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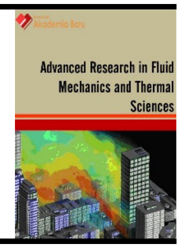

Exploration to Find Green Building Materials from Recycled Solid Wastes

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ABSTRACT

This research studied the properties and the production of thermal insulation materials from recycled solid waste and their applications in residential house construction. Recycled materials that were used as specimens are aluminum, plastic, bagasse, textile, oil palm leaves, twigs, paper, corn cob, rubber, coconut husk, coconut shell, granite, wood, iron, glass, kenaf, and concrete. The specimens were produced by using composite method with epoxy solution as the binder to the loose grain of recycle waste material. Experimental method of the specimens has also been discussed in this project which is by recording the temperature of each specimen in several time periods and apply the data in the Fourier's equation to determine heat transfer rate. This project therefore discussed mainly about theory of heat transfer which consist of conduction and radiation. From the research, it is found that textile, oil palm leaves, kenaf, coconut shell, twigs, paper, and coconut fiber are good insulator. Since the quantity of oil palm leaves and textile are abundantly available and have longer life span as compared to the rest, the oil palm leaves and textile are selected to be the based materials for the building insulation.

1. Introduction

According to American Society of Heating, Refrigerating and Air Conditioning Engineer [1], there are three types of building construction. They are heavy construction, medium construction and light construction. The differences of the construction type may be differs based on how the building was built such as using heavy crane or not, the design of the building, the thickness of the wall and many other aspects that can be considered. Thus, different types of building construction give the different value of heat gain.

Along with the increasing in global warming issues, many products have been developed as one way to maintain the comfortability and to control the temperature in a building. To maintain and control the thermal comfort in the building especially during summer time, the heat transfer into the

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building should be reduced. The air conditioner and fan are some of the mediums used to control thermal comfort in building.

Most residents use fan or air conditioner to remove the heat gain in the house. However, not everyone is able to own an air conditioner because it is quite costly thus low-income residents cannot afford to bear all costs. Furthermore, the maintenance cost of an air conditioner is also high as it uses significant amount of electricity.

In term of waste materials, shortage of landfills sites lead to the worldwide research to develop the recycling technology and to reduce the solid waste as much as possible. The landfill in Malaysia is indeed need solution due to the increase of waste dramatically. To overcome this problem, the recycling of certain waste materials can save the earth from the rubbish heap.

The objective of the research is to identify suitable recycled waste material or combination of waste materials to be used as thermal insulation. Thermal insulation is one of the ways to cool and control the temperature in the house, especially during the day. The cost criteria in the material will be selected from abundant recycled waste materials.

2. Theoretical Analysis

In order study the heat property of the solid waste materials, we need to know how the heat is being transmitted into the specimens and which process is significant to determine the rate of heat transfer. There are 3 method of heat transfer into the specimens, i.e. by conduction, convection and radiation. It is important to determine whether all three processes of heat transfer take place in the specimen during absorbing sunlight or only certain process.

2.1 Heat Conduction

Conduction is the transfer of heat energy from materials that have more energetic particles to less energetic particles nearby as the result of the interaction between particles. Conduction can take place in solids while convection and radiation in liquid and gases respectively. In liquids and gases, convection occurred due to the collision and diffusion of the molecules while in solids, conduction happened due to the combination of vibrations of the molecules.

The geometry of the medium, the thickness, the material, and the temperature difference across the medium can be used to calculate the rate of heat conduction through a medium. For example, a hot water tank which is wrapped with insulating material reduces the rate of heat loss from the tank. The thicker the insulation layer, the better it insulates [2] . Thus, it can be taken that the rate of heat conduction through a plane layer is proportional to the temperature difference across the layer and heat transfer area, but is inversely proportional to the thickness of the layer. The relationship is

$$\dot{Q}_{cond} = kA\frac{T_1 - T_2}{\Delta x} = -kA\frac{\Delta T}{\Delta x} \quad \text{(W)} \tag{1}$$

Where $\dot{Q}_{cond}$ stands for the rate of heat transfer by conduction, k is thermal conductivity of material, A is the area of specimen, ΔT is the temperature different across the specimen, and Δx is the thickness of the specimen. The thermal conductivity (k) used to measure the ability of a material to conduct heat. The above equation is called Fourier's law of heat conduction. This formula is used to determine the rate of heat transfer by conduction through the specimen. $\dot{Q}_{condmax}$ is the maximum value of heat transfer of the specimen which is important in comparing the best material to be used for the building insulation.

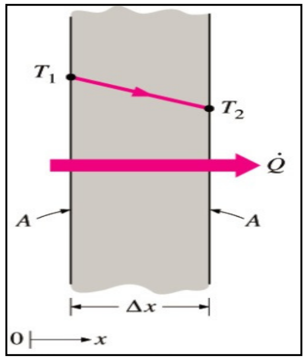

Fig. 1. Heat conduction through a large plane wall of thickness, Δx and area, A [3]

From the analysis, it is obvious that the heat is transferred from the surface that receiving sunlight to the other side of the specimen surface that shading the sun. Therefore, conductivity values of all specimen will be compared to analyze the results.

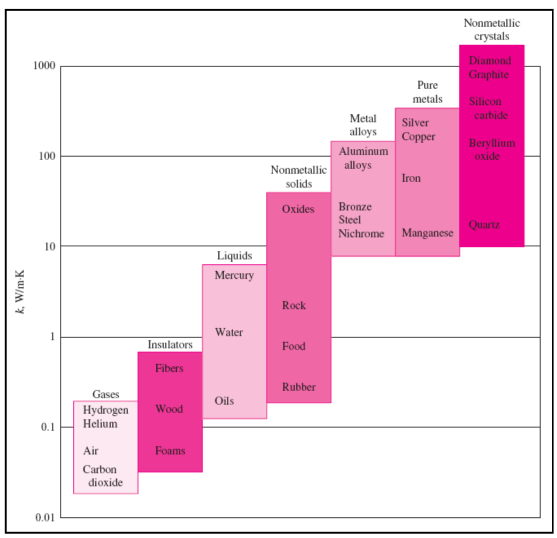

Fig. 2. The range of thermal conductivity of various materials at room temperature [3]

2.2 Heat Convection

Determination of convection heat transfer can be done using Newton's law of cooling. The equation is

$$\dot{Q}_{conv} = hA_s(T_s - T_\infty) \ \ \text{(W)} \tag{2}$$

where $\dot{Q}_{conv}$ stands for the rate of heat transfer by convection, h is the convection heat transfer coefficient, A_s is the surface area through which convection heat transfer takes place, T_s is the surface temperature, and T_∞ is the temperature of the fluid sufficiently far from the surface.

As there is no gas or air in the specimen, therefore no convection process takes place in the specimen. So it is not required here to carry out convection analysis.

2.3 Heat Radiation

Thermal radiation is the emission of electromagnetic waves from all matter which has a temperature greater than the absolute zero where by absolute zero is the lowest limit of the thermodynamic temperature scale, a condition in which the enthalpy and entropy of an ideal gas is cooled to a minimum value of zero (0). Thermal radiation also known as the result of the thermal energy in kinetic energy of randomly moved atoms and molecules in any matter.

The characteristic of heat radiation is depending on the various types and surface properties including temperature, the absorption of the power spectrum and emission spectrum, as stated by Kirchhoff's Laws. Absorption, reflectivity, and emissivity of a material depend on the wavelength of the radiation. The wavelength distribution of electromagnetic radiation can be determined by collecting the temperature.

However, since the thermal radiation transfer a common rate of heat to all specimen as all specimens are placed under the sunlight simultaneously under the same place, it is assumed that all specimen absorbing similar amount of heat by radiation.

3. Methodology

3.1 Materials Selection

Seventeen (17) different types of recycle materials are tested and the best material was selected for thermal insulation based on several criteria of insulation. By using recycle waste materials to produce low cost of thermal insulation, the materials were divided into two categories which is the materials that can absorb heat and the materials that can reflect heat. These categories were determined by conducting repeated experiments running within 15 days.

Figure 3 shows that the material that reflect the ray from sunlight and decrease the rate of heat transfer into the house to make sure it remains in comfortable temperature, while Figure 4 is the specimen that acts as a heat store. This means the specimen absorbs the heat from inside the house and keeps the heat within the materials. So, this will maintain the house in comfortable conditions.

Seventeen waste materials that are suitable for thermal insulation have been collected and undergone some screening. The total of fiber or cellulose contain in the material will influence the data. The higher the amount of fiber or cellulose in a material, the better is the thermal insulation. This is due to the fiber or cellulose have low thermal conductivity which is better for insulation. All insulation material is based on this principle; the more air it is contain in relation to its own weight, the better it insulate [2] . Means, it is the air between the materials is insulating, not the materials.

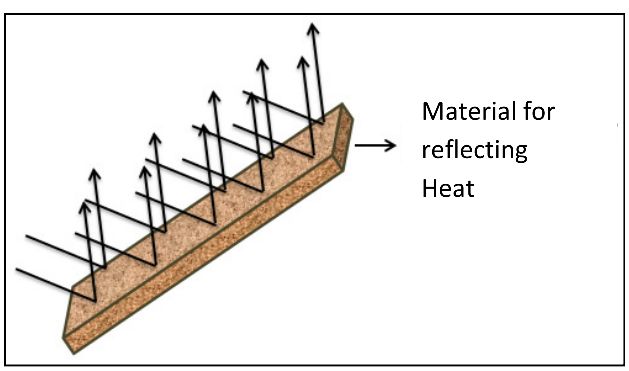

Fig. 3. Illustration of heat reflection on the specimen

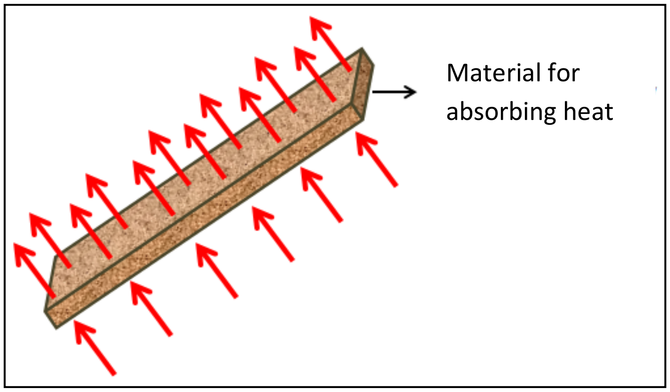

Fig. 4. Illustration of heat absorption into the specimen

The first waste material collected is coconut husk. This coconut fiber consist of 30% of fiber and 70% of pitch [4] . Coconut fiber is a material with low heat conduction and it is practical for thermal insulation. The thermal conductivity for coconut husk is 0.14 W/mK [5]. The second waste material is coconut shell. Coconut shells have the thermal conductivity value of 0.143 W/mK.

The third waste material collected is bagasse. Bagasse is a byproduct of sugarcane production or in other word is a waste material from sugarcane production. Bagasse consist about 11%-16% of fiber and it rich in cellulose. The fourth waste material collected is corn cob. Corn cob is one of the waste materials that have greater thickness. Corn cob has thermal conductivity of 0.096 W/mK. The fifth waste material collected is oil palm leaves. Oil palm leaves are a byproduct from the palm oil production process [5]. Large amount of lingo-cellulose components and high fiber yield can be found in oil palm leaves.

The sixth waste material collected is textile waste. Many materials can produce a textile. The source of material may come from four main sources which are animal, plant, mineral and synthetic. Clothes, woven fabrics and threads are among the most common types of textile waste [4] . By using two types of textile waste which are woven fabric waste (WFW) and woven fabric sub waste (WFS), 56% and 30% of thermal behavior increase respectively. Textile waste known to had environmental, sustainable and economic advantages which lead it to become the possible thermal insulation materials.

Plastic is the seventh waste material collected in order to produce low cost thermal insulation. Plastic bottles and foil-type plastic are the two main forms of plastic. Usually bottle consists of polyethylene (PE) which has low value of thermal conductivity and suitable for thermal insulation application. Cellulose fiber is the eighth waste material collected. Paper is a material that produce cellulose, which in turn is derived from wood [4] . In a paper, about 82% to 85% of it is cellulose. Reprocessed old newspapers give a large amount of fiber.

The ninth collected waste material is rubber. Rubber is known as a though elastic polymeric substance which are made from the latex of a tropical plant or synthetically. Rubber usually produce product such as boots, shoe soles, tents, water container and etc. Thus, rubber often consists of polypropylene (PP) fibers bags which is suitable for insulation [6].

The tenth waste material is twigs. Twigs are easily found in Malaysia because Malaysia is a tropical country which having the same rate of drought and monsoon every year. Twigs are small branches of a tree. Twigs bring features like woods. Color, texture, and pattern of bark on twigs are important in addition to the thickness of the twigs.

Kenaf *(Hibiscus cannabicus)* is the eleventh collected material used to make insulation specimen. The fibers in kenaf are found in the bark and core wood [7]. The bark constitutes 40% of the plant. Kenaf are mostly grown in India, Bangladesh, United State of America, Indonesia, South Africa, Vietnam, Thailand, parts of Africa and even Malaysia for its fiber. The stem produces two types of fiber which are coarser fiber in the outer layer and finer fiber in the core [8].

Granite also the material collected to make insulation specimen. Granite is a stone that is always massive (lacking any internal structure), tough and hard, and therefore it has gained widespread use by all mankind, and more recently as a construction stone.

The thirteenth collected material for insulation is wood. Wood itself is a natural insulation due to air pocket within its cellular structure. A hollow cell which provides a minute air space hence an insulating unit showed that wood is the natural fiber [9].

Another four materials are aluminum, iron, glass and concrete. Aluminum happened to have shiny surface and it might be suitable for thermal insulation. Glass also has the shiny surface just like aluminum. The shiny surface of material will produce reflection to the surface. Material with shiny surface is suitable to be thermal insulation since it is poorly absorbing thermal radiation.

3.2 Experimental Apparatus and Instrumentation
3.2.1 The specimen

The specimen is made of crushed or fine grain of recycled waste materials mixed with the polymer binder namely epoxy in a mold of 50mm x 50mm x 12mm. After the mixture dried, they are taken out from the mold and kept in a safe place for use in the testing. Figure 5 shows the bagasse specimen that was prepared using this method.

Fig. 5. The bagasse specimen

3.2.2 The instrument

The instrument used are vernier calipers and laser thermometer as shown in Figure 6 below. The vernier calipers is used to measure the thickness of the specimen for Heat Transfer rate calculation.

Fig. 6. Infrared (IR) thermometer

3.2.3 Measuring procedures

17 specimens were arranged under the sunlight during day time from morning to late afternoon in order to absorb maximum heat so that the temperature difference would be more apparent. Figure 7 shows the 17 specimens being placed under the sunlight during experimenting.

Fig. 7. The specimen setup for the experiment

By using the laser infrared thermometer, as shown in Figure 8, the temperature of the specimens was taken every 30 minutes. The measuring procedure is repeated for the rest 17 number of other specimens.

Fig. 8. The temperature of the top surface of specimen is measured and recorded

4. Results and Discussion

The figures Figure 9 and Figure 10 below showed the graph of data collection for this project, representing measured temperature on the top and bottom surfaces of all specimens respectively. The data below were then used in the heat transfer formula to calculate the thermal conductivity of each specimen and filled up in the Table 1 below. The Table 1 below representing data calculated from the experiment for each specimen (average of 10 data).

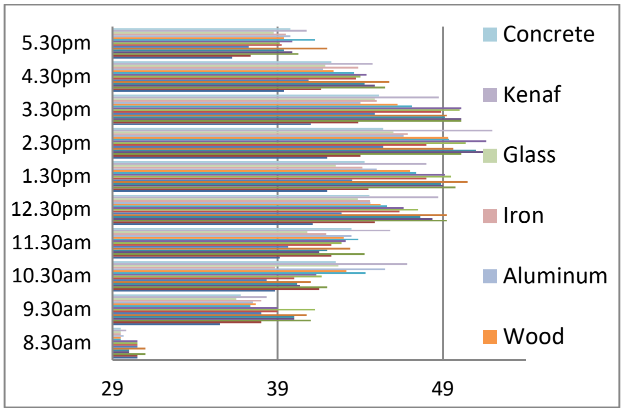

Fig. 9. Time of measuring versus Temperature in degree Celsius (top surface)

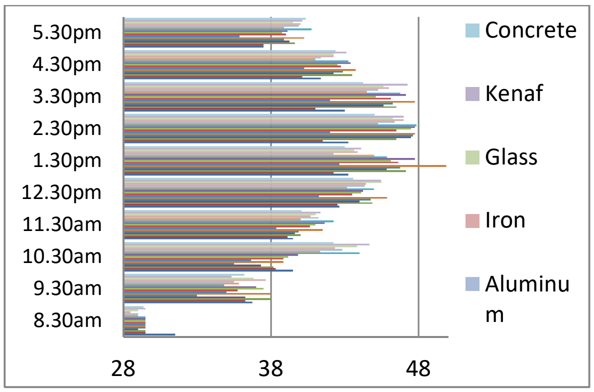

Fig. 10. Time of measuring versus Temperature in degree Celsius (bottom surface)

Table 1
Calculated Thermal Conductivity value for each specimen using measured data

Material	Thermal conductivity, $k\ (W/m.K)$	Area, $A\ (m^2)$	Thickness, Δx (m)
Plastic	0.400	0.00406	0.01443
Bagasse	0.046	0.00364	0.01618
Textile	0.230	0.00352	0.01545
Oil palm leaves	0.127	0.00365	0.01515
Twigs	0.130	0.00408	0.01548
Paper	0.230	0.00381	0.01520
Corn cob	0.096	0.00388	0.01528
Rubber	0.130	0.00418	0.01923
Coconut fiber	0.140	0.00388	0.01435
Coconut shell	0.143	0.00371	0.01505
Granite	1.700	0.00424	0.02135
Wood	0.130	0.00369	0.01615
Aluminum	205	0.00383	0.01540
Iron	80	0.00387	0.01514
Glass	1.05	0.00413	0.02145
Kenaf	0.0208	0.00386	0.01645
Concrete	0.7	0.00963	0.04535

Figure 11 shows the comparison of the rate of heat transfer for bagasse and oil palm leaves which both of them are opaque insulation. Bagasse and oil palm leaves had been chosen because bagasse has the lowest temperature while oil palm leaves has the highest temperature. Thus, the comparison can be seen clearly. The plotted graph is from the calculated data which use the equation of Fourier's law of heat conduction. The oil palm leave represented by the blue line while red line represented bagasse specimen. The thickness of the materials, Δx is the specimen thickness with 0.01515 m and 0.016175 m for oil palm leave and bagasse respectively.

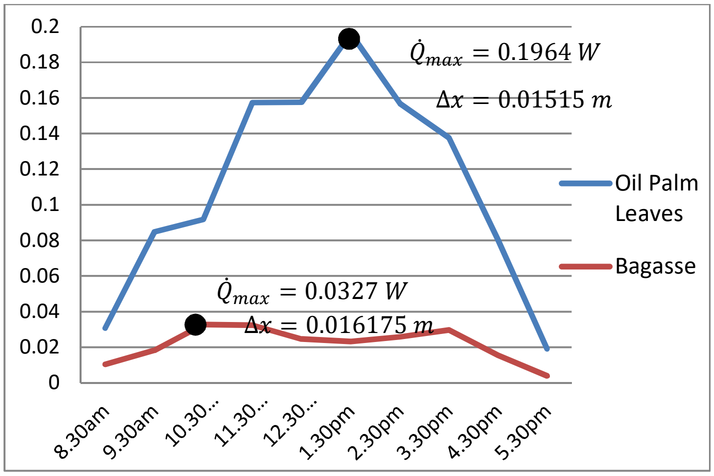

Fig. 11. Comparison for rate of heat transfer (in Watt) versus measuring time for bagasse and oil palm leaves

The rate of heat transfer, $\dot{Q}_{max}$ for oil palm leaves is 0.1964 W while for bagasse is 0.0327 W. Though the $\dot{Q}_{max}$ for each material did not occurred at the same time as for oil palm leaves, the maximum temperature difference occurred at 1.30 pm for oil palm leave while for bagasse at 10.30 am. Figure 12 is the data plotted for rate of heat transfer or transparent insulation and the value of $\dot{Q}_{max}$ for plastic which is -0.0422 W. Plastic gives negative value for rate of heat transfer as it has more heat gain from the solar radiation, therefore plastic give reverse reaction compare to the other material which give the positive value. As for that, it is obviously shown that plastic is the best material due to the lower the rate of heat transfer, the better it is insulated. Beside that plastic is abundantly available in our daily solid waste quantity.

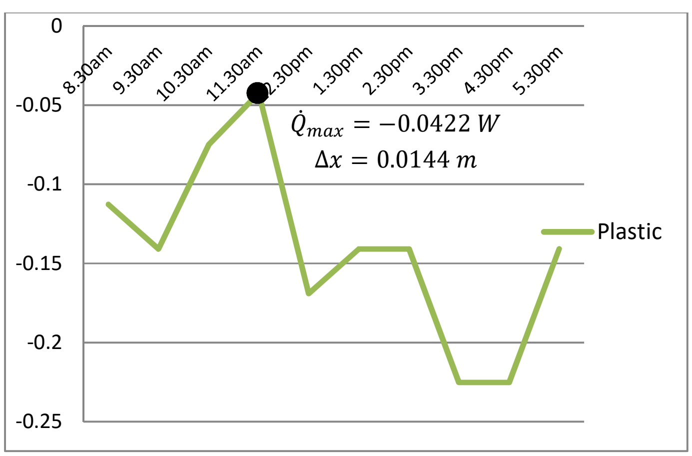

Fig. 12. Rate of heat transfer for plastic (in Watt) versus time of measuring

5. Conclusion

The material with the high rate of heat transfer or also known as the heat absorber materials which able to absorb heat such as textile, oil palm leaves, kenaf, coconut shell, twigs, paper, and coconut fiber. These materials recorded temperature of 50°C and above. That means these materials can absorb most of the heat from sunray before it transfers the balance heat into the house or room. Meanwhile, the material with high rate of heat transfer or also known as the heating materials which able to transfer heat into the house faster such as plastic, concrete, corn cob, bagasse, glass, aluminum, iron, rubber, wood, and granite. These materials recorded the temperature of 49°C and below as the heat is transferred to the other side of the specimen by conduction faster than the heat absorbing materials.

As to achieve the objective of this project which is to produce the insulating material, the materials that has lowest rate of heat transfer will be selected to be the insulating product for green building applications. The best materials are oil palm leaves and recycled textile due to their low heat transfer rate and abundantly available in solid waste materials disposal paths and networks. Residential house construction can consider recycled textile material as the insulation for under ground floor and oil palm leaves for the roof and wall insulation.

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