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**Research Paper**

# Thermal Behaviour of Agro-Waste Based Ceiling Board and Its Filler Material

Ezenwa O. N[1], Obika E. N[1], Ekengwu I. E[1], Okafor O. C[2]
[1]*Department of Mechanical Engineering, Nnamdi Azikiwe University, Awka, Nigeria*
[2]*Grundtvig Polytechnic, Oba, Nigeria*

***Abstract***
*The thermal behavior of a ceiling board produced with breadfruit seed coat as the filler material, and recycled Low Density Polyethylene,as the binder, was investigated. The Breadfruit seed coat was treated with sodium hydroxide andacetic acid, to remove the pigments. The ceiling material was produced with 19.722% filer-binder ratio, and pressed for 10 minutes, attemperature and pressure of 197.31 °C and 9.042 MPa respectively. Lee-Charton's apparatus was used to determine the thermal conductivity of the produced material, which gave a value of 0.362 $Wm^{-1}K^{-1}$ and the corresponding thermal diffusivity and resistivity of 5.24 x $10^{-7}$ $m^2/s$, and 2.76 $Wm^{-1}K^{-1}$, respectively. Thermo-gravimetric analyzer and Digital Scanning Calorimeter was used to study the thermal behavior the filler material and the produced sample, which showed a good thermal stability. Hence, this research showed that the produced material is suitable for ceiling board application.*

***Keywords:*** *Agro-waste, Breadfruit seed coat, Thermal conductivity, Thermal diffusivity, Thermal Resistivity, Thermo-gravimetric analysis, Digital Scanning Calorimetry*

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## I. Introduction

In tropical countries, the major source of heat within a building occurs through the roof of the building. This is because of the use of zinc and aluminum-made roofs in most countries such as Nigeria (Ettah et al, 2016). These roof materials are exposed to the sun, and because of its high thermal conductivity, allows the transfer of intense heat to the internal environment of the building, which causes thermal discomfort to the inhabitants (Onyeaju et al, 2012). Hence the need for thermal insulation of roof section using ceiling board to reduce or eliminate the thermal discomfort from the roof section.

Ceiling board materials are used for ceiling padding in building construction, for insulation and aesthetic purposes. It covers the upper internal section of the building, thereby concealing the details of the roof trusses (aesthetics) (Oladele, et al, 2014), and preventing thermal radiation from the roof section due to the roofing materials which are mostly zinc, and its long exposure to the sun (Gesa et al, 2014). These desires for aesthetic and thermal comfort in building determines the choice of ceiling materials and influences technological advancement in ceiling board production (Oyekunle et al, 2018). These ceiling materials ranges from plant-originated materials, such as thatches, plywood and cardboard, to synthetic and composite ceiling materials, such as asbestos, plaster of Parish (POP) and the more recently PVC (George et al, 2010).

In the past, asbestos which are natural fibers in rocks, were commonly used to produce ceiling boards, due to its high tensile strength, low thermal conductivity and high fire resistance. However, asbestos causes asbestosis, which leads to cancer (Amenaghawon et al., 2016). The carcinogenic nature of asbestos necessitated the research for alternative materials for ceiling board production. These alternatives include shredded wood, cellulose fibre, agricultural waste, industrial and man-made products (Ameh et al, 2019). Another commonly used material for ceiling padding is shredded wood, but the demand load on wood for other applications is comparatively high with the rate at which it replenishes, thereby making wood a relatively high commodity (Amenaghawon et al., 2016). Hence the need to look into other options, such as natural fibres especially from agro waste, rather than industrial and man-made materials, due to its friendly effect to humans and environment, as well as cost.

The demand for ceiling board and other panel products have been on the increase in recent time due to increased activities in the building industries (Ameh et al, 2019). In other to meet up with these demand, production of ceiling board with readily available materials such as cellulose and natural fibres, and agro-waste becomes imperative. Natural fibres and agro-waste are readily available, and in large quantity due to high agricultural activities, especially in most developing countries that engages more in peasant farming (Ezenwa et al, 2019). The agro-wastes generated as a result of these agricultural activities are mostly burnt off at the dumping sites thereby constituting environmental hazards such as emission of $CO_2$ into the atmosphere, which is the major cause of global warming and soil degradation. (Ezenwa et al, 2019).

Researchers have been investigating the use of these available agro-waste for the production of construction materials, depending on its use, ranging from particle boards, thermal insulators, masonry composites/bricks, cementations/binder, to aggregates, etc (Amit and Ipshita, 2015). Some of the available literature for ceiling board production using agro-waste include; the use of breadfruit seed coat (Ezenwa et al, 2019), rice husk (Oladele et al., 2009; Suleiman et al., 2013; Madu et al., 2018), banana fibres (Stephen et al., 2014), jatropha curcas seedcake material (Olorunmaiye and Ohijeagbon, 2015), water melon peels (Idris et al., 2011), bamboo (Chibudike et al., 2011), corn cobs and cassava stalks (Amenaghawon et al., 2016) , and sawdust (Idehai, 2012; Akinyemi et al., 2016; Atuanya and Obele, 2016; Isheni et al., 2017; Olufemi et al, 2012), as well as other synthetic wastes like waste paper (Ekpunobi et al., 2015).

The use of these ceiling boards in building construction exposes the ceiling board materials to intense heat from the sun through the roof by conduction (Onyeaju et al, 2012). Therefore, this is need to study the thermal behavior of theses ceiling board materials in other to determine its suitability. The thermal behavior to consider, for proper selection of insulating materials include: the thermal conductivity, thermal absorptivity, thermal diffusivity, specific heat capacity and thermal stability. (Gesa *et al* 2014). Most of the available literature such as Gesa et al (2014), Oyekunle et al (2018), Oyekunle et al (2018), Adepitan et al (2019), Onyeaju et al (2012), and Ettah et al (2016), investigated thermal conductivity, thermal absorptivity, thermal diffusivity, and specific heat capacity of asbestos, and synthetic ceiling materials such as Plaster of Paris (P.O.P), and Poly Vinyl Chloride (PVC). Though Onyekunle et al (2018), and Onyeaju et al (2012), went further to include Thermal Inertia, thermal absorptivity, and specific heat capacity, in their studies. Also, some researchers reported the thermal properties of ceiling board made from agro-waste. Seun and Ige (2018), reported the thermal conductivity, diffusivity and resistivity of ceiling board produced from sugarcane bagasse and rice husk. Isheni et al (2017) reported that of ceiling board produced from combination of maize husk, rice husk, and saw-dust, while Ezenwa et al (2019) reported that of ceiling board produced from breadfruit seed coat, as well as some other researchers. However, only few research are available that investigated thermal behavior such as thermal stability and phase change over long exposure of these materials to heat. Hence the knowledge gap for this work.

## II. Materials and Method

### 2.1 Materials

The materials that are used for this work are breadfruit seed coat as seen in figure 1(a), recycled low density polyethylene as seen in figure 1(b), sodium hydroxide (NaOH), acetic acid, and water. The breadfruit seed coat, which serves as the filler material was sourced from a market waste dump at Amansea, Anambra, while recycled Low Density Polyethylene (rLDPE), which serves as a binder was sourced from a vendor in Onitsha, both in Anambra, Nigeria. The chemicals, NaOHand acetic acid used for sample treatment was obtained from Pure Chemicals Co., Anna Nagar, Chennai, India

(a) (b)

Figure 1: The picture of (a) breadfruit seed coat (BSC), and (b) recycled low density polyethylene

### 2.2 Materials Preparation

A sample of the breadfruit seed coat was socked in 1 mol/dm$^3$ solution of NaOH for 60 mins, and washed to remove the material's pigment. The sample was then neutralized in 0.5 mol/dm$^3$ of acetic acid, washed with water to remove the acetic acid and sun dried. The dried sample was ground into powder and sieved to 600μm particle size. Also the recycled low density polyethylene which comes in pellets form was ground into powdery form and sieved to 600µm particle size.

## 2.3 Sample Production

The optimized process parameter combination reported by Ezenwa et al (2019) which are 19.7% filler/rLDPE, 10 minutes press time, 197.31 $^0$C and 9.042 MPa press pressure. A weighed sample of prepared breadfruit seed coat and the binder (rLDPE) in the ratio of 19.7 % of filler/rLDPE, was put into a bowl and thoroughly mixed to obtain a homogeneous mixture. The mixture is then transferred into a rectangular mold and placed in a hot press. The mixture then pressed at a temperature 197.31 $^0$C and pressure of 9.042 MPa, for 10 minutes. The produced sample as seen in figure 3, is then allowed to cool.

## 2.4 Sample Characterization

The specific heat capacity of the produced sample was determined using the experimental method reported by Dirisu et al (2019). From the experiment, the following parameters; such as mass of sample $m_s$, mass of calorimeter with stirrer $m_c$, mass of calorimeter with stirrer and water $m_{cw}$, initial temperature of normal water $T_1$, temperature of boiling water $T_2$, and final temperature of mixture $T_3$, was obtained. While thermal energy Q and Specific heat capacity (S.H.C.) of copper calorimeter $c_c$ and water $c_w$ used for the experiment was noted. The specific heat capacity of the produced sample $c_s$ was determined by equating the heat loss by the sample to the sum of heat gain by water and the calorimeter with stirrer as stated in equation (1).

$$c_s = \frac{Q}{m_s \Delta T} \tag{1}$$

The thermal conductivity was also determined using Lee Chalton's stead state method as reported by Dirisu et al (2019). Before the experiment, the dimension of the specimen such as the thickness (x) and diameter (d) of the sample was noted, while the area (A) and volume (V) was calculated using equation (2) and (3) respectively.

$$A = \pi \frac{d^2}{4} \tag{2}$$

$$V = A.x \tag{3}$$

The temperatures changes for both heating and cooling was obtained during the experiment for 5 minutes interval up to 60 minutes, and 2 minutes interval up to 22 minutes respectively. The obtained data was applied using equation (4) to determine the thermal conductivity (k) of the sample.

$$k = mc_s x \frac{\left(\frac{dT}{dt}\right)}{A(T_1 - T_2)} \tag{4}$$

Other properties of the sample such mass density ($\boldsymbol{\rho}$), thermal diffusivity (α), and thermal resistivity (R), was obtained using equation (5), (6), and (7) respectively.

$$\rho = \frac{m_s}{V} \tag{5}$$

$$\alpha = \frac{k}{\rho c_s} \tag{6}$$

$$R = \frac{1}{k} \tag{7}$$

Also, Thermo-Gravimetric Analysis and Differential Thermal Analysis was carried out on the raw material and on the produced sample to determine their thermal stability and phase changes. These thermal characterization was done with TA Instruments Thermo-Gravimetric Analyzer TGA2950, and TA Instruments Modulated Differential Scanning Calorimeter MDSC2920/DTA1600 respectively as shown in figure 2(a) and (b) respectively. These devices are computer interfaced and controlled with theTA Instruments universal analysis 2000 software

(a) (b)

Figure 2: The experimental setup of (a) TGA and (b) DSC

For TGA experiment, ceramic panwas placed on the sample platform and tarred by clicking TARE on the instrument panel. The nitrogen purge gas was set at 60 ml/minute and 40ml/minute for the furnace and balance chambers respectively, while the pan with sample was placed on the sample platform. The experiment is then allowed to run by clicking the start icon on the software control program, which automatically loads, weighed and rantheexperimenttocompletion.Realtimeplotwas then generatedastheexperiment proceeds.
Similarly, for DSC experiment, aluminumpanswithlidswereselectedforboththesampleand the emptyreference, and placedintheirrespectivepositionsintheheatingcell.By clicking STARTonthe software Controlprogram,theinstrumentautomaticallyranthe experiment tocompletion.Realtimeplotwasgeneratedsimultaneouslyastheexperimentran.

## III. Result and Discussion

Figure 3: The picture of the produced sample

The produced sample as seen in figure 3, is brownish in colour, and of polymer form due to type and the amount of binder used for the production.

### 3.1 Specific Heat Capacity

Table 1: Specific heat experimental data

| Parameters | Symbol | Unit | Value |
|---|---|---|---|
| Mass of sample | $m_s$ | Kg | 0.006 |
| Initial temperature of water | $T_1$ | K | 304 |
| Temperature of boiling water | $T_2$ | K | 373 |
| Final temperature of the mixture | $T_3$ | K | 315 |
| Thermal energy supplied | Q | W | 60 |

Table 1, shows some of the data obtained from the experiment to determine the specific heat capacity of the produced sample. These data were applied in equation (1), to obtain 909.1 $JKg^{-1}K^{-1}$ as the specific heat capacity of the produced sample. The obtained result is close to the specific heat capacity of asbestos reported by Oyekunle et al (2018), which means that the developed sample is a good replacement for asbestos.

### 3.2 Thermal Conductivity, Diffusivity and Resistivity

Table 2: Thermal conductivity experimental data for heating and cooling process

| Heating Process | | | Cooling Process | |
|---|---|---|---|---|
| Time (mins) | $T_1$(°C) | $T_2$ (°C) | Time (mins) | T (°C) |
| 5 | 28 | 28 | 0 | 80 |
| 10 | 32 | 28 | 2 | 78 |
| 15 | 39 | 30 | 4 | 77 |
| 20 | 47 | 34 | 6 | 76 |
| 25 | 55 | 39 | 8 | 74 |
| 30 | 63 | 46 | 10 | 73 |
| 35 | 67 | 51 | 12 | 71 |
| 40 | 70 | 55 | 14 | 69 |
| 45 | 75 | 59 | 16 | 67 |
| 50 | 77 | 62 | 18 | 65 |
| 55 | 81 | 65 | 20 | 65 |
| 60 | 88 | 71 | 22 | 65 |

Table 2, presented the data obtained from the thermal conductivity experiment for both heating and cooling process. From the table, the average temperature for $T_1$ and $T_2$ are 60.16 $^oC$ and 47 $^oC$ respectively, while dT/dt was obtained from the plot of temperature change against time during cooling process, as presented in figure 4.

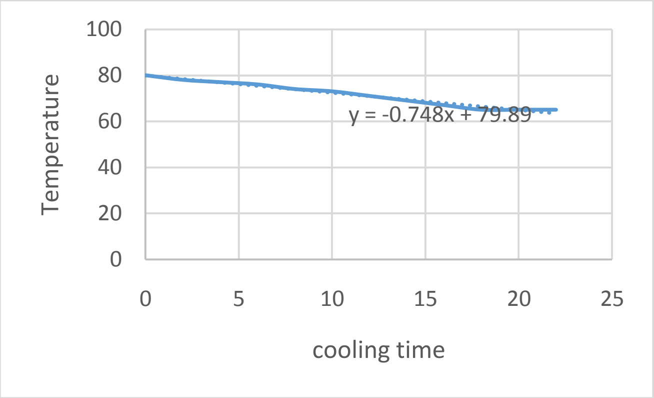
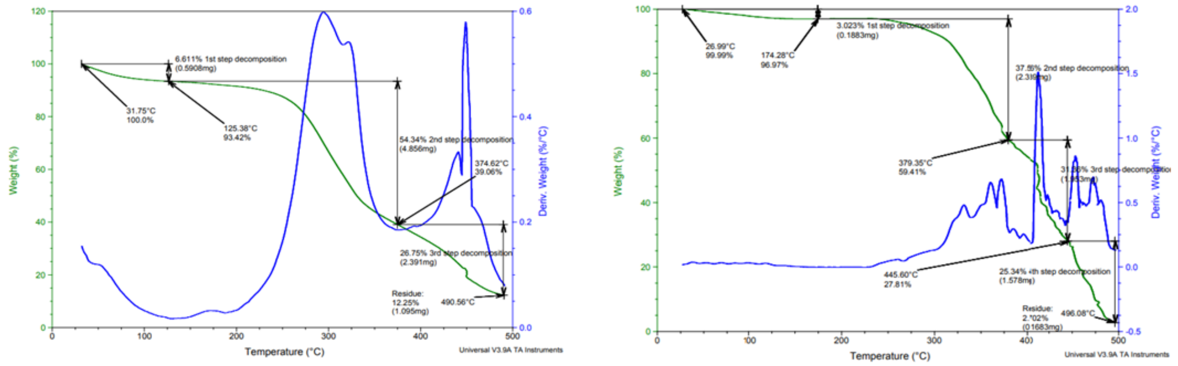


Figure 4: Graph of temperature drop against time during cooling process.

From figure 4, the rate of cooling dT/dt was obtained by determining the gradient of the curve, with the assumption that the heat lost from the sides of the sample itself is negligible. The plot gave a cooling rate of 0.75 K/min. Also the diameter and the thickness of the sample given as 0.01 m and 0.003 m respectively, was measured with caliper, while the weight of the sample was measured with a weighing balance and given as 0.018 Kg. these parameters are applied in equation (4) to give the thermal conductivity of the produced sample as 0.362 $Wm^{-1}K^{-1}$

Similarly, thermal diffusivity and resistivity of the produced sample was obtain by applying the obtained data to equation (6) and (7) respectively, and the values given as 5.24 x $10^{-7}$ $m^2/s$, and 2.76 $Wm^{-1}K^{-1}$. This shows that the produced material has a very low thermal conductivity, which makes it very suitable ceiling board application and also other low heat insulation application.

### 3.3 Thermo-Gravimetric Analysis Result



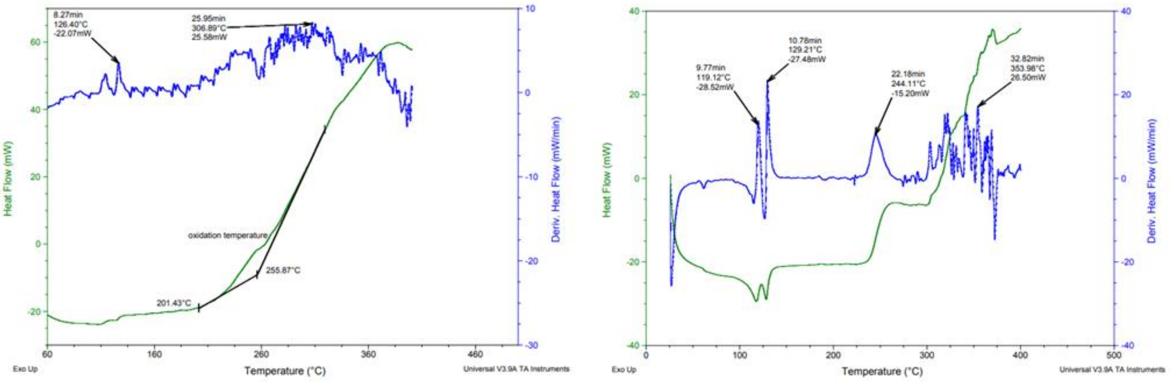
(a)

(b)

Figure 5: Thermo-gravimetric analysis of (a). BSC sample and (b). produced sample

Figures 5(a) and (b) represent the TGA results of the breadfruit seed coat (BSC) and produced samples. In figure 5(a), the BSC sample experienced a slight weight loss of 6.611% when heated from 31.75℃ to 125.38℃. A weight loss of 54.34% occurred when the BSC sample was heated from 125.38℃ to 374.02℃. Also, from 374.02℃ to 400.50℃ a weight loss of 26.75% was observed during the third decomposition operation. While in figure 5(b), it could be seen that a weight loss of 3.023% occurred when the produced sample was heated from 26.99℃ to 174.28℃ during the first decomposition. From 174.28℃ to 250℃ the sample maintained a stable weight (no decrease or increase) until the sample was heated beyond 250℃ to 379.35℃, a weight loss of 37.56% was observed. During the third decomposition operation, the sample was heated from 379.35℃ to 445.60℃ which led to a weight loss of 31.397% of the produced sample. In addition, the fourth decomposition heating from 445.60℃ to 496.08℃ caused a weight loss of 25.34% of the sample. Therefore, considering the gradual rate at which the produced sample lost weight due to thermal heating in comparison to the BSC sample that was more rapid, it can be inferred that the produced sample is more stable thermally, than the BSC sample. This observation would be because of the BSC raw material that was used in the development of the sample.

### 3.4 Differential Scanning Calorimetry Analysis Result



(a) (b)

Figure 6: Differential scanning calorimetry of (a) BSC sample and (b) produced sample.

Figures 6(a) and (b) depict the differential scanning calorimetry (DSC) analyses of the BSC and produced samples. From figure 6(a), the BSC sample experienced a slight heat loss of about 2MW when heated from 60℃ to 110℃, which was regained when the sample was heated up to 201.43℃. Also, the BSC sample could be observed to absorb 60MW of heat energy when heated from the inflexion temperature point of 201.43℃ to 385℃. When the BSC sample was heated beyond 385℃, the material started to dissipate heat energy. This could be seen from the heat drop of about 2MW as delineated in figure 6(a). In other words, the thermal capacity of the material will most likely be at the 60MW zone. The heat absorption operation of the BSC sample rapidly increased the enthalpy parameter of the sample within the temperature bound of 201.43℃ to 385℃. While figure 6(b) showed a very rapid heat dissipation of the produced sample from 0MW to -30MW (that is heat loss of -30MW) in the negative gradient within the temperature boundary of 25℃ to 112.5℃. This was followed by a small ranged heat loss within the temperature bound of 112.5℃ to 125℃. The sample maintained a constant heat loss from 125℃ to 237.5℃ at -20MW. From 237.5℃ to 250℃ the material's heat loss decreased from 20MW to 5MW. This was because the material has started regaining stability to withstand and absorb heat energy. From 300℃ to 375℃ the material experienced abrupt heat again of about 35MW. Therefore, the heat absorptivity potential of the produced sample is within the temperature boundary of 300-375℃ for a heat gain of 35MW.

### 3.5 Comparison of TGA and DSC Analysis of the BSC and Produced Sample

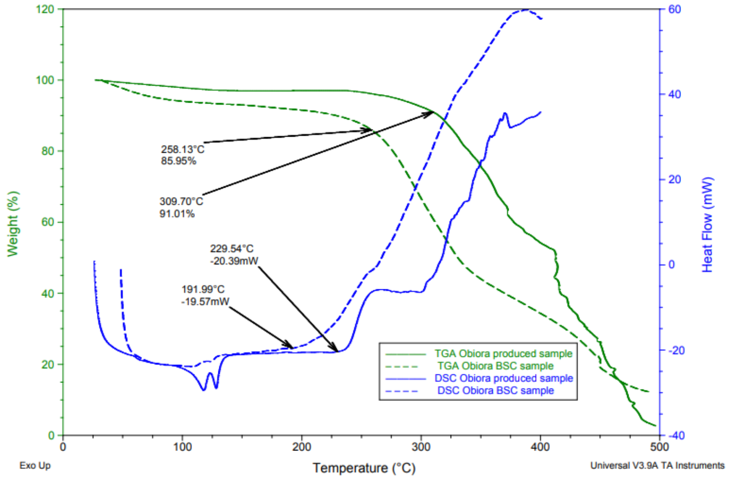


Figure 7: TGA and DSC comparison of the BSC and produced sample.

Figure 7 depicts the comparison between the TGA and DSC analyses of the BSC sample and produced sample. From figure 5, it could be observed that the produced sample was more thermally stable than the BSC sample. The thermal gap of 51.57℃ between the TGA curve of the produced sample and BSC sample in addition to the inflexion temperature points of the two samples- 309.70℃ and 258.13℃ respectively validated this conclusion. From 26.99℃ to the inflexion point temperature of 309.70℃, the weight of the produced sample was 91.01%, implying that a weight loss of only 8.99% occurred during thermal heating. But, from 31.75℃ to the inflexion point temperature of 258.13℃ of the BSC sample, a total weight loss of 14.05% occurred. In addition, the DSC curve of the produced sample identified a heat loss of -20.39MW from 25℃ to the inflexion temperature point of 229.54℃. Also, the DSC curve of the BSC sample showed a heat loss of -19.57MW from 60℃ to the inflexion temperature point of 191.99℃. Therefore, the BSC sample absorbed more heat flux than the produced sample, but its weight loss rate is higher than that of the produced sample.

### 3.6 Data Availability

All the data generated during this study, starting from the thermal conductivity experiment, to thermo-gravimetric analysis, and differential scanning calorimetry analysisof the breadfruit seed coat and the produced sample, are included in this published article and in its supplementary information files.

## IV. Conclusion

This research has shown that the board material developed from a breadfruit seed coat, using the optimal production parameters reported by Ezenwa et al (2019), has a good thermal properties for ceiling padding application. The developed material has a very low thermal conductivity of 0.362 $Wm^{-1}K^{-1}$, and specific heat capacity of 909.1 $JKg^{-1}K^{-1}$,which is very close to that of asbestos reported by Oyekunle et al (2018). This makes the developed material a very good replacement for asbestos. Also the TGA and the DSC analysis shows a good thermal behavior of the produced material to heat. The material showed thermal stability up to the temperature of 379.35°C. Meaning that the material when applied to building as ceiling boards will withstand the heat from sun over long duration.

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