British Journal of Applied Science & Technology
2(3): 227-239, 2012

SCIENCEDOMAIN *international*
www.sciencedomain.org

Experimental Investigation of Building Thermal Insulation from Agricultural By-products

Krishpersad Manohar[1*]

[1]*Mechanical and Manufacturing Engineering Department, The University of the West Indies, St. Augustine Trinidad and Tobago, West Indies.*

Author's contribution

The work reported in this study was the individual research and experimental findings of the author. The laboratory facilities used were that of the Mechanical and Manufacturing Engineering Department of The University of the West Indies located at St. Augustine, Trinidad and Tobago, West Indies. All the Experiments were designed and performed by the author.

Research Article

Received 1st May 2012
Accepted 31st May 2012
Online Ready 8th June, 2012

ABSTRACT

The thermo-physical properties of environmentally friendly biodegradable agricultural by-products, oil palm, coconut and sugarcane fiber, were investigated for use as potential building thermal insulation. Thermal conductivity measurements were conducted on 51 mm thick, 254 mm square test specimens in accordance with ASTM C518 where the apparent thermal conductivity, ª, was measured under steady-state one-dimensional test conditions with heat flow upwards. The test apparatus provided λ measurements with ±0.2% repeatability and ±0.5% reproducibility within the range 0.005 W/m.K to 0.35 W/m.K. For all three materials, experimental data at various mean test temperatures show the thermal conductivity variation with density followed the characteristic hooked shape associated with loose-fill fibrous insulation. Test results indicated that sugarcane fiber with the lowest solid fiber density of 686 kg/m^3 exhibited the lowest apparent thermal conductivity of 0.04610 W/m.K and a trend of increase in solid fiber density of the material reflected an increase in the minimum ª of the fibrous batt. The minimum λ for the materials ranged between 0.04160 W/m.K to 0.05784 W/m.K over the mean temperature ranges 15.6°C to 32°C. These λ values are within the range 0.02 W/m.K to 0.06W/m.K which is normally used for thermal building insulation.

**Corresponding author: E-mail: krishpersad.manohar@sta.uwi.edu;*

Keywords: Coconut fiber; sugarcane fiber; oil palm fiber; building insulation; thermal conductivity.

1. INTRODUCTION

Maintaining a comfortable indoor building environment is fast becoming one of the largest single consumers of energy (Pasic et al., 2010; Omar and Mohammed, 2004). In many countries worldwide this trend is leading to increased environmental pollution and global warning problem due to the fossil fuel used on daily basis to maintain comfort inside buildings (Saidur, 2009). Energy demand in buildings can be significantly reduced with the use of thermal insulation. One technique for reducing the demand of air conditioning is to apply thermal insulation in walls and roofs (Panyakaew and Fotios, 2008). Effective thermal insulation material is the largest building energy conservation component that directly results in decrease in the cost of cooling and the resultant decrease in pollution of the environment (Radhi, 2008; Lombard et al., 2008). However, development of new thermal insulation materials requires knowledge of the thermo-physical properties of the material.

Commonly used inorganic building insulating materials include mineral wool, lightweight and cellular concretes, foam glass, fiberglass, plastic foams, Styrofoam and expanded perlite (Manohar and Yarbrough, 2003). However, besides their long-term financial benefit the use of inorganic insulating materials may be harmful to human health and body and also cause environmental pollution, such as emissions of toxic gas and particle, and stick to skin (Liang and Ho, 2007). Also, the production of these materials is highly energy intensive and the eventual disposal is an environmental hazard (Panyakaew and Fotios, 2008). Therefore, alternative materials having same or better properties as the conventional material need to be explored as it can offer lower cost (Mohd Yuhazri et al., 2011). One of the alternative materials that is been widely investigated is natural fiber. This material is very easy to get and it is cheap (Guilbert et al., 2011). This need has prompted research in the direction of renewable fibrous thermal insulation made from trees, plants or animals. These naturally occurring materials has the ability to regenerate itself, requires less energy for production and biodegrade easily when disposed as waste which will significantly reduce the negative environmental impact (Manohar, 2012). In many countries increased interest in the use of agro-fibers as building thermal insulation is being researched. Published work from many different regions of the world indicate the use of agricultural materials, such as, coffee husk and hulls, wood, waste tea leaves, coconut husk, bagasse, cotton and oil palm for particle board production (Tangjuank, 2011; Manohar et al., 2006; Panyakaew and Fotios, 2008). Using agricultural by-products as thermal insulation also generates economical development for farming and rural areas (Panyakaew and Fotios, 2008; Ramli, 2002).

If managed effectively renewable biodegradable building thermal insulation can have a net reduction in CO_2 emissions over the life cycle and be continuously replenished. A cheap, reliable and abundant supply of biodegradable fibrous materials can be obtained as waste by-products from many commercial agricultural processing industries (Rodriguez et al., 2011). Materials such as coconut fiber, sugarcane fiber, cotton, wheat straw, date palm leaves, oil palm fiber and others consist of lignocelluloses fibers and are promising alternatives for use as biodegradable, renewable, environmentally friendly building thermal insulation (Zhou et al., 2010; Al-Juruf et al., 1988).

However, the main indicator of the quality of an insulating material is the thermal conductivity. Accurate determination of the thermal conductivity requires special equipment (Khomenko, 1974; Laser Comp, 2006). Also, the effective thermal conductivity of a fibrous material varies with bulk density (Bankvall, 1974; Bhattacharyya, 1980). The optimum density of the material at which minimum thermal conductivity is exhibited is required for best thermal and economical use of the material (Stephenson and Mark, 1961). This study investigates the physical properties and the variation of thermal conductivity with bulk density of oil palm fiber, sugarcane fiber and coconut fiber and their potential for use as building thermal insulation.

2. TEST MATERIALS

The agricultural by-products in this study were selected from the oil palm, coconut and sugarcane industry. The residual waste products of mature crops in each case consisted of a high fibrous content of cellulose lignin fibers. The high lignin content made the fibers relatively strong. Three stock piles of 25 kg each of oil palm, coconut and sugarcane fiber were obtained from the respective agricultural processing companies. The fibers were air dried for one month and then allowed to acclimatize to laboratory conditions of an average of 28°C, 60% relative humidity for another week. In determining the physical properties of the material samples were randomly selected from the respective stockpile.

2.1 Fiber Diameter Measurement

The mean fiber diameter, diameter range and spread for the three materials were determined from two independent sources. Fiber diameter measurements were conducted in the laboratory with the ONO-SOKKI GS-322 linear gauge sensor (Fig. 1).

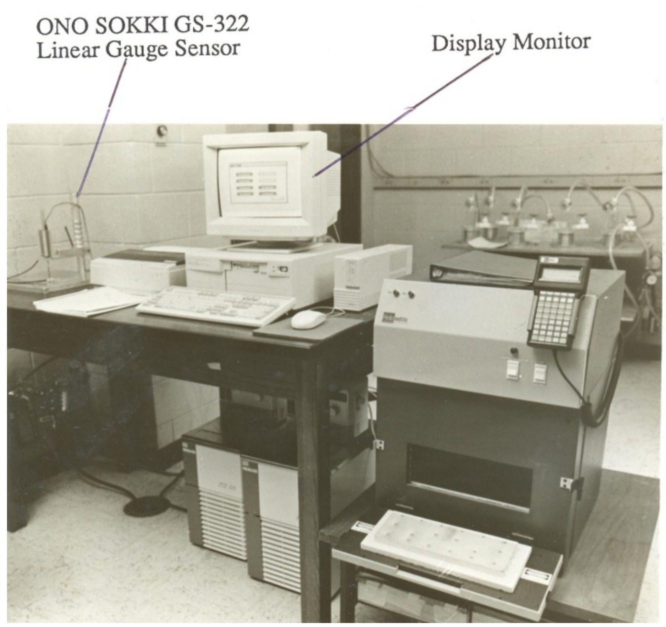

Fig. 1. ONO-SOKKI GS-322 linear gauge sensor apparatus

This instrument provided an automatic digital display up to 10^{-3} mm with an accuracy of ± 0.0005 mm. For each material 100 randomly selected fiber strands were tested and the data recorded and analyzed. The results are shown on Table 1. Another set of fiber diameter measurements were conducted on all three materials by the Caribbean Industrial Research Institute (CARIRI). They used a Nikon V-12 Profile Projector at a magnification of 10 to measure the fiber diameter. This instrument provided readings up to 0.0001 mm with an accuracy of ± 0.00005 mm. In this case four batches of 25 fiber strands each were measured for the respective material and the data recorded and analyzed. The results are shown on Table 2.

Table 1. Fiber diameter measurements; ONO-SOKKI GS-322

	Oil Palm Fiber	Coconut Fiber	Sugarcane Fiber
Number of fibers	100	100	100
Mean Fiber Diameter	0.240 mm	0.262 mm	0.302 mm
Standard Deviation	7.11×10^{-2}	9.05×10^{-2}	6.12×10^{-2}
Largest Diameter	0.389 mm	0.502 mm	0.459 mm
Smallest Diameter	0.137 mm	0.104 mm	0.157 mm

Table 2. Fiber diameter measurements; nikon V-12 profile projector

	Oil Palm Fiber	Coconut Fiber	Sugarcane Fiber
Number of fibers	100	100	100
Mean Fiber Diameter	0.2398 mm	0.2744 mm	0.3120 mm
Standard Deviation	5.21×10^{-2}	1.26×10^{-1}	7.53×10^{-2}
Largest Diameter	0.4190 mm	0.5790 mm	0.5400 mm
Smallest Diameter	0.1170 mm	0.0925 mm	0.1560 mm

2.2 Solid Fiber Density Measurement

The density of the solid fiber material was determined from specific gravity measurements in accordance with ASTM D-792. The specific gravity measurements were found by conducting buoyancy tests with water as the medium for immersion. The equipment consisted of a SARYORIUS electronic balance that displayed values up to 10^{-2}g with an accuracy of ±0.005g. The sample holder was made from fine-mesh nylon attached to a metal frame sinker. The metal frame sinker, while resting on the balance, was used to immerse the specimen completely into the water bath. A schematic of the test apparatus is shown on Fig. 2. With no specimen in the sample holder, the sinker and sampler holder were immersed in the water bath and the balance set to zero. The sinker with sample holder was then withdrawn from the water bath and a randomly selected weighed fibre specimen placed in the holder.

The sinker with sample holder and specimen was then immersed into the water bath and the apparent mass recorded. Readings were recorded within 10 seconds of immersion of the fibre in the water so as to minimize water soaking in the fibres. The specific gravity was calculated using the equation:

$$Specific\ Gravity = \frac{Mass\ in\ air}{mass\ in\ air - mass\ in\ water}$$

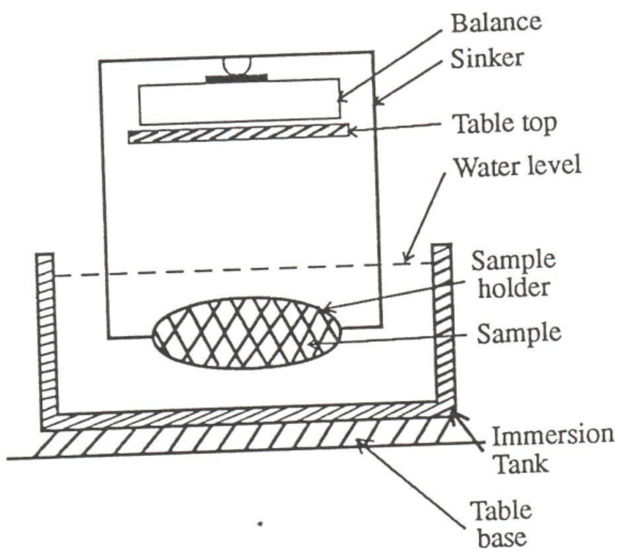

Fig. 2. Schematic of specific gravity measurement apparatus

And the density calculated using the equation:

$$Density = (Specific\ gravity \times 997.6)\ kg/m^3$$

Where 997.6 kg/m^3 is the density of water at 24°C.

For each material buoyancy, measurements were conducted on ten randomly selected specimens and the results are shown in Tables 3-5.

Table 3. Buoyancy test results and solid fiber density calculation for oil palm fiber

Specimen #	Mass in air (g)	Mass in water (g)	Specific gravity	Solid fiber density (kg/m^3)
1	8.50	-2.45	0.7762	774.3
2	11.82	-2.83	0.8071	805.2
3	10.23	-2.60	0.7972	795.3
4	7.89	-2.12	0.7884	786.5
5	8.61	-2.14	0.8009	799.0
6	10.25	-2.40	0.8101	808.2
7	8.44	-1.95	0.8124	810.5
8	10.61	-2.47	0.8109	800.0
9	9.58	-2.42	0.7986	796.7
10	12.36	-3.11	0.7989	797.0

Table 4. Buoyancy test results and solid fiber density calculation for coconut fiber

Specimen #	Mass in air (g)	Mass in water (g)	Specific gravity	Solid fiber density (kg/m^3)
1	7.50	-2.03	0.7870	785.1
2	10.81	-3.71	0.7445	742.7
3	12.13	-3.64	0.7692	757.3
4	6.88	-2.73	0.7159	714.2
5	6.60	-1.41	0.8240	822.0
6	9.35	-4.17	0.6916	689.9
7	8.42	-2.50	0.7711	769.2
8	13.71	-4.64	0.7471	745.3
9	7.68	-2.26	0.7649	763.0
10	11.33	-3.56	0.7609	759.1

Table 5. Buoyancy test results and solid fiber density calculation for sugarcane fiber

Specimen #	Mass in air (g)	Mass in water (g)	Specific gravity	Solid fiber density (kg/m^3)
1	8.20	-3.85	0.6805	678.8
2	9.94	-4.32	0.6971	695.4
3	13.41	-6.38	0.6776	675.9
4	7.49	-4.47	0.6263	624.8
5	8.76	-3.70	0.7031	701.4
6	12.23	-5.66	0.6836	681.9
7	9.36	-4.78	0.6619	660.3
8	10.47	-3.64	0.7420	740.2
9	11.88	-5.05	0.7017	700.0
10	9.60	-4.25	0.6931	691.4

From the data on Tables 3-5 the mean solid fiber density for oil palm, coconut and sugarcane fiber was calculated as 797 kg/m^3, 755 kg/m^3 and 686 kg/m^3, respectively.

2.3 Fiber Length Measurement

The physical length of the fibers was measured by physically straightening and recording the length on a mm measuring scale. The scale was graduated to the nearest mm and provided readings with an accuracy of ±0.5mm. For each material 200 randomly selecting fiber strands were chosen and the mean length and range determined and the physical shape of the fiber strands noted.

For oil palm fiber the fiber strands were twisted and curled in physical relation to the oil palm nut. The fiber length ranged between 30 mm to 100 mm with an average length of 72 mm.

For coconut fiber the fiber strands were twisted and curled in physical relation to the coconut nut. The coconut being physically larger than the oil palm, the coconut fiber strands was comparatively not as curled as the oil palm fiber. The fiber length ranged between 45 mm to 150 mm with an average length of 120 mm.

For sugarcane fiber the fiber strands were straight in physical relation to the sugarcane. Due to the sugarcane processing the fibers were cut. The fiber length ranged between 20 mm to 50 mm with an average length of 35 mm.

2.4 Thermal Conductivity Measurement

The thermal insulating properties of oil palm fibre, coconut fibre and sugarcane fibre were measured in accordance with ASTM C518-04, Standard Test Method for Steady-State Thermal Transmission properties by Means of the Heat Flow Meter Apparatus. The FOX 304 instrument was calibrated using NIST SRM 1450b, Standard Reference Material of the National Institute of Standards and Technology. The calibrations were done with a 20°C temperature difference between the plates with upward heat flow. Resulting values of thermal conductivity were calculated in accordance with ASTN C1045-01, Standard Practice for Calculating Thermal Transmission Properties under Steady-State Conditions. Experiments were conducted on oil palm, coconut and sugarcane fibre samples where the apparent thermal conductivity, ^{a}, was measured under steady-state one-dimensional test conditions with heat flow upwards. The test equipment used constant temperature plates 305 mm x 305 mm with centrally located 102 mm x 102 mm heat flux transducers. The test apparatus provided λ measurements within the range 0.005 W/m.K to 0.35 W/m.K with ±0.2% repeatability and ±0.5% reproducibility (LaserComp FOX 304, 2006).

Thermal conductivity measurements were conducted on 51 mm thick, 254 mm square test specimens (Fig. 3). The specimens were contained in a polystyrene specimen holder constructed from 25.4 mm thick polystyrene strips, 51 mm high (Fig. 4).

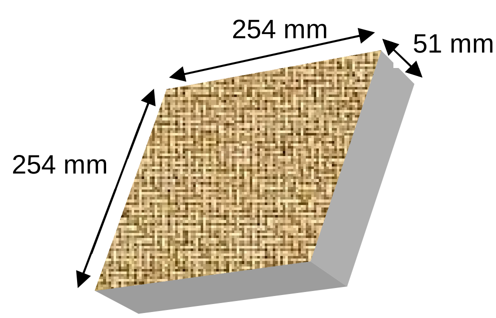

Fig. 3. Schematic of Oil Palm Fiber Test Specimen

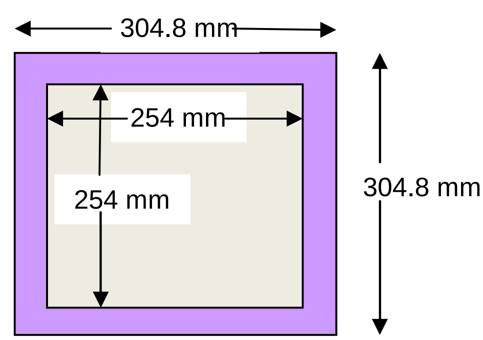

Fig. 4. Schematic of polystyrene specimen holder

Due to the compressible nature of the fibrous materials under consideration the 51 mm high rigid specimen holder was used to maintain and determine the specimen thickness. On 'Auto Thickness' mode the test apparatus closed the constant temperature plates with a pre-set clamping force against the rigid specimen holder.

2.4.1 Test specimen bulk density

The bulk density of the fibrous test specimen was determined by calculating the respective mass based on the fixed volume of the rigid specimen holder. For each material fibre was randomly selected from the respective stockpile of air-dried, laboratory conditioned material. After weighing the respective mass for the target density, the fibre was arranged uniformly within the specimen holder. The fibre strands were generally 'perpendicular to the heat flow' direction within the specimen holder forming an insulation batt.

The minimum test density for each material was determined by the lowest possible density at which the material existed under gravity without any appreciable settling. This was found by leaving the test specimen to settle over a 48 hour period. For each material samples were prepared in increments of 5 kg/m^3 starting with a minimum bulk density of 10 kg/m^3. When no settling was observed below the level of the 51 mm high specimen holder after 48 hours, this density was used as the minimum test density.

The maximum test density was determined by the pre-set clamping force of the test apparatus. When the clamping force between the constant temperature plates was not sufficient to compress the fibrous test specimen to the required 51 mm thickness the maximum test density was taken as that of the last compressible specimen.

For oil palm, coconut and sugarcane fibre specimens the minimum and maximum test density were found to be 20 kg/m^3, 40 kg/m^3, 70 kg/m^3 and 120 kg/m^3, 90 kg/m^3, 120 kg/m^3, respectively. Within the test density range specimens were prepared in increments of 10 kg/m^3.

2.4.2. Thermal conductivity experimental results

For oil palm fiber thermal conductivity tests were conducted at mean test temperatures of 20°C, 25°C and 30°C with a temperature difference of 20°C between the constant temperature plates. For these test conditions five experiments were conducted on each specimen of density 20 kg/m^3, 30 kg/m^3, 40 kg/m^3, 50 kg/m^3, 60 kg/m^3, 70 kg/m^3, 80 kg/m^3, and 90 kg/m^3. The mean values of the experimental test results for the oil palm fiber were computed and the results are shown on Table 6 and a plot in Fig. 5.

For coconut fiber thermal conductivity tests were conducted at mean test temperatures of 15.6°C with a temperature difference of 16.3°C and 21.8°C with a temperature difference of 13.2°C. For these test conditions five experiments were conducted on each specimen of density 40 kg/m^3, 50 kg/m^3, 60 kg/m^3, 70 kg/m^3, 80 kg/m^3, and 90 kg/m^3. The mean values of the experimental test results for coconut fiber are shown on Table 7 and a plot in Fig. 5.

Table 6. Experimentally determined [a] for oil palm fiber

Density (kg/m^3)	Thermal Conductivity [a] (W/m.K)		
	20°C mean temp.	**25°C mean temp.**	**30°C mean Temp**
20	0.09167	0.09466	0.09824
30	0.07576	0.07777	0.07809
40	0.06754	0.06801	0.06950
50	0.05961	0.06115	0.06316
60	0.05987	0.06006	0.06041
70	0.05730	0.05829	0.05997
80	0.05699	0.05690	0.05813
90	0.05607	0.05733	0.05796
100	0.05550	0.05690	0.05784
110	0.05580	0.05733	0.05800
120	0.05642	0.05782	0.05890

Table 7. Experimentally determined [a] for coconut fiber

Density (kg/m^3)	Thermal Conductivity [a] (W/m.K)	
	15.6°C mean temp.	**21.8°C mean temp.**
40	0.05624	0.05758
50	0.05099	0.05184
60	0.05051	0.04970
70	0.04891	0.04884
80	0.04800	0.04886
90	0.04869	0.05009

For sugarcane fiber thermal conductivity tests were conducted at mean test temperatures of 18°C, 24°C and 32°C with a temperature difference of 22°C in each case. For these test conditions five experiments were conducted on each specimen of density 70 kg/m^3, 80 kg/m^3, 90 kg/m^3, 100 kg/m^3, 110 kg/m^3 and 120 kg/m^3. The mean values of the experimental test results for sugarcane fibre are shown on Table 8 and a plot in Fig. 5.

Table 8. Experimentally determined [a] for sugarcane fiber

Density (kg/m^3)	Thermal Conductivity [a] (W/m.K)		
	18°C mean temp.	**24°C mean temp.**	**32°C mean Temp**
70	0.04977	0.05094	0.05314
80	0.04851	0.04966	0.05060
90	0.04851	0.04896	0.04947
100	0.04610	0.04680	0.04862
110	0.04909	0.04992	0.04963
120	0.04888	0.04964	0.05099

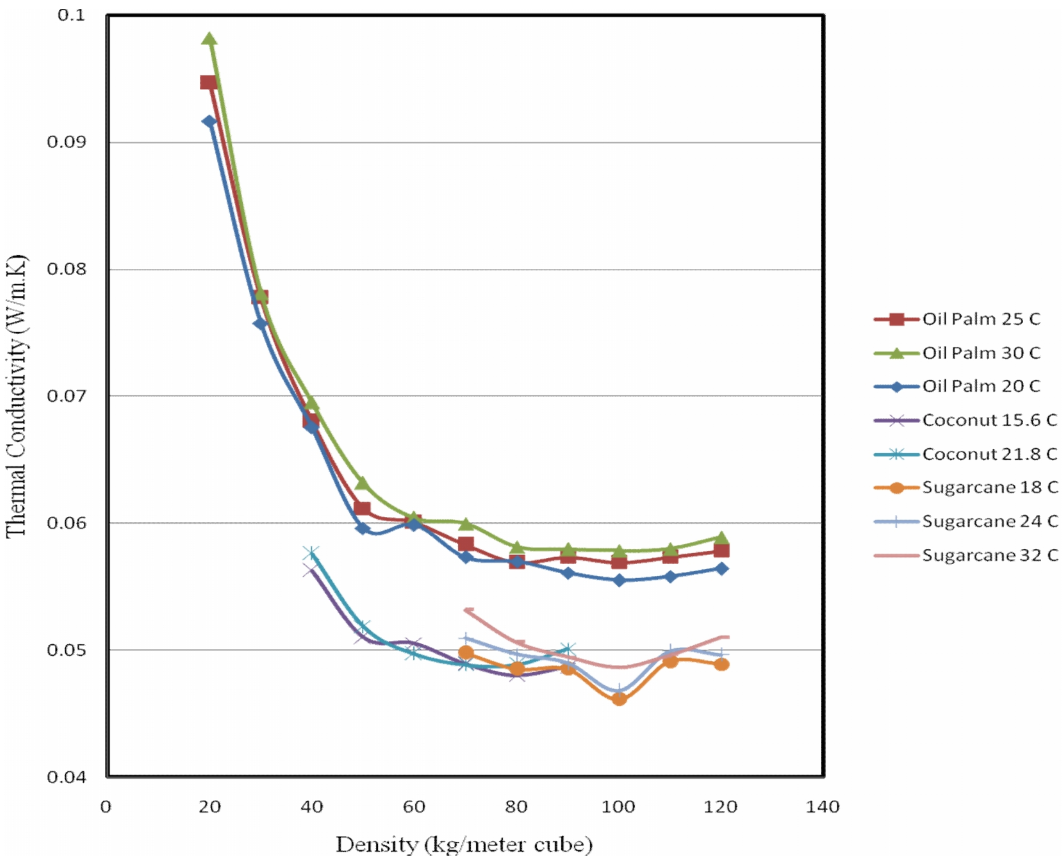

Fig. 5. Line plot of thermal conductivity variation with bulk density for oil palm, sugarcane and coconut fiber

3. DISCUSSION

The thermal conductivity experimental results for oil palm, coconut and sugarcane fibers indicated the general trend associated with loose-fill thermal insulation (Bankvall, 1974; Pratt, 1978). That is, as density increased from the minimum possible value upwards, ª decreased to a minimum and then increased. A combination of the thermal and physical properties showed that the sugarcane fiber with the lowest solid fiber density of 686 kg/m^3 exhibited the lowest apparent thermal conductivity of 0.04610 W/m.K. The solid fibre density of coconut and oil palm fibre was 755 kg/m^3 and 797 kg/m^3 and the respective minimum apparent thermal conductivity was 0.04800 W/m.K and 0.05550 W/m.K. This trend shows that an increase in solid fibre density of the material reflected an increase in the minimum ª= of the fibrous batt.

The optimum thermal conductivity for the materials under consideration is closer to the upper limit of the thermal conductivity range for building thermal insulation. This finding is consistent with loose fill materials having higher thermal conductivity than close celled thermal insulation. As naturally occurring materials there is the advantage of being environmentally friendly (biodegradable). Coupled with the fact that the source of the raw materials are waste by-products from the oil palm, coconut and sugarcane industries and are in a semi processed form for use as fibrous insulation the cost associated with the final product may be significantly lower than the production of conventional thermal insulation.

Another factor considered for thermal insulation is the weight. The physical twisted and curled property if both oil palm and coconut fiber can be the reason for these materials being able to form an insulation batt at low densities of 20 kg/m^3 and 40 kg/m^3, respectively, in comparison to the straight sugarcane fiber that showed a minimum density of 70 kg/m^3. The optimum ª=occurred at a bulk density of approximately 100 kg/m^3 for both oil palm and sugarcane fibre and 75 kg/m^3 for coconut. No correlation or trend was observed between the optimum density and thermal conductivity or solid fiber density. In comparison to the commercially available fiberglass and Styrofoam with densities between 25 kg/m^3 to 40 kg/m^3 that are being used for thermal insulation the optimum density 100 kg/m^3 is high. However, being environmentally friendly, biodegradable and the relatively low production cost are advantages.

For all three materials the experimental data at various mean test temperatures show the thermal conductivity variation with density followed the characteristic hooked shape associated with loose-fill fibrous insulation (Stephenson and Mark, 1961; Bhattacharyya, 1980; Tye, 1980). For each material λ showed an increase with mean test temperature which is consistent with the behavior of loose-fill thermal insulation. The minimum λ for the materials ranged between 0.04160 W/m.K to 0.05784 W/m.K over the mean temperature ranges 15.6°C to 32°C. These λ values are within the range 0.02 W/m.K to 0.06W/m.K which is normally used for thermal building insulation (Manohar and Yarbrough, 2003). Of the three materials investigated sugarcane fiber showed the lowest thermal conductivity followed by coconut fiber. Oil palm fiber showed the highest thermal conductivity.

As naturally occurring biodegradable materials consideration has to be given to the flammability of the material and the high density at which λ is minimum. Also, susceptibility to insect attack and fungal growth over long time periods need to be investigated.

4. CONCLUSION

- Experimental data indicated an increase in solid fibre density of the material reflected an increase in the minimum ª= of the fibrous batt.
- Oil palm, coconut and sugarcane fiber showed acceptable λ values for use as building thermal insulation.
- The optimum λ value within the 15.6°C to 32°C mean test temperature range between 0.04160 W/m.K to 0.05784 W/m.K.
- The λ increased with temperature within the test range. This behavior is consistent with loose fill insulating material.
- All three materials exhibited the characteristic hooked shape graph of thermal conductivity with density. This behavior is consistent with loose fill insulating material.
- The material has the advantage of being environmentally friendly (biodegradable) and possibly lower processing cost.
- Sugarcane fiber showed the lowest thermal conductivity followed by coconut fibre and oil palm fiber showed the highest thermal conductivity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Al-Juruf, R.S., Ahmed, F.A., Alam, I.A., Abdel-Rahman, H.H. (1988). Development of heat insulating materials using date palm leaves. Journal of Building Physics, 6(3), 158-164.

Bankvall, C. (1974). Mechanism of heat transfer in permeable insulation and their investigation in a special guarded hot plate. Heat Transmission Measurements in Thermal Insulation, American Society for Testing and Materials, ASTM STP 544, Philadelphia, 34-38.

Bhattacharyya, R.K. (1980). Heat transfer model for fibrous insulations. Thermal Insulation Performance, ASTM STP 718, D.L. McElroy and R.P. Tye, Eds., American Society for Testing and Materials, 272-286.

Guilbert, S., Guillaume, C., Gontard, N. (2011). New packaging materials based on renewable resources: properties, applications and prospects. Food Engineering Interfaces. Food Engineering Series, Springer, Part 5, 619-630.

Khomenko, A.I. (1974). Elektrotekhnicheskii Spravochnik, fifth ed., 1, Moscow.

Laser Comp FOX 304 (2006). Heat flow meter thermal conductivity instrument. Information Sheet, Laser Comp, Wakefield, MA, USA.

Liang, H.H., Ho, M.C. (2007). Toxicity characteristics of commercially manufactured insulation materials for building applications in Taiwan. Construction Building Materials, 21, 1254-1261.

Lombard, L.P., Jose, O., Christine, P. (2008). A review on buildings energy consumption information. Energy Building, 40, 394-398.

Manohar, K., Yarbrough, D.W. (2003). A comparison of Biodegradable Fiber Insulation with Conventional Fibrous Insulation, Proceedings of the International Conference on Thermal Insulation, Volume 18, January 13–15, White Sulphur Springs, West Virginia, U.S.A., Product Safety Corporation, 133-140.

Manohar, K., Ramlakhan, D., Kochhar, G.S., Haldar, S. (2006). Biodegradable fibrous thermal insulation. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 28(1), 53-55.

Manohar, K. (2012). Renewable building thermal insulation – oil palm fibre. International Journal of Engineering and Technology, 2(3), 475-479.

Mohd Yuhazri, Y.Y., Sihombing, H., Jeefferie, A.R., Ahmad, M.A.Z., Balamurugan, A.G., Norazman, M.N., Shohaimi, A. (2011). Optimization of coconut fibers toward heat insulator applications. Global Engineers & Technologist Review, 1(1), 35-40.

Omar, M.A., Mohammed, M.A. (2004). A survey of energy-efficient strategies for effective air conditioning. Energy Conservation Management, 45, 1643-1654.

Panyakaew, S., Fotios, S. (2008). Agricultural waste materials as thermal insulation for dwellings in Thailand. Preliminary Results, PLEA 2008–25th Conference on Passive and Low Energy Architecture, Dublin, 22nd to 24th October 2008.

Pasic, Z., Topalovic, M., Kobas, A. (2010). Natural fibrous thermal insulation materials in buildings. Proceedings of the 14th International research/Expert Conference on ‘Trends in the Development of Machinery and Associated Technology’, September 11-18, Mediterranean Cruise, 597-600.

Pratt, A.W. (1978). Heat Transmission in Buildings, John Wiley and Sons – Interscience Publication, London, 31-42.

Radhi, H. (2008). A systematic methodology for optimizing the energy performance of buildings in Bahrain. Energy Building, 40, 1297-1303.
Ramli, R., Shaler, S., Jamaludin, M.A. (2002). Properties of medium density fibreboard from oil palm empty fruit bunch fibre. Journal of Oil Palm Research, 14(2), 34-40.
Rodriguez, N.J., Ya-nez-Limon, M., Gutierrez-Micella, F.A., Gomez-Guzman, O., Matadamas-Ortiz, T.P. (2011). Assessment of coconut fibre insulation characteristics and its use to modulate temperatures in concrete slabs with the aid of finite element methodology. Energy and Building, 43, 1264-1272.
Saidur, R. (2009). Energy consumption, energy savings and emission analysis in Malaysian office buildings. Energy Policy, 37, 4104-4113.
Stephenson, M.E., Mark, M. (1961). Thermal conductivity of porous materials. ASHRAE Journal, 1, 75-81.
Tangjuank, S. (2011). Thermal insulation and physical properties of particleboards from pineapple leaves. International Journal of Physical Sciences, 6(19), 4528-4532.
Tye, R.P., Ashars, E., Guyer, E.C., Sharon, A.C. (1980). An assessment of thermal insulation materials for building applications. Thermal Insulation Performance, ASTM STP 718, D.L. McElroy and R.P. Tye, Eds., American Society for Testing and Materials, 9-26.
Zhou, X., Zheng, P.Z., Li, H., Lu, C. (2010). An environmentally-friendly thermal insulation material from cotton stalk fibers. Energy and Building, 42, 1070-1074.