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Investigation of the Thermal Conductivity of Polyvinyl Chloride (Pvc) Ceiling Material Produced In Epz Calabar, For Application Tropical Climate Zones

Emmanuel B. Ettah,[1] Jerome G. Egbe[2] Stephen. A. Takim,[3] Uwak P. Akpan,[4] Everest B. Oyom[5]
[1, 4, 5.] *Department of Physics, Cross River University of Technology, Calabar, Nigeria*
[2,] *Department of Civil Engr. Cross River University of Technology, Calabar, Nigeria*
[3,] *Department of Mechanical Engr. Cross River University of Technology, Calabar, Nigeria*

Abstract: *The thermal properties of PVC produced in the Export Processing zone (EPZ) in Calabar, Nigeria with the view of establishing it suitability as an insulating ceiling material for building design in tropical region has been investigated. Parameters investigated were: thermal conductivity, thermal resistivity and thermal diffusivity. Lee's disc apparatus under steady state method was employed in the investigation. Result from the study shows that, thermal conductivity was 0.17*$Wm^{-1}K^{-1}$*, thermal resistivity 5.88*$Wm^{-1}K^{-1}$ *and thermal diffusivity of 7.8X10*$^{-6}$ m^2/s*. The results of the thermal conductivity value which is 0.17* $Wm^{-1}K^{-1}$*, falls within the range of good insulating materials which range from 0.023-2.9* $Wm^{-1}K^{-1}$*. This makes it suitable as ceiling material for application in tropical climate zones.*

Keyword: *Thermal conductivity, PVC, Tropical climate, Ceiling material*

I. Introduction

In tropical climate zones, the greatest thermal gain occurs through the roof of a house. In Nigeria, the use of zinc made roofs without a ceiling is very common, thus there is intense heat transfer to the internal environment, which may cause thermal discomfort to the inhabitants (Etuk *et al.*, 2007).One way to reduce the thermal discomfort is the use of radiant barrier which reduce the heat flux.

The knowledge of thermal properties of different materials is very important in the choice of the type of material to be used as a radiant barrier since the heat flow through any building depends on the thermal properties of the materials used in the building (Michels *et al.*, 2008) and (Etuk *et al.*, 2007).

The study of the thermal properties of PVC material will help in knowing whether it is suitable as a ceiling material for application in tropical climate zones. Polyvinyl chloride (PVC) is the third most widely produced polymer, after polyethylene and polypropylene (Allsopp *et al.*, 2012). It is insoluble in alcohol, but slightly soluble in tetrahydrofuran

Structurally the polymers are linear and strong. The monomers are mainly arranged head to tail, meaning that there are chlorides on alternating carbon centres. PCV has mainly an atactic stereochemistry of the chlorides centres which are random. The presence of chloride groups gives the polymer very different properties from the structurally related material polyethylene (Mc Graw-Hill *et al.*, 2002).

The product of the polymerization process is unmodified PVC. Before PVC can be made into finished products, it always requires conversion into a compound, by the incorporation of additives such as heat stabilizers, UV stabilizers, plasticizers etc (Cadogan *et al.*, 2000).

PVC comes in two basic forms; rigid RPVC and the flexible. The rigid form of PVC is used in construction of pipes, and in profile application such as doors and windows. It is also used for bottle and other non-food packaging, and cards. It can be made softer and flexible by the addition of plasticizers, like phthalates. PVC in a flexible form can be used in plumbing, electrical cable insulation, imitation leather, signage, inflatable products and many applications where it replaces rubber (W. V. Titow, 1984). PVC is a thermoplastic polymer, its properties are usually categorized based on rigid and flexible PVCs. PVC has high harness and mechanical properties enhance with the molecular weight increases, but decreases with the temperature increasing.

The mechanical properties of rigid PVC (UPVC) are very good, the elastic modulus can get to 1500-3,000Mpa. The soft PVC (flexible PVC) elastic modulus is 1.5-15Mpa. However, elongation at break is up to 200-450%. PVC friction is ordinary, the static friction factor is 0.23 (JT-Extrumermachine.com).

The heat stability of raw PVC is very poor so the addition of a heat stabilizer during the products is necessary in order to ensure the product's properties. PVC starts to decompose when the temperature reaches 140^0C with melting temperature starting around 160^0C. PVC is a polymer with good insulation properties but because of its higher polar nature, the electrical insulating property is inferior to non-polar polymers such as polyethylene and polypropylene. As the dielectric constant, dielectric loss value and volume resistivity are high, the corona resistance is not very good, and it is generally suitable for medium or raw voltage and low frequency insulation materials.

In our homes, indoor thermal discomfort has been very challenging. It depends on one or more of the materials used either as ceiling board; rock used as walling materials; wood used in making roofing support, the roofing sheet itself or combination of all of them. One of the special concerns of the trained builders is to design a building that the indoor environmental condition is thermally tolerable and conducive to the occupants of the building (Ajibola *et al.*, 1995) and (Straaten, *et al.,* 1967).

George *et al.,* (2010) investigated comparatively the thermal insulation efficiency of some selected materials frequently used as ceiling in building design, in terms of their thermal properties such as thermal conductivity, thermal diffusivity, thermal resistivity and thermal absorptivity using the lee's disc apparatus and a steady state method. The material investigated where PVC, POP, cardboard, Asbestos and suspended ceiling tiles.

Generally, they concluded that in terms of thermal conductivities, the samples show good compliance with standard values obtained in textbooks and the values recommended for heat-insulating materials.

However, thermal absorptivity which is usually lower for best insulation indicates that the materials POP, Asbestos and suspended ceiling tile are recommended as ceiling materials that would have good thermal insulation efficiency when compared to PVC and cardboard. Although thermal resistivity are low in samples of the material of POP and Asbestos recommended, thermal absorptivity which has to do with absorption and retention of heat, plays the major role when it comes to insulation efficiency. Lower absorptivity in materials is a clear indication of lower molecular point of view, low thermal absorptivity with higher or lower thermal diffusivity portrays good thermal insulation efficiency.

Onyeaju *et al.,* (2012) also worked comparatively on the thermal properties of Asbestos and PVC ceiling sheet according to their thermal conductivity, (TC), thermal resistivity (TR), thermal diffusivity, thermal absorptivity, and specific heat capacity (SHC). They treated the samples under investigation as an ideal one dimensional heat transfer problem. They obtained results in their study which shows that both PVC and asbestos ceiling, sheet has low density, low thermal conductivity and high thermal resistivity which compared favourably with those of other good thermal insulators in building design (Etuk *et al.*,2007) Demirdag (2006) (Zhua *et al.,* 2003), Zhang et al. (2006). Also the value of the thermal resistivity obtained correlate well with the experimental data. (Michels *et al.,* 2008). They also recommend these types of insulators as a ceiling sheet not only to reduce the thermal gain in summer but also to reduce the winter losses, thereby decreasing the energy consumption for heating or cooling of the interior space in a building.

Therefore in view of the above comparison, PVC ceiling coupled with its physical appearance, strength, chemical resistance, fire resistance, maintenance-free and freedom from toxicity, odour and taste may be a better material for thermal design application.

This work is aimed at the investigation of the thermal properties of PVC ceiling material produced in EPZ Calabar. To know if it is suitable as a ceiling material for application in tropical climate zone

II. Materials And Method

The materials used in this work were:a sample of PVC ceiling material collected from the open market produced at Export Processing Zone (EPZ) Calabar, Cross River State, Nigeria. VernierCalliper, Micrometrescrew gauge, mass balance, retort stands, heat source, steam boiler, water, and mercury in glass thermometers, stop watch and Lee Charlton's apparatus. The sample was then shaped to take the dimension of the Lee Charlton's apparatus used. The diameter and the thickness of the sample were measured and tabulated as shown below.

TABLE I: Materials Specification

Materials	Thickness	Mass	Specific Heat Capacity	Diameter	Mean Surface Areas
	(m)	(kg)	(J/kgk)	(m)	(m^2)
PVC	0.0056	0.0092	900	0.089	0.0063

Haven use the mass balance, micrometer screw gauge, Vernier caliper, to obtain the tabulated value above in table I, the setup was then obtained as shown in figure I above. Using the steady state method, the steam boiler was filled with water to nearly half and heated to produce steam that cause the rise in temperature of the steel disc and sample specimen until steady temperatures $T_1$and T_2 were obtained after a certain time interval.

The specimen was then removed and the steel disc heated directly by the steam chamber till its temperature was slightly above T_2. The steam chamber was then removed and sample specimen placed on the steel disc. The initial temperature was noted continually in intervals of two minute till there was no observable change in temperature. The result was plotted to obtain temp-time graph from where the cooling rates was determined. Then thermal properties computed as shown in table II

III. Result Presentation

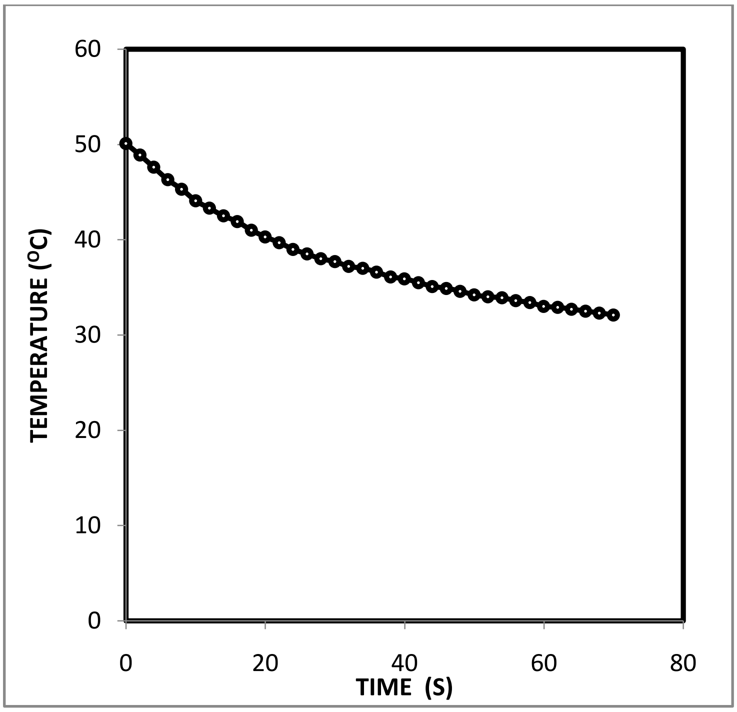

Figure I: Graph of Temperature against Time

Result Analysis

Accordingto (Newton *et al*., 2014) the Fourier's law heat transfer below can be used in calculating the thermal conductivity, since, at steady state, the heat conducted through the sample will be equal to heat lost per second from the exposed portion of the metallic disc.

$KA\frac{T1-T2}{X} = MC\frac{DT}{dt}$ 1

$k = [MC\ X\ dT/dt\ \ /\ (A(T_1 - T_2)]$ 2

$\lambda = \frac{K}{PC}$ 3

r= $\frac{1}{K}$ 4

Thermal diffusivity λ and resistivity, r are calculated using equations (3 and 4).

Where K = thermal conductivity of the sample, C = specific heat capacity of the sample, X = thickness of the sample, $dT/\ dt$ is the Cooling rate of the steel disc at T_2, A = Area of the sample in contact with the steel disc, (T_{1-T_2})equal totemperature difference across the samples thickness, λ = thermal diffusivity, ρ=density of the sample, C=specific heat capacity of the steel disc, r = thermal resistivity of the sample and m = mass of the metallic disc. The thermal conductivity, resistivity, and diffusivity were calculated and presented as shown in table II below.

- Thickness of the sample = 5.64mm = 0.0056M diameter of the sample = 8.889cm=0.089M
- Steady state temperatures = T_1= 92, T_2= 42°C
- Specific heat capacity of the sample according to Dirac Delta. CO.UK=900J/Kgk
- Specific heat capacity of the steel according to Dirac Delta CO. UK=420 J/Kgk
- Area of the sample = πr^2 = 3.143 $(0.045)^2$
  = 0.0063M_2
- Volume of the sample =4/3 $\pi r3$ = 4/3 (3.143) $(0.045)^3$
  =4/3 (3.143) X9.1X10^{-5}
  = $\frac{0.0011452}{3}$ = 0.00038M^3
- $K =$ 0.65 X 420 X 0.0056 X 0.22

0.0063 X 323

$K =$ 0.336336 / 2.0349

$K =$ 0.17 W/KM

- r $= \frac{1}{K} = \frac{1}{0.17} = 5.88 MK/W$
-
- λ $= \frac{K}{Pc} = \frac{0.17}{900 \; X \; 24.21} = \frac{0.17}{2178}$

$= 7.8 \text{ x } 10^{-6} M^2/S$

Table II: thermal properties of PVC sample

Materials	Density	Thermal Conductivity	Thermal Diffusivity	Thermal Resistivity
	(Kg/m^3)	k(W/MK)	(m^2/S)	(W^{-1}MK)
PVC	24.21	0.17	7.8 X 10^{-6}	5.88

IV. Discussion Of Result

Table I and fig. I shows the cooling rate of the PVC ceiling material at ambient temperature of 29^0C. The cooling curve of the sample corresponds with the pattern of cooling of good insulating materials. Table II presents the calculated thermal parameters such as thermal conductivity, k, thermal diffusivity λ; and thermal resistivity r of the PVC material is a good ceiling material, since its thermal conductivity falls within the conductivity of construction and heat insulting materials which ranges from 0.023 to 2.9 $Wm^{-1}k^{-1}$ according to (Twidell J, Mahhrer. Y (1982) and Weir 1990).

The investigated polyvinyl chloride (PVC) sample has a thermal conductivity of 0.17$Wm^{-1}k^{-1}$ thermal diffusivity of 7.8X$10^{-6}M2/S$ and thermal resistivity of $5.88W - 1Mk$. Theoretically, a substance with a large thermal conductivity value is a poor conductor of heat; one with a small thermal conductivity value is a poor heat conductor that is a good insulator. In order words a good insulation material will have high resistivity value for thickness other than 1m.

Thermal diffusivity measures the ability of a material to transmit a thermal disturbance. It indicates how quickly a material's temperature will change. Thermal diffusivity therefore increases with the ability of a body to conduct heat and decreases with the amount of heat needed to change the temperature of a body (Newton *et al.*, 2014).

V. Conclusion

The thermal conductivity of the sample under investigation, show good compliance with standard value for heat-insulating materials which range from 0.023-2.9 $Wm - 1K -^1$, according to (Twiddle*et al.*, 1982) haven gotten the conductivity of the PVC to be $0.17Wm - 1K - 1$. Therefore, it can be conclude that PVC ceiling material produced in EPZ Calabar are suitable for application as ceiling material in Tropical Zones.

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