Assessing Physical Properties of Building Insulation Materials Prepared from Oyster Shells and Gypsum

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ABSTRACT

The purpose of this research is to study the physical properties of insulation material made from the mixture of gypsum and oyster shells powder. The insulation sheet of 150×150×10 mm^3 was fabricated with different percentage of oyster shells powder (0%, 10%, 20% and 30%). Consequently, the density, thermal conductivity and compressive strength of insulation sheets were determined. The relationship between physical properties and the composition of insulation sheets were reported. The results show that the density, thermal conductivity and compressive strength decrease as the percentage of oyster shell powder increase. The comparison of test results from this work and others were shown. In conclusion, by mixing the oyster shell powder with conventional material to fabricate construction material improves the thermal insulation quality and encourages the utilization of natural waste materials to industrial use.

Keywords: insulation materials, oyster shells, gypsum, physical properties

INTRODUCTION

At present, the application of waste materials, especially agricultural waste, for energy generation in waste power plant or manufacturing construction materials allow them as a resource material that would solve disposal problems and reduce the cost. Many composite materials were studied using waste such as sawdust, wastepaper (Saadie, 2016; Aigbomian et al., 2013), wood waste (Ogunwusi, 2014), rubber waste (Benazzouk et al., 2008) and agricultural waste (Binici et al., 2016; Ballester et al., 2007). Therefore, the developing construction materials with low thermal conductivity and lightweight based on the mixture of conventional and waste materials will be an interesting approach.

Oyster is well-known food as a good source of protein, calcium and other essential nutrients. Chon Buri is famous for many types of fresh seafood, especially oyster fishing. As the consumption of oyster grows, results the greater accumulation of oyster shells. Chemical composition of oyster shells is mainly calcium carbonate, approximately 96% and other minerals (Yoon et al., 2003; Huh et al., 2016). Some researchers have conducted experiments on using crushed oyster shells to fabricate

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interlocking bricks (Klathae, 2017; Yoon et al., 2003). Gypsum board, which is a mixture of gypsum, fiberglass, and silicon, is widely used in both residential and commercial building due to its lightweight, fast installation and ease of disassembly. Some researchers conducted the experiment by mixing gypsum power and waste material to study physical and thermal properties of those composite materials (Faiza et al., 2015; Binici et al., 2016).

In this work, the objectives are to use oyster shell, as a waste material, to develop the construction material with low thermal conductivity and determine some physical properties. The mixtures are prepared using different composition of oyster shell and gypsum powder. The experiment tests were conducted to investigate density, thermal conductivity and compressive strength of samples. The relationship of physical properties with the percentage of oyster shell powder are also reported.

MATERIALS AND METHODS

Materials

Natural oyster shells used in this study were acquired from Bang Saen beach and then dried under sunlight for 7 days. The oyster shell powder was obtained by crushing using stone mortar and then sieved using a 1 mm sieve. The preparation steps are shown in Figure 1.

Mixing Procedure

The oyster shell powder and gypsum powder will be weighed using 0.01 g precision digital balance. The powders were mixed, and the distilled water was slowly added while stirring to ensure uniform paste. The ratio of water and mix powders are 1:2 (water: powder = 1:2). The oyster shell powder compositions of the mixture are 0% (control), 10%, 20% and 30% (by weight) as described in Table 1.

Sample preparation

Three 150 × 150 × 10 mm^3 sheets were prepared from each mixture. First, the pastes were delivered in a mold, a rectangular stainless-steel tray, and compressed by 58.8 newton weight. The tray, especially around the edges, was oiled so that the paste would not stick. Due to the water content in the samples is a major factor that affect the thermal conductivity, so the samples were dried in an oven at 45 ºC for 24 h and then weighed until it retained a consistent weight. The average density, thermal conductivity and compressive strength of each conditions were

a b c d

Figure 1 Preparation of oyster shell powder. a) Dried under sunlight. b) Crushing. c) Sieving through 1 mm sieve. d) Oyster shell powder.

Table 1 Mixture compositions of all samples and determined properties.

Samples	Fresh mixture proportions			Physical properties of finished samples		
	Gypsum powder (g)	Water (g)	Oyster shell (g)	Density (kg/m^3)	Thermal conductivity (W/m-K)	Compressive strength (kPa)
0% oyster shells	300	150	0	1,248	0.1470	48.0
10% oyster shells	300	150	45	1,236	0.1282	28.5
20% oyster shells	300	150	90	1,206	0.0923	19.9
30% oyster shells	300	150	135	1,165	0.0704	15.0

determined.

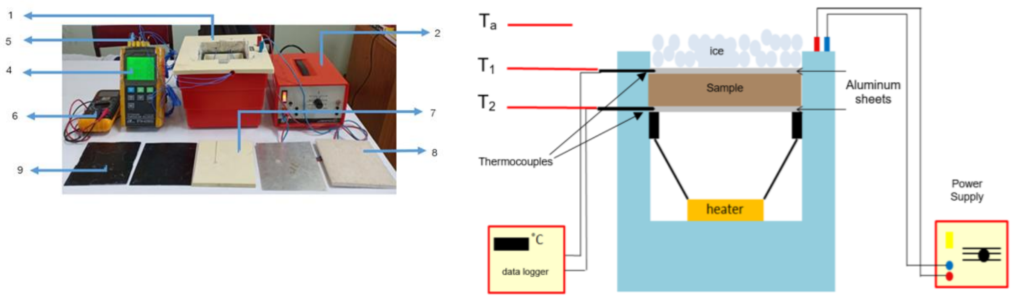
Physical properties measurement

Density

Each sample was measured for its size by using a digital Vernier caliper and was then weighed. The density of each sample was calculated, and the average values of each mixture are recorded in Table 1. The average density versus percentage of oyster shell powder are shown in Figure 4.

Thermal conductivity

Heat conduction of the sample sheet was determined using the standard DIN-52612 heat transfer measuring set (one direction heat flow), as showed in Figure 2. The instrument consists of a heater (1), 12-V DC power supply (2), 12 channels temperature recorder model BTM-4208SD (4), thermocouple K-type (5), multimeter (6), intermediate plate for aligning thermocouple (7), sample sheet (8), aluminum sheets of 150 × 150 × 3 mm^3 (9). During the measurement, the upper surface is in contact with ice bag as the heat sink and lower surface will face the



a b

Figure 2 a) Heat conduction measurement set and b) Schematic diagram of thermal conductivity testing (side view).

flow of heat conduction. The temperature difference was recorded every 10 seconds by thermocouple and plotted as shown in Figure 3. At thermal equilibrium, the temperature difference between sample surfaces is constant. Due to the well-insulated container, all the power radiated from the heater is flowed upward in one-direction. The rate of heat flow is calculated from the electric current multiply by voltage applied. The thermal conductivity values (k) were calculated using the following equation:

$$k = \frac{\Delta Q}{\Delta t}\frac{d}{A\Delta T}$$

where $\Delta Q/\Delta t$ is the rate of heat flowing through the sample sheet (W), d is the thickness of the sample materials (m), A is the cross-sectional area (m^2) and ΔT is temperature difference between the upper and lower surfaces of sample (°C). The thermal conductivity versus percentage of oyster shell powder are shown in Figure 5.

Compressive strength

The compressive strength test was performed by placing the sample material at the central point between the supporting base and the flat stainless-steel plate (TIS 219-2552). The rate of load was adjusted gradually until its limit. The compressive strengths σ were calculated using maximum load, F, per square unit area, A. The compressive strength versus percentage of oyster shell powder are shown in Figure 7.

RESULTS AND DISCUSSION

Density

The sheet density of different compositions was reported in Table 1. The

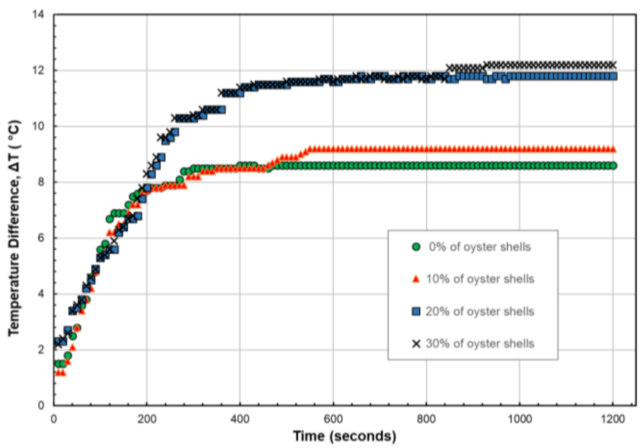


Figure 3 Temperature difference between sample surfaces versus time for different percentage composition of oyster shell.

average density of each mixture decreased from 1,248 kg/m^3 for pure gypsum to 1,165 kg/m^3 for 30% oyster shell powder. The density decreases as the percentage of oyster shell powder increases as shown in Figure 4. The relationship is: $\rho = 1255.6 - 2.7766X$, where X is percentage of oyster shell powder (%), with R^2=0.9445. The equation has been a good agreement to experimental with high R^2 value. The density of sample sheet depends on the water-powder ratio and trapped air. The weight compression during sample preparation was ensured that the trapped air is minimized. The trend of density for oyster shell is quite similar to 1,152 kg/m^3 that obtained by Yoon (Yoon et al. 2003). Table 2 shows the comparison of the sample density with other sources.

Thermal conductivity

The thermal conductivity of different compositions was reported in Table 1. The average thermal conductivity of each mixture decreased from 0.1470 to 0.0704 W/m-K for 30% oyster shell powder. The thermal conductivity decreases as the percentage of oyster shell powder increases as shown in Figure 5. The relationship is: $k = 0.1493 - 0.0027X$, where X is percentage of oyster shell powder (%), with R^2=0.9858. The equation has been a good agreement to experimental with high R^2 value. To compare with other works, Table 2 shows the comparison of the sample thermal conductivity with other sources. It can be observed that the thermal conductivity of sample sheets in this work can be compared to other source. The reduction of thermal conductivity was partly result of trapped air, porosity, lower thermal conductivity of oyster shell powder and discontinuous in microscopic structure. The thermal conductivity decreases with the decrease of density as shown in Figure 6. The correlation is: $k = 2E\text{-}06e^{0.0089\rho}$, where ρ is the density in kg/m^3, with R^2= 0.9813. Benazzouk (Benazzouk et al., 2008) conducted experimental and modelling investigation and reported a similar result from Figure 6.

Compressive strength

The compressive strength of different compositions was reported in Table 1.

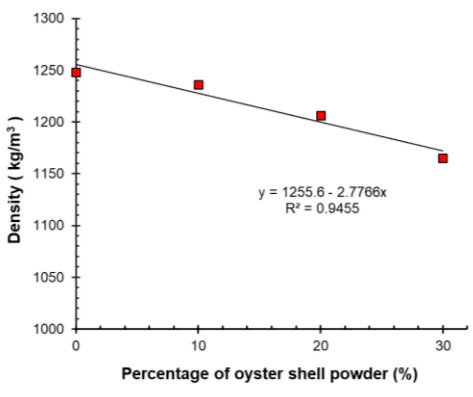


Figure 4 Average density versus percentage of oyster shell powder.

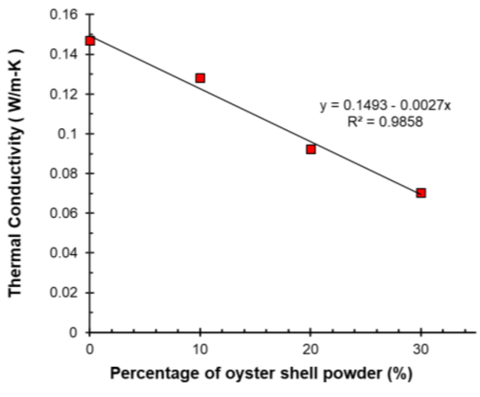


Figure 5 Thermal conductivity versus percentage of oyster shell powder.

Table 2 Comparison of physical properties.

Source	Density (kg/m^3)	Thermal Conductivity (W/m-K)	Compressive Strength (kPa)
This work	1,165 – 1,248	0.0704 – 0.1470	15 – 48
Gypsum board (*Notification of the Ministry of Energy, B.E.2552, **TIS219-2552)	800	0.282*	37 – 98 **
Concrete slab (Notification of the Ministry of Energy, B.E.2552)	2,400	1.442	NA
Gypsum board (USA and Japan) (Manzello et al., 2008)	NA	0.238 – 0.292	NA
Gypsum with waste materials (Saadie, 2016)	500 – 630	0.05 – 0.29	1,500 – 5,000 (Cylindrical shape)

The average compressive strength of each mixture decreased from 48.0 to 15.0 kPa for 30% oyster shell powder. The compressive strength decreases as the percentage of oyster shell powder increases as shown in Figure 7. The relationship is: $k = 47.64 - 2.171X + 0.0365X^2$, where X is percentage of oyster shell powder (%), with R^2=0.9959. The equation has been a good agreement to experimental with high R^2 value. Table 2 shows the comparison of the sample compressive strength with other sources. It shows that they were comparable with other materials, however the strength of 30% oyster shell powder mixture were slightly below of the standard. The reduction in strength with an increase of oyster shell powder proportion is due to the poor adhesion between oyster shell powder and gypsum powder. As a result, the bond strength becomes weaker.

CONCLUSIONS

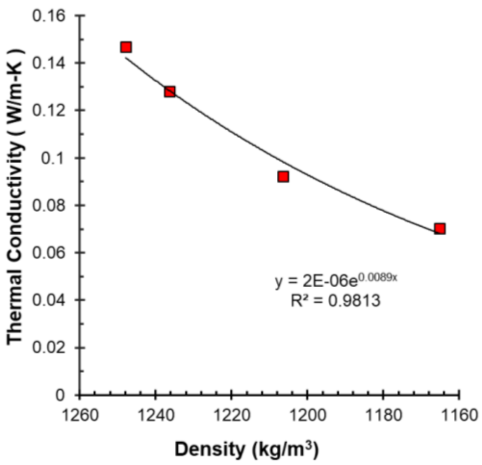


Figure 6 Thermal conductivity versus density.

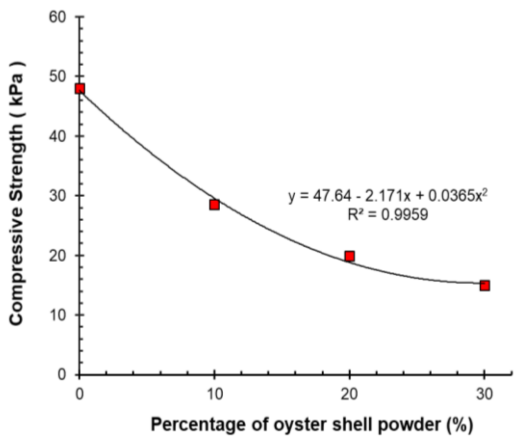


Figure 7 Compressive strength versus percentage of oyster shell powder.

This work presented the application of oyster shells to fabricate insulation sheets by mixing gypsum powder and oyster shell powder with different compositions. Some physical properties; density, thermal conductivity and compressive strength were determined. The study also proposed the relationships between the physical property and the percentage of oyster shell powder. The use of oyster shell powder can decrease the density and thermal conductivity significantly, however, the compressive strength also decreases.

In conclusion, the oyster shell powder can be used as the alternative substance for fabrication of insulation material. The enhancement in lightweight and thermal conductivity are promising but the load-bearing structure application would not be recommended unless the required strength is verified. However, they can be used for many purposes such as for ceiling insulation and for decorative painting.

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