Transient versus steady-state thermal conductivity measurements: A case study of thermal characterisation of a novel biobased insulation material

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Abstract. For quick measurement of the thermal conductivity of building materials, the transient method is favoured by researchers. However, the steady-state method is recognised as a more reliable method for measuring thermal conductivity. The current work is part of the hygrothermal characterisation of a novel biobased material for building envelope applications. The aim of this part of the research work was to assess the reliability of the transient method in determining the thermal conductivity of the novel biobased material. As such, steady-state thermal conductivity values of the materials were determined using a Fox 600 guarded hotplate. Transient thermal conductivity was determined with an Isomet 2114 Thermal Properties Analyzer. To measure transient thermal conductivity both surface probes and needle probes were used with and without the application of thermal paste between the probes and the surface of the materials. It was observed that, in comparison to a steady-state measurement, transient measurement with needle probe overestimates and with disk probe underestimates thermal conductivity by about 14%. However, the average of the values determined by needle probes and disk probes were close to the values determined by steady-state method. It was further observed that the direct application of thermal paste on the material surface resulted in an increase of thermal conductivity by 52% from the values obtained by steady-state method.

Keywords: Thermal conductivity, biobased materials, transient method, steady-state method.

1 Introduction

Hemp-lime has proven to be a viable building material for building applications. Since the introduction of hemp-lime, a lot of research has been carried out to characterise the material in terms of various hygrothermal and structural properties [1-6]. Since hemp-lime is a composite material requiring a substantial proportion of lime as binder, there have been attempts to reduce the proportion of lime binder with the intention to improve thermal conductivity and reduce embodied carbon. The current paper discusses a novel insulation material that is made of only hemp shive and natural binder without the use of any lime or cement as a bonding agent.

2 Material and method

2.1 Material

The building material is prepared by mixing hemp shive with a biobased bonding agent. As such, it is a biodegradable and ecofriendly material. As part of characterisation, the thermal conductivity values of several samples with different densities are determined using transient and steady-state method. The density and constituents of the samples are provided in Table 1.

Table 1. Material density and types.

Name	Dimension (+/- mm)	Apparent Density	Constituents
A1	150 X 150 X 50	202.31	Hemp shive, biobased binder
A2	150 X 150 X 50	207.08	Hemp shive, biobased binder
B1	150 X 150 X 50	229.28	Hemp shive, biobased binder
B1	150 X 150X 50	225.06	Hemp shive, biobased binder

2.2 Method

Thermal conductivity values of the samples are determined using the following transient and steady-state methods.

Transient method: For transient method, Isomet 2114 Thermal Properties Analyzer was used. Isomet 2114 is a hand-held measuring instrument to measure the following heat transfer properties of various materials: thermal conductivity, thermal diffusivity, volumetric heat capacity and temperature. While the manufacturer's manual states that, it can measure heat transfer properties of woods, it is better suited to thermally charecterise isotropic materials like stone, soil etc. The measurement is based on the temperature response of the target material to the induced heat flow impulses. Thermal conductivity is determined by analysing the materials temperature as a function of time. Two types of probes are used separately to determine thermal conductivity, these are surface probe or disk and needle probe. Thermal conductivity of each material is determined at least three times for each type of probe. Three samples of each type were measured. Each determination consists of an average thermal conductivity value of three runs. The materials were were kept at 50% relative humidity and 23℃ temperature for three months prior to the measurements.

Steady-state thermal conductivity: Fox 600 hotplate was used to determine steady-state thermal conductivity. The average dimension of the sample was 400 X 400 X 50 mm. Thermal conductivity is obtained from the values of heat flux through the insulation sample and the temperature gradient between the hot and cold surface of the sample. The steady-state method conducts several runs until a threshold of confidence level is reached by the equipment software.

3 Results and discussion

For steady-state conductivity measurement, the following results are obtained (Table 2):

Table 2. Steady-state thermal conductivity test result.

Name	Sample thickness (from instrument) [mm]	Mean temperature [deg C]	Upper Conductivity [W/m K]	Lower Conductivity [W/m K]	Constituents
A1	51.94	20.01	0.072	0.07	Hemp shive, biobased binder
A2	50.05	20.02	0.069	0.069	Hemp shive, biobased binder
B1	47.46	20.02	0.073	0.074	Hemp shive, biobased binder
B1	47.68	20.02	0.073	0.073	Hemp shive, biobased binder

The steady-state method shows that the thermal conductivity values of all four types are about 0.07 W/mk, and the increase of density had little influence on the thermal conductivity values. However, the thermal conductivity values obtained by the transient method (Fig. 1) exhibited two different trends. Thermal conductivity values obtained by using surface or disk (A1S, A2S, B1S, B2S) probe exhibited a thermal conductivity value of about 0.058 W/mK for all types while thermal conductivity measured by using a needle probe showed values between 0.08 to 0.085 W/mK (A1N, A2N, B1N, B2N). The lower value obtained by the surface probe is thought to be due to the air resistance between the specimen surface and the probe surface. However, it is difficult to explain why the needle probe overestimated the thermal conductivity values by about 14% compared to the values obtained by steady-state method.

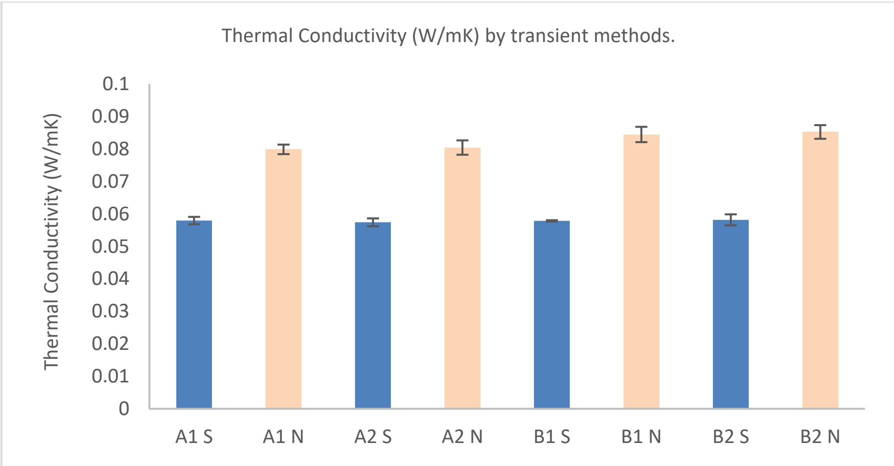

Fig. 1. Thermal Conductivity (W/mK) by transient methods with standard deviations.

It was further observed that the average of the values obtained from surface and needle probes exhibits closer values to those obtained by steady-state method for all material types (Fig. 2).

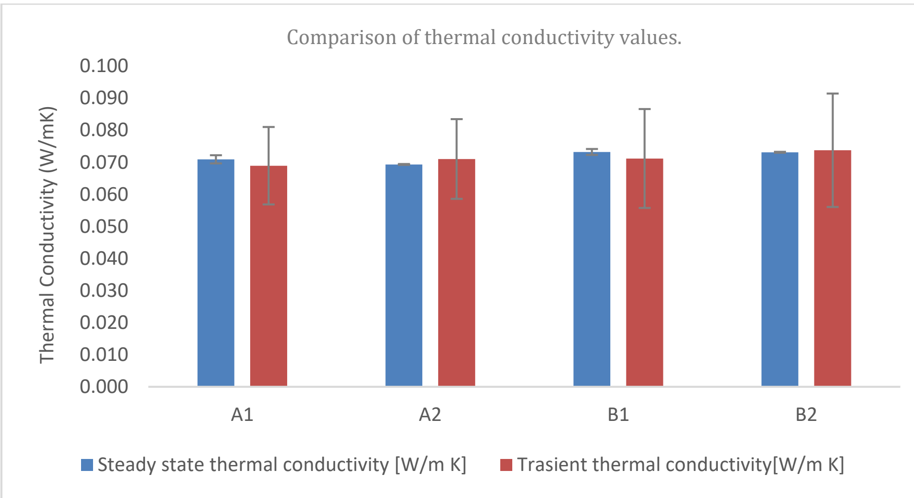

Fig. 2. Comparison of thermal conductivity values with standard deviations.

To further investigate the under and overestimation of thermal conductivity values by surface and needle probes, respectively, highly conductive thermal paste was applied to the interfaces between the probes and the materials on sample A1. It was observed that application of thermal paste does not change the thermal conductivity values obtained by using a needle probe. However, direct application of thermal paste on the material surface resulted in an increase of thermal conductivity with a value of 0.11 W/mK. This value is 52% higher than the value obtained by the steady-state method. The current paper does not intend to resolve the issue, but it highlights that extreme precautions should be taken while measuring thermal conductivity of biobased materials using transient methods.

4 Conclusion

For quick measurement of the thermal conductivity of building materials, the transient method is favoured by researchers. However, the steady-state method is recognised as a more reliable method for measuring thermal conductivity. The current work is part of the hygrothermal characterisation of a novel biobased ma-terial for building envelope applications. The aim of this part of the research work was to assess the reliability of the transient method in determining the thermal conductivity of the novel biobased material. As such, steady-state thermal conductivity values of the materials were determined using a Fox 600 guarded hot-plate. Transient thermal conductivity was determined with an Isomet 2114 Thermal Properties Analyzer. To measure transient thermal conductivity both surface probes and needle probes were used with and without the application of thermal paste between the probes and the surface of the materials. It was observed that, in comparison to a steady-state measurement, transient measurement with needle probe overestimates and with disk probe underestimates thermal conductivity by about 14%. However, the average of the values determined by needle probes and disk probes were close to the values determined by steady-state method. It was further observed that the direct application of thermal paste on the material surface resulted in an increase of thermal conductivity by 52% from the values obtained by steady-state method. In future, it will be useful to compare thermal conductivity values with the values determined by absolute methods using a hot box to better understand the discrepancies.

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