and Resistivity

The Lee Disc method was used in determining the thermal conductivity and resistivity of the six different material formulations presented in Table 1 and also the rate of cooling of the disc. The ff formulas were used in the experiment:

Rate of cooling is:

$$Rate\ of\ cooling = \frac{dT}{dt}$$

Where: dT is the change of temperature; and dt is the change of time

Thermal Conductivity is k which is:

$$k = \frac{m_{SS}\, c_{SS}\, d_{SS}\, (dT/dt)}{A_{MS}\,(T_1 - T_2)}$$

Where: k is the thermal conductivity;
mss is the mass of the stainless-steel disc;
css is the specific heat of the stainless-steel disc; dss is the thickness of the stainless-steel disc;
(dT/dt) is the rate of cooling of the stainless-steel disc; AMS is the area of the material sample; and
(T1 – T2) is the temperature difference across the material sample
The unit is in metric, W/m-°K, watts per meter- degree Kelvin. Thermal Resistivity is R which is:

$$R = \frac{x}{k}$$

Where: R is the thermal resistivity;
x is thickness of the material sample;
k is the thermal conductivity of the material sample; R-Value rating are in ft2·h·°F/Btu

Computation for building heat gain computer simulation

Lastly, a comparative computation were done for the estimated cooling loads of all six formulations against commercial drywall boards and masonry units using the building heat gain computer simulation model. A housing unit model with 56 square meter floor area as shown in figure 1 was the sample used the comparative computation of the total building heat gain. The following heat loading were assumed 50% of the appliance load (470 W) for the living area and another 50% for kitchen appliances with an average of six people in sedentary position within the unit. The temperature assumed around the vicinity of the unit were an indoor temperature at 25°C., outdoor temperature at 35°C and the daily range at 9 K.

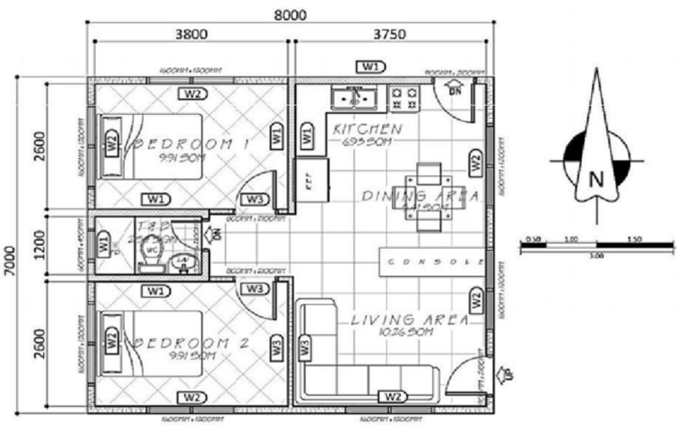

***Figure 1:** 56-SQM Housing Unit Model.*

Computations in determining the heat gain included the ff: (a) glass and windows, (b) doors (c) exterior walls (d) roof (e) interior partitions (f) infiltration and (g) appliances and body heat loads. All computations were as per ASHRAE Handbook requirement.

Results and Discussion

Rate of Cooling of Stainless-Steel Disc T-202

The samples were tested using a Lee's Disc Apparatus.

All material formulations were placed between the steam chamber and the stainless-steel disc T-20, which served as an insulator that reduced the heat transfer from the heat source (steam chamber) to the stainless-steel disc. The rate of cooling in the experiment tested the rate of the stainless-steel disc to cool from high temperature to steady state temperature testing each of the formulation samples with the same time interval. In table 2 below the average rate of cooling of stainless-steel disc T-202 in each formulation sample were presented.

Formulation Sample	Average Rate of Cooling (°C/sec)
P-1	0.0140
P-2	0.0111
WR	0.0078
WB	0.0085
RB	0.0075
WRB	0.0091

Table 2: *Average Rate of Cooling of Stainless Disc T-202.*

The formulation samples which contained rice straw, banana fiber, and/or waste paper, exhibited a lower rate of cooling compared to pure plaster of Paris and/or Perlite. The rice and banana fiber formulation (RB) showed the lowest rate of cooling at 0.0075°C/sec. This means that the presence of bio-waste cellulosic fibers actually slowed down the rate of heat transfer within the stainless-steel disc.

Based on the formula of rate of cooling, it can be derived that it is directly proportional to the value of the thermal conductivity while the change in temperature is inversely proportional to it, which means that as the rate of cooling decreases the thermal conductivity decreases and vice versa. On the other hand, as the change in temperature increases, thermal conductivity also decreases. Hence, the rice straw and banana fiber (RB) formulation is a poor conductor but a good thermal insulator.

Percentage of Moisture and Water Absorption of the Formulation Samples

In order to determine the performance of the various cellulosic fiber formulation samples, when exposed to water and humidity, its average rate of moisture and water absorption were taken. In Table 3 the obtained average moisture and water absorption percentage of each formulation sample were computed. The moisture and absorption rate were verified and compared from the recognized standard range level of commercial building boards. The results were as follows:

The average effective moisture absorption of commercially available drywall boards in the market ranges in less than or equal to 5% rating while the water absorption rate is from 10 to 45%. All the formulation samples, P-1, P-2, WR, WB, RB, and WRB surpassed on moisture absorption rating but failed in water absorption.

	Average Moisture Absorption	Effective Moisture Absorption Rate (≤5%)	Average Water Absorption	Effective Water Absorption Rate (10-45%)
P-1 (only plaster of paris)	0.4902%	significant	69.68%	insignificant
P-2 (only plaster of paris and perlite)	0.4078%	significant	95.71%	insignificant
WR (with waste paper and rice straw fiber only)	1.9795%	significant	160.99%	insignificant
WB (with waste paper and banana fiber)	1.7298%	significant	156.07%	insignificant
RB (with rice straw and banana fiber)	2.4847%	significant	107.76%	insignificant
WRB (with waste paper, rice straw and banana fiber)	2.1326%	significant	135.97%	insignificant

Table 3: *Moisture and Water Absorption Rate of the Formulation Samples.*

Thermal Conductivity and Resistivity of the Formulation Samples

The computed thermal conductivity and resistivity values based from the results of the experimentation are presented in Table 4. Included also in Table 4 are the thermal conductivity and resistivity values of the commercially available one-half inch thick drywall panel boards. The obtained thermal conductivity coefficients of the formulation samples, WR, WB, RB, and WRB, were lower by half against P-1 and P-2. Compared to all of the samples, RB exhibited the lowest thermal conductivity coefficient of 0.0969 W/m-°K but with the highest thermal resistivity coefficient of 0.8756 h-ft2-°F/BTU.

	Thermal Conductivity (W/m-°K)	Thermal Resistivity (h-ft2-°F/BTU)
Plaster of Paris (P-1)	0.21	0.36
Plaster of Paris and Perlite (P-2)	0.16	.049
Waste Paper and Rice Straw (WR)	0.11	0.83
Waste Paper and Banana Fiber (WB)	0.12	0.67
Rice Straw and Banana Fiber (RB)	0.10	0.88
Waste Paper, Rice Straw and Banana Fiber (WRB)	0.11	0.68
Fiber-Cement Board	0.58	0.13
Gypsum Wallboard	0.17	0.45
Particle Board	0.11	0.52
Hardboard	0.11	0.69
Plywood	0.15	0.62

Table 4: *Thermal Conductivity and Resistivity of the Formulation Samples and Commercial Drywall Boards.*

The lower the thermal conductivity rating the better is the thermal insulating quality. Hence, as shown in Table 4 the formulation sample RB had the better thermal insulating property compared to the commercially available boards and with the rest of the formulations.

Moreover, the density of the material is also related to thermal conductivity. The presence of fibers in the bio-waste formulation samples makes the bio-waste drywall board denser. The P-1 and P-2 samples were denser than WR, WB, RB, and WRB and the denser the material the more it tends to transfer the heat rapidly and hence becomes a good conductor of heat.

Among the commercially available drywall panel boards in the market, the fiber- cement boards have the highest thermal conductivity value, which means that it can transfer heat faster compared with other commercially available panel board products and compared to other bio-waste cellulosic formulation samples. RB has the lowest thermal conductivity with a 1.7 rating, which is much lower than the Gypsum board. However, the thermal resistivity of RB is higher than the Gypsum board. All the remaining formulation samples other than RB can very well compete with majority of the commercially available drywall panel board in the market.

Building Heat Gain Analysis using Cooling Load Calculation

The final investigation in this study was to analyze the overall thermal performance of both the formulation samples and commercial boards. The method used in the study was a computer simulation model of a fifty-six square meter housing unit. The prime objective of the computer simulation was computing for the building heat-gain within interior spaces by using each of the bio waste drywall boards

Partition Wall Material	Exterior Walls (W1) U- Value *w/m^2-K*	Interior Partitions (W2) U-Value *w/m^2-K*	Total Sensible Heat Gain *kW*
Bio Waste Drywall Board	0.66	0.79	22.46
Gypsum Drywall Board	0.73	0.90	22.57
Ordinary Plywood	0.70	0.86	22.52
CHB with Cement Plastering	2.87	2.47	24.88

Table 5: *Summary of Computed Exterior and Interior Wall System U-Value, and Total Sensible Heat using BWDB, Gypsum Drywall Board, Ordinary Plywood, and CHB as Walls Systems.*

Thermal transmittance, also known as, U-value, is the total heat transfer. Among the wall panel systems, WB (formulation) wall system which were made up of rice straws and banana fibers, exhibited the lowest U-value in both exterior and interior walls. A Low U-value means that a system is a good inhibitor of heat from a heat source. Hence, the panel system is a good thermal insulator. And among all the wall systems used in the simulation, the WB formulation sample exhibited the lowest total sensible heat gain used in the simulated model of a housing unit.

Conclusion

In conclusion, RB (rice straw and banana fiber) formulation has consistently resulted with the best insulating properties. From the results of the rate of cooling, RB has exhibited the lowest rate of cooling of .0075, followed by WR at .0078 and P-1 which turned out the highest at .0140 degree Celsius per second. For the test with moisture absorption, RB has the most effective percentage at 2.48, following was WRB at 2.14 and with plaster of Paris as the least effective with value percentage at .49.

More so in terms of thermal conductivity, all of the formulations with bio cellulosic fibers garnered lower compared to both non-bio cellulosic formulations and commercial drywall boards. Consistently RB has the lowest value at .10 followed at .11 for three samples, which are the WR, particle board and hardboard. The highest value for thermal conductivity was .21 for P-1. Moreover these results were validated by the values acquired for the results in thermal resistivity. The formulation with the best insulating quality has the highest thermal resistivity, which is once again RB at .88. The lowest thermal resistivity was the fiber cement board.

Finally, the outcome for the U-value, which is the total heat gain transfer still resulted RB with the highest at .69 w/m2 –k for exterior wall and .79 w/m2-k for partition wall with total sensible heat gain at 22.46 kw. Among the commercially available products ordinary plywood exhibited the better at 22.57, but with RB still had the best U-value rating for thermal insulation. The best application for the RB as a Bio Waste Drywall Board would only be for interiors considering that its water absorption resulted to a higher rate.

For further study, fire rating or resistivity can be explored to add to the baseline data to the new material. The packaging of this new bio waste drywall board and added measures to protect from breakage particularly in handling during transport can also be done.

References

1. Borgnakke, Claus & Sonntag, Richard (2009). Fundamentals of Thermodynamics: Seventh Edition. John Wiley & Sons. United States of America.
2. Chemistry of everyday life: What is cellulose? (2014). <http://antoine.frostburg.edu/chem/senese/101/consumer/faq/what-is-cellulose.shtml>. Date Retrieved: September 11,
3. Gertrude, Ayugi. (2011). Thermal properties of selected materials for thermal insulation available in Uganda
4. (2009/HD13/15595U). A Dissertation for the Award of a Degree of Master of Physics Science. Makerere University.
5. Giancoli, Douglas. (2005). PHYSICS: Principles with Applications – 6th Edition. Pearson Education Inc. United States of America.
6. Hall, Dennis & Giglio, Nina. (2010). Architectural Graphic Standards for Residential Construction. John Wiley & Sons.
7. Hogben, Lancelot. (1951). "Printing, Paper and Playing Cards". Bennett, Paul A.(ed.) Books and Printing: A Treasury for Typophiles. New York: The World Publishing Company. 15-31. p. 17.
8. Lee's Disc Apparatus (Theory): Heat & Thermodynamics Virtual Lab: Physical Sciences: Amrita Vishwa Vidyapeetham Virtual Lab. <http://amrita.vlab.co.in/?sub=1&brch=194&sim=353&cnt=1>. Date Retrieved September 10, 2013.
9. Mieck KP, Nechwatal A., Knobelsdorf, C. (1994). "Melliand Textilberichte". Vol. 11, pp 892–898.
10. Mukherjee, PS & Satyanarayana, KG (1986). Structure and Properties of Some Vegetable Fibres. Journal of Materials Science. 21: 51–56.
11. (2009). Crop Production Statistics. FAO Stat. FAO Statistics. Retrieved 30 March 2011.