

# Experimentally Determined Apparent Thermal Conductivity of Banana Fibre

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**ABSTRACT:** Environmental concerns from the disposal of non-biodegradable conventional building thermal insulation prompted the investigation of naturally occurring fibrous biodegradable material as alternatives. Banana fibre obtained from the trunk of the banana tree is a waste by-product of the industry and can be obtained relatively cheap and managed properly can be a continuous source of a renewable biodegradable fibre material. The thermal conductivity test results for 25.4 mm, 38 mm, and 50.4 mm thick specimen at mean temperatures of 20°C, 25°C, 30°C 35°C and 40°C with a 20°C temperature difference between the hot and cold constant temperature plates for density ranging from 20 kg/m<sup>3</sup> to 120 kg/m<sup>3</sup> indicated a decrease in thermal conductivity with density to a minimum value at 80 kg/m<sup>3</sup> and then increased with further increase in density. This result is consistent with that for loose fill thermal insulation materials. The test results indicated an average increase in thermal conductivity of 1.8% for a 5°C increase in mean test temperature. At the optimum density of 80 kg/m<sup>3</sup> the minimum thermal conductivity was 0.3880 W/m.K for test conditions 25.4 mm thick, 20°C mean test temperature and the maximum thermal conductivity was 0.04495 W/m.K for test conditions 50.4 mm thick, 40°C mean test temperature showing that banana fibre is within the range for use as building thermal insulation.

**KEYWORDS:** Banana fibre, Thermal insulation, Loose-fill material, Thermal conductivity.

## I. INTRODUCTION

The thermal conductivity of fibrous insulation is a combination of conduction, convection and radiation across the porous material [1]. The development and use of new materials require initial investigation to determine the suitability as thermal insulation. The apparent thermal conductivity is a good indicator for gauging the suitability and possible range of application for a prospective insulating material [2, 3]. Building thermal insulation is a multimillion dollar industry in which loose-fill fibrous materials are used as a passive means to reduce the rate of heat flow across a thermal gradient. Synthetic materials such as mineral fibre, fiberglass, foam and polystyrene has dominated the rapidly expanding building thermal insulation industry for decades [4]. However, the non-biodegradability of these materials has resulted in environmental issues as retrofitting, refurbishing, reconstruction and upgrading existing structures has seen a growing volume of discarded insulation material for disposal [5, 6].

The environmental concern has prompted research to focus on the potential use of natural fibres in developing new and innovative insulation techniques and materials to accommodate, facilitate and improve the thermal needs of society. Banana fibre is a natural fibre obtained from the trunk of the banana tree [7]. After harvesting the banana the tree is discarded as a waste by-product of the banana industry. All varieties of banana plants can yield banana fibre. These fibres fall within the category of bast fibres, which are fibres found within the inner part of the tree and has relatively good mechanical properties [8]. Due to the relatively high tensile strength of banana (bast fibre) it is commonly used in high-quality textiles (sometimes in blends with cotton or synthetic fibres), ropes, yarn, paper, composite and burlap [9]. Banana fibres can also serve as a renewable biodegradable thermal insulation if the thermal conductivity fall within the range 0.02 W/m.K to 0.06 W/m.K for building thermal insulation use [10, 11]. If managed effectively, this can result in a net reduction in CO<sub>2</sub> emissions over the life cycle with a cheap, reliable and abundant supply of banana fibre as waste by-products from the commercial agricultural industries [12].

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

## II. TEST SPECIMEN

Banana fibre for testing was prepared by stripping the banana trunk in approximately 10cm wide pieces. The innermost part of the banana trunk was not used as it contained softer fibres. The strips were processed in a grooved rotating drum machine to remove the soft material and expose the fibres. Figure 1 shows the banana strips after processing in the machine. The fibres were then cut and allowed to air dry under laboratory conditions for five days.



Figure 1. Exposed banana fibres

The dried fibres were then randomly arranged in a slab-like form as a thermal insulation batt. The minimum density at which the slab-like batt showed no settling was at  $20 \text{ kg/m}^3$ . This density was used as the minimum test density for sample preparation.

Thermal conductivity test specimens were prepared by randomly arranging the banana fibres horizontally to form an insulation batt in square polystyrene frames of thickness 25.4 mm, 38 mm and 50.4 mm, respectively. The polystyrene frames were constructed from 25.4 mm strips with a thin plastic base to hold the fibres from falling through (Figure 2). The inner dimensions of the specimen holder was 254 mm x 254 mm.

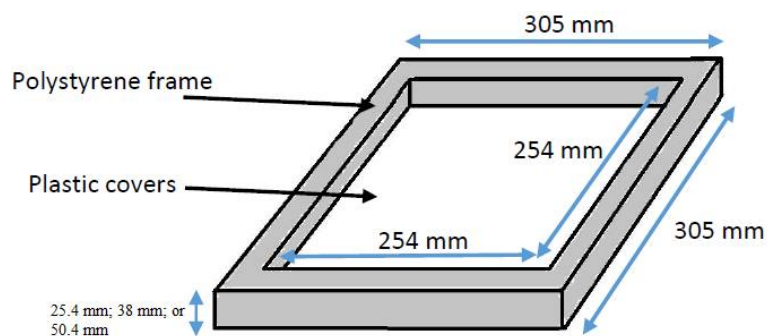


Figure 2. Polystyrene specimen holder

Test specimens were prepared at densities  $20 \text{ kg/m}^3$ ,  $30 \text{ kg/m}^3$ ,  $40 \text{ kg/m}^3$ ,  $50 \text{ kg/m}^3$ ,  $60 \text{ kg/m}^3$ ,  $70 \text{ kg/m}^3$ ,  $80 \text{ kg/m}^3$ ,  $90 \text{ kg/m}^3$ ,  $100 \text{ kg/m}^3$ ,  $110 \text{ kg/m}^3$  and  $120 \text{ kg/m}^3$ , at the respective thickness of 25.4 mm, 38 mm and 50.4 mm. The mass of fibre for the respective test specimens was calculated from the target density and the known specimen holder volume.

## International Journal of Innovative Research in Science, Engineering and Technology

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Thermal conductivity measurements were conducted using the LaserComp FOX 304 steady state thermal conductivity measurement apparatus [13]. The FOX 304 measures thermal conductivity under steady state one-dimensional test conditions with heat flow upwards via a centrally located 102 mm X 102 mm centrally located heat flux transducer. The lower constant temperature plates in the machine moved upwards and stopped automatically when a pre-set clamping force was exerted on the specimen. This ensured good thermal contact between the constant temperature plates and the test specimen. The upper test density of 120 kg/m<sup>3</sup> was determined by the clamping force of the machine. For higher density test specimen the machine was not capable of compressing the specimen to the respective 25.4 mm, 38 mm and 50.4 mm thickness. The FOX 304 provided thermal conductivity measurements within the range 0.005 W/m.K to 0.35 W/m.K with  $\pm 0.2\%$  repeatability and  $\pm 0.5\%$  reproducibility (Figure 3). The heat sink for the FOX 304 was provided by an independent chilled water system and a circulating pump.

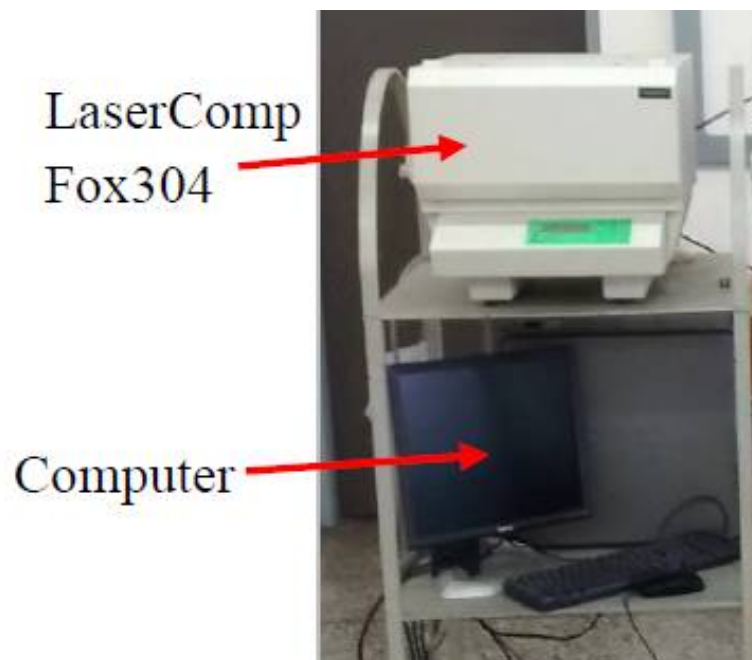


Figure 3. LaserComp FOX 304 test apparatus

The FOX 304 operated in accordance with ASTM C-518-04, Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus. The machine was calibrated using NIST SRM 1450b, Standard Reference Material of the National Institute of Standards and Technology with a 20°C temperature difference between the plates and upward heat flow. The experimental progress was continuously monitored via the computer link and the results recorded and stored automatically.

### III. EXPERIMENTAL RESULTS

Thermal conductivity measurements were conducted on 25.4 mm thick slab-like banana fibre specimens at mean test temperatures of 20°C, 25°C, 30°C, 35°C and 40°C with a 20°C temperature difference between the hot and cold constant temperature plates. The density of the banana fibre specimens tested were 20kg/m<sup>3</sup>, 30kg/m<sup>3</sup>, 40kg/m<sup>3</sup>, 50kg/m<sup>3</sup>, 60kg/m<sup>3</sup>, 70kg/m<sup>3</sup>, 80kg/m<sup>3</sup>, 90kg/m<sup>3</sup>, 100kg/m<sup>3</sup>, 110kg/m<sup>3</sup> and 120kg/m<sup>3</sup>. The thermal conductivity test results are shown on Table 1.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

Table 1: Banana Fibre Experimentally Determined Thermal Conductivity with 25.4 mm thick specimen

Density (kg/m <sup>3</sup> )	Experimental Determined Thermal Conductivity (W/m.K)				
	20 °C	25 °C	30 °C	35 °C	40 °C
20	0.05397	0.05563	0.05729	0.05891	0.06079
30	0.04787	0.04917	0.05046	0.05176	0.05327
40	0.04310	0.04424	0.04541	0.04657	0.04777
50	0.04158	0.04258	0.04361	0.04456	0.04564
60	0.04001	0.04092	0.04186	0.04256	0.04355
70	0.03930	0.04020	0.04112	0.04195	0.04285
80	0.03880	0.03949	0.03998	0.04075	0.04172
90	0.03923	0.03996	0.04070	0.04166	0.04276
100	0.04013	0.04080	0.04137	0.04202	0.04282
110	0.04187	0.04219	0.04276	0.04324	0.04366
120	0.04421	0.04463	0.04532	0.04611	0.4754

Thermal conductivity measurements were conducted on 38 mm thick slab-like banana fibre specimens at mean test temperatures of 20°C, 25°C, 30°C 35°C and 40°C with a 20°C temperature difference between the hot and cold constant temperature plates. The density of the banana fibre specimens tested were 20kg/m<sup>3</sup>, 30kg/m<sup>3</sup>, 40kg/m<sup>3</sup>, 50kg/m<sup>3</sup>, 60kg/m<sup>3</sup>, 70kg/m<sup>3</sup>, 80kg/m<sup>3</sup>, 90kg/m<sup>3</sup>, 100kg/m<sup>3</sup>, 110kg/m<sup>3</sup> and 120kg/m<sup>3</sup>. The thermal conductivity test results are shown on Table 2.

Table 2: Banana Fibre Experimentally Determined Thermal Conductivity with 38 mm thick specimen

Density (kg/m <sup>3</sup> )	Experimental Determined Thermal Conductivity (W/m.K)				
	20 °C	25 °C	30 °C	35 °C	40 °C
20	0.06740	0.06934	0.07150	0.07380	0.07597
30	0.05251	0.05419	0.05594	0.05740	0.05926
40	0.04638	0.04770	0.04918	0.05070	0.05148
50	0.04290	0.04387	0.04501	0.04626	0.04655
60	0.04107	0.04197	0.04321	0.04454	0.04601
70	0.04063	0.04119	0.04196	0.04282	0.04408
80	0.04054	0.04110	0.04196	0.04281	0.04379
90	0.04093	0.04132	0.04260	0.04319	0.04427
100	0.04174	0.04176	0.04292	0.04395	0.04489
110	0.04268	0.04312	0.04409	0.04587	0.04621
120	0.04562	0.04629	0.04748	0.04924	0.05042

Thermal conductivity measurements were conducted on 50.4 mm thick slab-like banana fibre specimens at mean test temperatures of 20°C, 25°C, 30°C 35°C and 40°C with a 20°C temperature difference between the hot and cold constant temperature plates. The density of the banana fibre specimens tested were 20kg/m<sup>3</sup>, 30kg/m<sup>3</sup>, 40kg/m<sup>3</sup>, 50kg/m<sup>3</sup>, 60kg/m<sup>3</sup>, 70kg/m<sup>3</sup>, 80kg/m<sup>3</sup>, 90kg/m<sup>3</sup>, 100kg/m<sup>3</sup>, 110kg/m<sup>3</sup> and 120kg/m<sup>3</sup>. The thermal conductivity test results are shown on Table 3.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

Table 3: Banana Fibre Experimentally Determined Thermal Conductivity with 50.4 mm thick specimen

Density (kg/m <sup>3</sup> )	Experimental Determined Thermal Conductivity (W/m.K)				
	20 °C	25 °C	30 °C	35 °C	40 °C
20	0.06679	0.06902	0.07135	0.07367	0.07533
30	0.05341	0.05499	0.05679	0.05855	0.05939
40	0.04816	0.04935	0.05096	0.05264	0.05395
50	0.04612	0.04674	0.04747	0.04850	0.04985
60	0.04355	0.04443	0.04520	0.04576	0.04677
70	0.04231	0.04392	0.04611	0.04567	0.04648
80	0.04202	0.04275	0.04436	0.04484	0.04495
90	0.04389	0.04466	0.04529	0.04593	0.04495
100	0.04496	0.04509	0.04573	0.04607	0.04523
110	0.04647	0.04667	0.04740	0.04839	0.04958
120	0.04854	0.04921	0.05013	0.05141	0.05248

## IV. ANALYSIS AND DISCUSSION

Environmental concerns from the disposal of non-biodegradable conventional building thermal insulation prompted the investigation of the thermal insulating properties of banana fibre. This naturally occurring biodegradable material obtained from the trunk of the banana tree is a waste by-product of the industry and can be obtained relatively cheap if not free. If managed properly, this can be a renewable biodegradable fibre material.

The thermal conductivity test results shown on Tables 1 to 3 indicated a decrease in thermal conductivity with density to a minimum value and then increased with further increase in density. This trend was observed for the three specimen thickness tested and at all the mean test temperatures tested. This result is consistent with that for loose fill thermal insulation materials and is an indication that the banana fibre is behaving as expected. The thermal conductivity variation of the 25.4 mm thick specimen at mean test temperatures of 20°C, 25°C, 30°C, 35°C and 40°C showed minimum thermal conductivity values of 0.03880 W/m.K, 0.03949 W/m.K, 0.03998 W/m.K, 0.04075 W/m.K and 0.04172 W/m.K, respectively, at a density of 80 kg/m<sup>3</sup>. The thermal conductivity variation of the 38mm thick specimen at mean test temperatures of 20°C, 25°C, 30°C, 35°C and 40°C showed minimum thermal conductivity values of 0.04054 W/m.K, 0.04110 W/m.K, 0.04196 W/m.K, 0.04281 W/m.K and 0.04379 W/m.K, respectively, at a density of 80 kg/m<sup>3</sup>. The thermal conductivity variation of the 50.4 mm thick specimen at mean test temperatures of 20°C, 25°C, 30°C, 35°C and 40°C showed minimum thermal conductivity values of 0.04202 W/m.K, 0.04275 W/m.K, 0.04436 W/m.K, 0.04484 W/m.K and 0.04495 W/m.K, respectively, at a density of 80 kg/m<sup>3</sup>. The thermal conductivity at all three thickness tested at the five different mean test temperature indicated that the optimum density for minimum thermal conductivity of banana fibre is about 80 kg/m<sup>3</sup>.

Thermal conductivity is a function of mean temperature and for fibrous insulation and increases with temperature. The experimental test results indicated this trend. For the 25.4 mm thick specimen at the optimum density of 80 kg/m<sup>3</sup> the increase in mean test temperature from 20°C to 25°C showed an increase of 1.78% in thermal conductivity, increase in mean test temperature from 25°C to 30°C showed an increase of 1.24% in thermal conductivity, increase in mean test temperature from 30°C to 35°C showed an increase of 1.92% in thermal conductivity, and increase in mean test temperature from 35°C to 40°C showed an increase of 2.38% in thermal conductivity. This indicated an average increase in thermal conductivity of 1.81% for an increase in mean test temperature of 5°C.

For the 38 mm thick specimen at the optimum density of 80 kg/m<sup>3</sup> the increase in mean test temperature from 20°C to 25°C showed an increase of 1.38% in thermal conductivity, increase in mean test temperature from 25°C to 30°C showed an increase of 2.09% in thermal conductivity, increase in mean test temperature from 30°C to 35°C showed an increase of 2.03% in thermal conductivity, and increase in mean test temperature from 35°C to 40°C showed an

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

increase of 2.29% in thermal conductivity. This indicated an average increase in thermal conductivity of 1.95% for an increase in mean test temperature of 5°C.

For the 50.4 mm thick specimen at the optimum density of 80 kg/m<sup>3</sup> the increase in mean test temperature from 20°C to 25°C showed an increase of 1.74% in thermal conductivity, increase in mean test temperature from 25°C to 30°C showed an increase of 3.76% in thermal conductivity, increase in mean test temperature from 30°C to 35°C showed an increase of 1.08% in thermal conductivity, and increase in mean test temperature from 35°C to 40°C showed an increase of 0.24% in thermal conductivity. This indicated an average increase in thermal conductivity of 1.71% for an increase in mean test temperature of 5°C. From the analysis across the three thickness tested results indicated an average increase in thermal conductivity of 1.8% for a 5°C increase in mean test temperature.

For use as building thermal insulation the thermal conductivity is normally within the range 0.02 W/m.K to 0.06 W/m.K. The thermal conductivity of loose fill banana fiber at the optimum density of 80 kg/m<sup>3</sup> ranged between 0.04054 W/m.K at 20°C mean test temperature to 0.04379 W/m.K at 40°C mean test temperature. Therefore, the banana fibre is within the range for use as building thermal insulation.

## V. CONCLUSIONS

The thermal conductivity test results for the three specimen thickness and at all the mean test temperatures indicated a decrease in thermal conductivity with density to a minimum value and then increased with further increase in density. This result is consistent with that for loose fill thermal insulation materials and is an indication that the banana fibre is behaving as expected. From the analysis across the three thickness tested results indicated an average increase in thermal conductivity of 1.8% for a 5°C increase in mean test temperature. At the optimum density of 80 kg/m<sup>3</sup> the minimum thermal conductivity was 0.3880 W/m.K for test conditions 25.4 mm thick, 20°C mean test temperature and the maximum thermal conductivity was 0.04495 W/m.K for test conditions 50.4 mm thick, 40°C mean test temperature. Banana fibre is within the range for use as building thermal insulation.

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## **BIOGRAPHY**



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