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Fabrication of a Wall-Panel Board Using Rice Husk and Red Clay-Based Geopolymer

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Abstract

This study fabricated a wall-panel board made of rice husk and red clay-based geopolymer. The geopolymer paste was studied at varying molarities of alkali-activator solution with a fixed ratio of Na_2SiO_3/NaOH at 2.5. A calcined red clay was used as the aluminosilicate precursor at a mass ratio of 1:1 to the activator solution. The geopolymer paste was heated at 80 °C for 12 h in a conventional oven and then aged for seven days at room condition. It was found out that 12 molars of NaOH in geopolymer paste provided the maximum flexural strength of 5.48 MPa. The rice husk was then introduced to the geopolymer paste at varying amounts from 10 to 20 wt% based on the mass of the paste. It was observed that the flexural strength and bulk density of the solidified composites decreased with an increasing amount of rice husks. Correspondingly, the measured flexural strengths varied from 4.21 to 3.13 MPa, whereas the bulk densities measured from 1.84 to 1.51 g/cm^3. It was further observed that the addition of rice husks at 15 wt% in the geopolymer composite exhibited a lower thermal conductivity of 0.297 W/m-°K. The increased addition of rice husks above such amount negligibly decreased the thermal conductivity of the geopolymer composite. Lastly, the fabricated wall-panel board using the rice husk and red clay-based geopolymer is a promising lightweight and insulating material in the construction industry.

***Keywords**: red clay, geopolymer, wall-panel board, alkali activator, thermal conductivity*

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1. Introduction

A wall-panel board is a single piece of construction material that is usually flat and cut into a rectangular shape. It is commonly fabricated at an offsite location and brought to the site as a fully assembled piece for installation (Erik and Hensly, 2017). This construction material is usually made of concrete, timber, masonry and others. The hardened flat materials are used to fill the area between two adjacent supports or joints, which provide stability and enclosure. Among the construction materials, the concrete wall-panel composed of cement, sand and gravel is readily available. Other construction materials are introduced to the concrete mix to provide tailored properties such as decoration, lightweight, thermal insulation and soundproofing.

To minimize the reliance on the concrete mix in the wall panel fabrication, industrial waste and natural resources are introduced in the construction batch. One of the abundant natural resources in the Philippines is rice husks that potentially contribute thermal insulation and lightness to the wall panel. This natural by-product is usually abandoned in a postharvest area with an average of 2 million metric tons accumulated per year (Nindoy, 2016), which severely affect the environment. Also, the cement binder in the concrete mix can be readily replaced with a natural binder in the form of red clay deposits that are available in large quantities. The red clay is commonly used in traditional fired brick or tile production (high energy-consuming process). On the other hand, the rice husks, having a significant amount of silica, are usually used in ceramic production (Babaso and Sharanagouda, 2016). The specific applications to the industry of these natural resources are greatly influenced by their inherent chemical and physical characteristics. Hence, the pairwise combination of red clay and rice husk could become a potential aluminosilicate precursor for a geopolymer composite.

Geopolymer is a natural binding agent that predominantly employs an amorphous clay together with active chemical agents. It potentially replaces cement as a binder. Geopolymer is an aluminosilicate ceramic with alkaline-activated minerals that are formed by the polymerization of silicon and aluminum species. The principal binding phase in geopolymers is an amorphous aluminosilicate gel that consists of three-dimensional frameworks of SiO_4^- and AlO_4^- tetrahedra linked by corner-shared O atoms. The negatively charged tetrahedral Al sites in the network are charged balanced by alkali metal ions such as Na^+ and/or K^+. The geopolymer possesses a lot of interesting properties such as quick setting and hardening, excellent bond strength, long-term durability, and good fire and acid resistance. Due to such properties, the geopolymer has a wide variety of industrial applications (Dimitrios and Ioana, 2004). Also, the most important advantage of geopolymer is its low manufacturing energy consumption and low gaseous emissions (Glasby, 1991), making it a “green material” (Dimitrios and Ioana, 2004).

As reported by Davidovits (1991), the original raw material of geopolymer is a metakaolinite that is a calcined clay from any clay of white clay, ball clay and kaolin. The calcination is conducted to achieve the amorphous phase metakaolinite structure. This amorphous structure is conveniently activated by alkali hydroxide and/or alkali silicate (Glasby, 1991). The resulting geopolymer is a mixture of these main raw materials: aluminosilicate precursor, alkali-activator and water. The mixture is either cured at room temperature or in a conventional oven at 40-85 °C (Wattanasiriwech *et al.*, 2017) for 24 h or longer to give time for the polymeric reaction to take place. To achieve the optimal physical properties, the solidified geopolymer paste is further aged from 7 to 28 days. The physical properties of the solidified geopolymer paste are strongly dependent on the type of aluminosilicate precursor and the molarity of the alkali-activator.

Owing to the eco-friendly process of geopolymer, many researchers have demonstrated experiments on alternative aluminosilicate materials such as fly ash and kaolinite. However, only few studies were conducted on low purity clays such as red clay. Still, it has been proven that the low purity clays and/or red clays can be used as aluminosilicate materials for geopolymer (Uddin and Saraswathy, 2007; Essaidi *et al.*, 2013; Mostafa *et al.*, 2014). This is particularly reported in a study that used calcined low purity clays as raw materials for geopolymer to produce a geo-concrete (Mostafa *et al.*, 2014). The high silica content and feldspar in the low purity clays are considered as fillers, which add to promising properties of the geopolymer concrete. On the other hand, a unique study of Duan *et al.* (2017) presented thermal insulating and lightweight composites from metakaolin geopolymer and polystyrene particles as fillers. This is similar to a study that uses wood particles as aggregates (Sarmin, 2015) in a geopolymer mix. Moreover, Korniejenko *et al.* (2016) reported the incorporation of other natural fibers such as coir, cotton, raffia and sisal fibers in a geopolymer mix, which acted as reinforcing aggregates and filler.

With the aforementioned composites of geopolymer and additives, there are very limited reports on using the red clay as the aluminosilicate precursor for fabricating a non-load bearing structural board. To the best of the authors' knowledge, the use of rice husk as aggregate fibers in the red clay-based geopolymer has not yet been reported elsewhere. Therefore, this study was carried out to fabricate a wall-panel board using a red clay-based geopolymer paste incorporated with natural rice husk. The effect of varying amounts of rice husks in geopolymer paste was investigated in terms of the physical, mechanical and thermal properties of the wall-panel board. Specifically, the study had fourfold aims. First, it determined the effect of the different concentrations of alkali activator in the red clay-based geopolymer paste in terms of its physical and mechanical properties. Second, the study characterized the effect of varying amount of rice husk added to the red clay-based geopolymer paste in terms of physical (density) and mechanical properties (flexural). Third, it measured the thermal conductivity of geo-composite with the different amounts of rice husk. Finally, the study fabricated a prototype of the panel board made of the geopolymer and rice husk composite.

2. Methodology

2.1 Preparation of the Raw Materials

The red clay raw material used in the experiment was taken from Lama-Lama, Lanao del Norte, Philippines. It was dried to constant weight at 110 °C and pulverized. Its oxide data (Table 1) was taken using X-ray Fluorescence Machine (XRF) (S2 PUMA, Bruker AXS GmbH Karlsruhe, Germany). The pulverized red clay was sieved through 100 mesh (149 μm) and was calcined at 800 °C for 5 h.

Table 1. The oxide analysis of uncalcined-red clay

Oxides	Lama-Lama clay
SiO_2	41.50
Al_2O_3	25.14
K_2O	0.50
Na_2O	0.50
Fe_2O_3	8.18
TiO_2	0.24
CaO	0.50
MgO	1.10
SO_3	0.00
ZrO_3	0.00
LOI	22.35
Total	100.00

The calcination process was conducted to ensure the amorphous structure of red clay. Sun-dried for a day, the rice husk was taken from Tamparan, Lanao del Sur. The unground form of rice husks was used directly in the experiment with particle size of about less than 2000 microns (Velioglu Tosuner *et al.*, 2019) as shown in Figure 1. The alkali-activator was a combination of sodium silicate (liquid form) and sodium hydroxide (solid). The former was bought from Tri-GL's Marketing in Poblacion, Iligan City, while the latter was purchased from Joelmar's Trading in Rabago in the same city.

Figure 1. The unground form of rice husks used in the study

2.2 Preparation and Solidification of the Geopolymer Paste

The alkali-activator solution was initially prepared by dissolving the pellet of sodium hydroxide in tap water with the aid of a stirring rod. Table 2 lists the mass of NaOH pellets dissolved in water to obtain the desired molarity.

Table 2. Mass of NaOH pellets in 1 L of water

NaOH molarity (M)	Mass of NaOH pellets dissolved in 1 L (0.26 gal) of tap water (g)
6	240
8	320
10	400
12	480

The solution was mixed with the sodium silicate (Na_2SiO_3) at a fixed molar ratio of 5:2 (Na_2SiO_3/NaOH). In calculating the number of moles of the sodium silicate needed to be mixed with any known molarities of NaOH, Equation 1 was used.

$$K\ moles\ NaOH \times \frac{5\ moles\ of\ sodium\ silicate}{2\ moles\ of\ NaOH} = C\ moles\ of\ sodium\ silicate \qquad (1)$$

where K is the known molarities of NaOH and C is the calculated molarities of the sodium silicate. For example, when six molarities of NaOH were prepared, the calculated amount of sodium silicate was 15 molarities mixed in solution. The same calculation was followed for the rest of the variation until 12 M of NaOH. The resulting stock solutions were then left to stand for about 24 h.

After formulating the alkali-activator solution with the different NaOH concentrations, the solution was mixed with the red clay powder at a fixed mass ratio of 1:1. This ratio was implemented in the experiment because it demonstrated sufficient fluidity for easy wetting on rice husks allowing convenient mixing with the geopolymer paste. The higher solid ratio had caused serious problems during mixing due to high viscosity. This observation was consistent with the previous study of Jaya *et al.* (2018a). Moreover, according to Ahmad *et al.* (2015), it is economical to form the geopolymer at that solid ratio. The mixing step was done using an egg mixer. Table 3 presents the composition of the alkali-activator solution with the addition of calcined red clay.

Table 3. Composition of alkali-activator solution

Red clay/alkaline activator ratio	Na_2SiO_3/NaOH (M) ratio	Na_2SiO_3 (g)	Molarity, NaOH (g)
(1:1)	(5:2)	150	6M (60)
		200	8M (80)
		250	10M (100)
		300	12M (120)

The geopolymer paste was then cast into 10 pieces of test bar molds made of acetate film (Figure 2). The rectangular cavity of the acetate mold had dimensions of 80 x 20 x 15 mm. Wooden popsicle sticks were fastened to the external surface of the acetate mold with the aid of a double-sided tape to prevent the samples from sagging and warping. After casting the geopolymer paste, the mold was covered with an acetate film to prevent excessive drying. Afterward, the samples were heated at 80 °C in a conventional oven for 12 h.

After this, the samples were aged for about 7 days at room conditions before a flexural strength test.

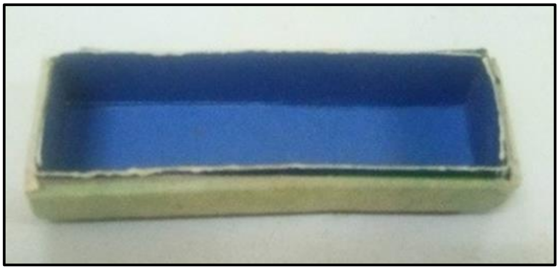


Figure 2. Test bar mold made of acetate film

2.3 Fabrication of Geopolymer Composite with Rice Husk

Table 4 shows the batch formulations of the geopolymer paste (GP) incorporated with varying amounts of rice husks (RH). The amounts of rice husks were at 10, 15 and 20 wt% based on the mass of the geopolymer paste. The geopolymer paste that demonstrated the highest mechanical strength (flexural) was used for this experiment. The rice husk was then manually mixed with an egg mixer to achieve better homogeneity. The homogenized composite slurries were then cast into the acetate molds presented in Figure 2. Three samples were made for each batch formulation to allow replication for testing the mechanical properties. The composite samples were heated in a conventional oven at 80 °C for 12 h and were aged for seven days at room conditions.

Table 4. Batch compositions of the geopolymer composites

Materials	GP + 0 RH	GP + 10 RH	GP + 15 RH	GP + 20 RH
Red clay (g)	336	336	336	336
Rice Husk % added (g)	0	33.6	50.4	67.2
NaOH (M) solution (g)	96	96	96	96
Na_2SiO_3 solution (g)	240	240	240	240

A prototype of the wall-panel board was fabricated using the amount of rice husks that provided the best mechanical property. Since the fabrication required a large mass of the geopolymer composite, the geopolymer paste and rice husks were mechanically blunged for about 20 min to achieve uniform mixing. About 2 kg of calcined red clay were prepared for this fabrication step. A rectangular metal mold was assembled in the laboratory with an interior cavity of 330 x 220 x 30 mm. It was constructed by manually folding a plain metal sheet with a thickness of 2 mm. The folded sheet was attached to a welded angular frame to establish rigidity. The geopolymer composite paste was then cast into the metal mold cavity equipped with a metal sheet cover as shown in Figure 3a. The cover was interfaced with an acetate film to avoid unwanted corrosion. For fabricating the thermal conductivity samples, an acetate film mold was assembled to dimensions of 100 x 10 x 20 mm as shown in Figure 3b. About 336 g of calcined red clay were prepared for each amount of rice husks, which were mechanically blunged with the geopolymer paste. One sample was made for each proportion of rice husk for a total of three samples. Subsequently, the cast samples were heated in the conventional oven using the same heating protocol mentioned previously.

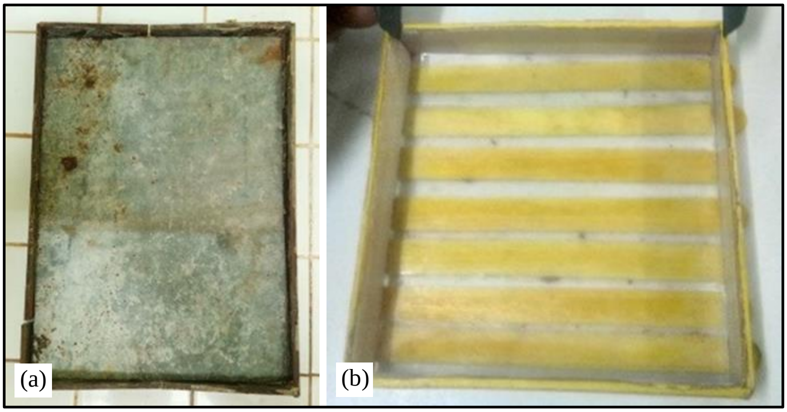


Figure 3. Molds for geopolymer and rice husk composites: metal mold for the wall-panel board (a) and acetate mold for thermal conductivity samples (b)

2.4 Characterizations of Physical, Mechanical and Thermal Properties

The measurement of the flexural strength followed the standard of American Society for Testing and Materials (ASTM) C78 (2002). Each test bar sample was measured using an unconfined compressive machine (AASHTO T 208, Marui & Co. Ltd., Japan). The mass and dimensions of the sample were measured for this test. There was also a 5 cm allowance from both ends of the test bar sample. This was done to determine the real flexural strength of the sample. The load was oriented to the center of the sample, which was called the point of fracture. After which, the lever was rotated continually to allow the dial to move, which was situated at the upper part of the instrument. The lever was then rotated continually until the sample broke. The number of rotations of the lever was recorded, and the load on the dial at which the sample broke was also computed as in Equation 2.

$$y = 0.2669 + 0.1809x \tag{2}$$

where y is applied load (kg) and x represents the number of divisions. After determining the load, the modulus of rupture (MOR), σ, was computed using Equation 3.

$$\sigma = (3FL)/(2bh^2) \tag{3}$$

where F is the load applied to the sample or the breaking load, L is the length between supports (mm), b is the width and h is the thickness of the sample.

For the determination of the bulk density (ρ) of the samples, Equation 4 was utilized. The samples were weighed using an electronic balance, and the volume was determined by measuring the length, width and height of the samples.

$$\rho = Mg/Vg \tag{4}$$

where Mg is the mass of the sample (g), and the Vg represents the computed bulk volume.

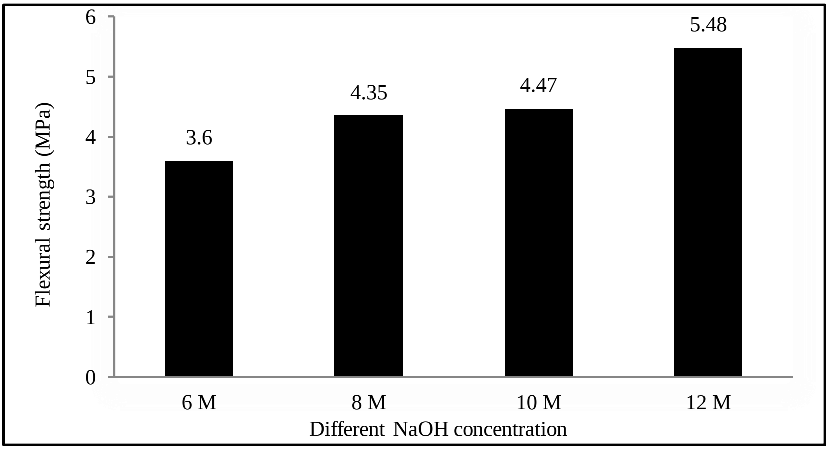
The thermal conductivity of the geopolymer composites was characterized using three samples with varying amounts of rice husks (10, 15 and 20%). The solidified tile samples were polished using sandpaper (number 60) to produce the flat surfaces required by the test. The thermal conductivity test was conducted at the Department of Chemical Engineering and Technology, Mindanao State University – Iligan Institute of Technology (MSU-IIT) using a heat flow meter apparatus (TA FOX 200, KATO, United States). The specific procedure is described in ASTM C518-17 (2017).

3. Results and Discussion

3.1 Strength of Solidified Geopolymer Paste

The development of strength in the geopolymerized body is dependent upon the formation mechanism of the gel structures during the solidification of the geopolymer paste. The first stage involved the dissolution of silica and alumina in the calcined clay by the alkaline activator, which results in the release of silicate (SiO_4^-) and aluminate (AlO_4^-) (Hamidi *et al.*, 2016). It was followed by hydrolysis at which the water molecules help to further break the bond and allow these SiO_4 and AlO_4 tetrahedral units to link with each other as the polymeric precursors. Lastly, the polycondensation occured in the final stage where the geopolymer gel solidifies to form three-dimensional aluminosilicate networks for paste solidification.

It is theoretically evident that the molarity of the alkaline activator strongly influences the strength development of geopolymer. Indeed, the trend of flexural strength in this study continued to increase until 12 molarities of NaOH as shown in Figure 4. The highest flexural strength (5.48 MPa) was achieved at that molarity. In the present study, the compressive strength of the red clay-based geopolymer was not measured because the flexural strength might give a more direct measure to the mechanical property of the geopolymer material. Previous study reported that the flexural strength is about 14 to 22% of the compressive strength of the materials (Zhang *et al.*, 2018). Hence, upon knowing the flexural strength, the compressive strength of the materials can be approximated without actually measuring it.



M = molarity

Figure 4. Relationship of NaOH concentration to flexural strength of red clay-based geopolymer

The increasing flexural strength of the red clay-based geopolymers is consistent with the previous study of Bijen and Waltje (1989) on fly ash-based geopolymers. This is because the increasing molarity of the alkaline activator will increase the dissociation of the active species in the calcined clay to yield a higher concentration of gel networks in geopolymer (Hamidi *et al.*, 2016). However, the present study did not explore molarities higher than 12 because it was reported elsewhere that the strength of geopolymer begun to degrade. This is due to the fact that there is a disruption in the geopolymerization process under the excessive quantities of OH^- ions that lead to an inefficient reaction. Also, the increased NaOH molarity elevated the viscosity of the geopolymer paste, which hindered the leaching of the silica and alumina in the calcined clay to result in a lesser degree of geopolymerization (Bijen and Waltje, 1989). Nevertheless, the flexural strength obtained in this study of about 5.48 MPa is a common value for red clay since it belongs to low purity clays (Uddin and Saraswathy, 2007; Essaidi *et al.*, 2013; Mostafa *et al.*, 2014). Hence, the geopolymer paste prepared with 12 M of NaOH was chosen for the fabrication step of the geopolymer composite with the rice husks.

3.2 Physical and Mechanical Properties of the Geopolymer Composite

The addition of rice husks to the geopolymer paste was expected to reduce the bulk density of the geopolymer composite. The reduction of the bulk density of the composite with the increasing addition of rice husks is shown in Figure 5.

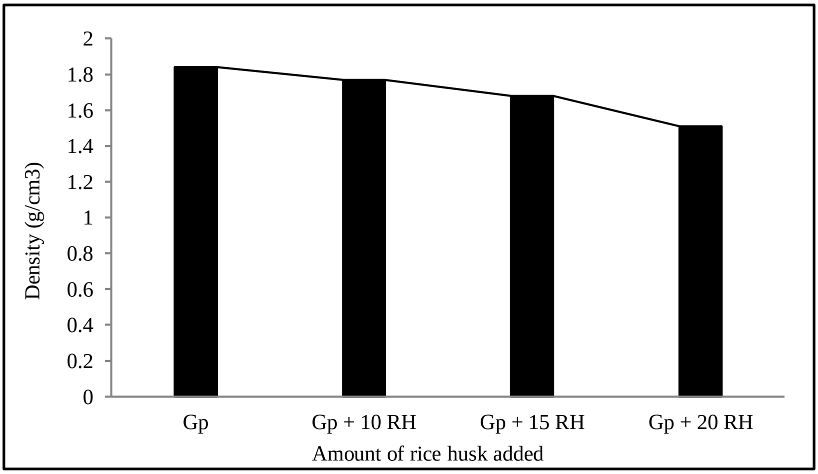


Figure 5. Effect of the amount of rice husks to the density of the red clay-based geopolymer

It can be observed that the bulk density of the solidified geopolymer paste was about 1.84 g/cm^3, and it was reduced to about 1.51 g/cm^3 at the addition of 20 wt% rice husks. The geopolymer matrix contributing to high density was minimized with the added rice husks; hence, the noticeable reduction of density. The natural fiber like the rice husks is always lower in density, about 0.71 g/cm^3 as determined by the volume tap density method. The bulk densities of the geopolymer composites in this study corroborate with the previous findings of Sarmin and Welling (2016) that the bulk density of a geopolymer lightweight was reasonably decreased with the addition of wood particles. Also, the measured bulk densities in this study were compared with the bulk density of the lightweight concrete, which is between 0.3 and 2.0 g/cm^3. The normal concrete has bulk densities to range from 2.1 to 2.5 g/cm^3 (Mohammed and Hama, 2014). Hence, it can be deduced that the geopolymer composite fabricated in this study is a potential lightweight construction material.

The flexural strength was measured on the geopolymer composite samples with varying amounts of rice husks as presented in Figure 6. It can be noticed that the flexural strength of the solidified paste is the highest when compared with the composite counterparts. The flexural strength of the composites decreased with the addition of increased amount of rice husk. The degradation of flexural strength was caused by the reduction in the mass of the geopolymer matrix when it was replaced by the mass of rice husk to form the geopolymer composite.

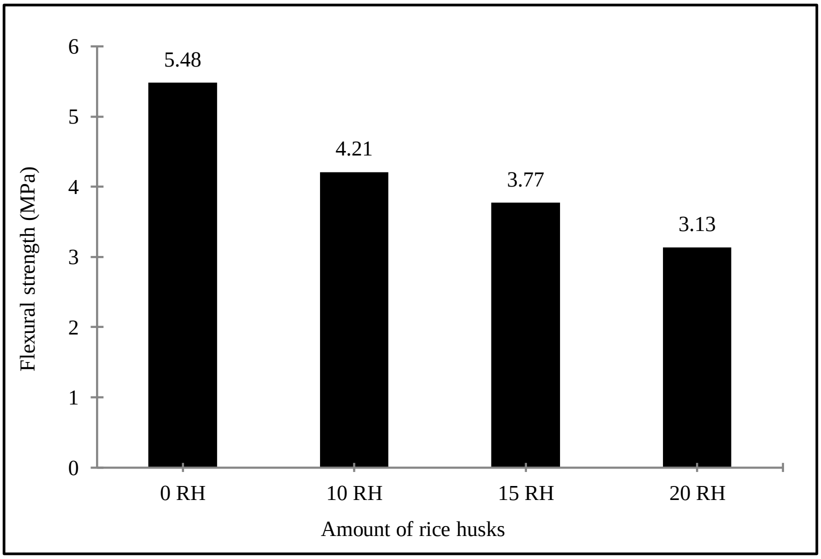


Figure 6. Flexural strength of geopolymer composite with varying amounts of rice husks

It is worthy to note that the geopolymer matrix provided mechanical support, whereas the added rice husks introduced weak points in the geopolymer composite. This was illustrated above by the decrease in the bulk density as the rice husk was increased in the geopolymer composite. At 10 wt% addition of rice husk, the flexural strength was measured to about 4.21 MPa, which was reduced to about 3.13 MPa at 20 wt% addition. These findings are comparable with the flexural strengths of fly ash-based geopolymer added with 1 wt% raffia fibers as reported by Korniejenko *et al.* (2016). The findings of this study are promising since more rice husks can be loaded in the red clay-based geopolymer paste to achieve a lightweight composite, while the strength is strong enough for insulating applications requiring low mechanical property (Malanho and Veiga, 2020).

3.3 Thermal Conductivity of Geopolymer Composite

The thermal conductivity was measured using the polished tiles of the geopolymer composites with varying amounts of rice husks as shown in Figure 7. The visual observation revealed coarser surfaces of the polished tile composites as the amount of the rice husks increases. The coarsening in the surfaces was likely to reduce the contact area during the heat flow measurements. It hindered heat flow at increasing content of rice husks, which is aggravated with the very low thermal conductivity of rice husks of about 0.13 W/m-°K (Ze-Zu, 1982).

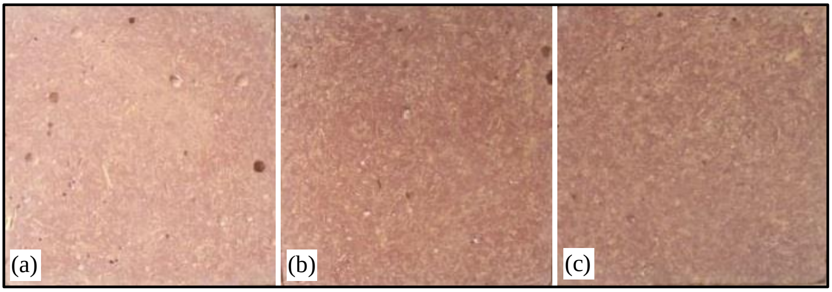


Figure 7. Square tile samples (side = 100 mm and thickness = 20 mm) for thermal conductivity measurements of geopolymer composites with 10% RH (a), 15% RH (b) and 20% RH (c)

Indeed, the thermal conductivity decreased from 0.302 to 0.296 W/m-°K, corresponding to 10 to 20 wt% rice husks shown in Figure 8. The thermal conductivity of the pure red clay-based geopolymer sample was not measured in this study, which was believed to be greater than 0.302 W/m-°K. According to Jaya *et al.* (2018b), the thermal conductivity of the clay-based geopolymers may range from 0.44 to 0.92 W/m.-°K, which depended on the moisture and density of the geopolymer material. In the present study, the density of the red clay-based composites noticeably decreased until the addition of 15 wt% rice husks. Correspondingly, the thermal conductivity of the geopolymer composite decreased until the 15 wt% addition of rice husks, whereas the higher addition than such amount (20 wt%) demonstrated a negligible decrease in the thermal conductivity.

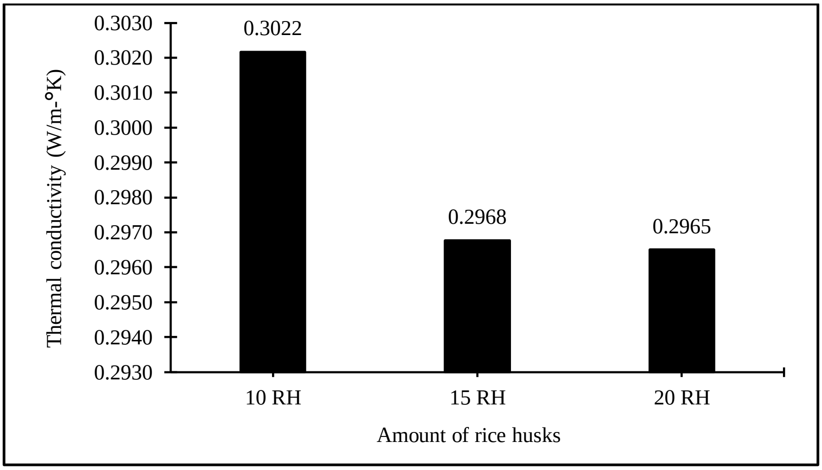


Figure 8. Thermal conductivity of the geopolymer composite with varying amounts of rice husks

It can be thought that the incorporation of 15 wt% rice husks in geopolymer could be decided as the percolation concentration of this type of geopolymer composite (Yi and Choi, 1999). At the 10 wt% addition of rice husks in the composite, the composite microstructure can be composed of geopolymer paste as the continuous conducting phase embedded with the rice husk particles as the discontinuous nonconducting phase. When the concentration of rice husks was increased to 15 wt%, the rice husk particles might already establish interconnection networks leading to a noticeable decrease in the thermal conductivity. It is worthwhile to point out that increasing the concentration beyond the percolation concentration did not significantly change any conductive properties of the composites. The measured thermal conductivities in this study were threefold lower than the thermal conductivity of geopolymer concrete with artificial lightweight aggregates as reported by Khalil *et al.* (2017). Moreover, the measured thermal conductivities are comparable with the findings on a composite wall panel made of foamed concrete that demonstrated values (Christopher *et al.*, 2016) ranging from 0.2 to 0.7 W/m-°K.

3.4 Prototype of the Wall-Panel Board

A large prototype of a wall-panel board was fabricated using the geopolymer composite with 10 wt% rice husks as presented in Figure 9. This formulation of the geopolymer composite was chosen because it has the highest flexural strength. Interestingly, a higher amount of rice husk additions can be made into wall-panel boards (Figure 7). It can be observed in Figure 9 that small holes on the surface of the wall-panel board were present. This was due to the trapped air bubbles during the casting operation of the composite geopolymer paste. This can be easily prevented by slow vibration and the use of a high amount of rice husks. The color of the panel board is reddish with brown particles as an indication of the presence of the rice husks.

Figure 9. Prototype of wall-panel board made of rice husks and red clay-based geopolymer

In fabricating insulating construction materials, the thermal conductivities are recommended to be in the range from 0.023 to 2.9 W/m-°K (Youngquist *et al.*, 1993). In this study, the thermal conductivities of the wall-panel board varied from 0.302 to 0.296 W/m-°K, which are indeed suitable as alternative insulating materials. Correspondingly, the measured flexural strengths varied from 4.21 to 3.13 MPa, whereas the bulk densities measured from 1.84 to 1.51 g/cm^3. These physical properties of the fabricated wall-panel board are promising, lightweight insulating materials in the construction industry (Sandermann, 1970; Newmann, 2003).

4. Conclusion and Recommendation

The fabrication of a wall-panel board was successfully demonstrated by geopolymerization of geopolymer paste with rice husks. Specifically, the 12 molarities of NaOH concentration in the alkali activator solution provided red clay-based geopolymers with the highest flexural strength of 5.48 MPa. The increasing amount of rice husk decreased the bulk density and flexural strength of the geopolymer composite at 20 wt% addition of rice husks, with respective values of 1.51 g/cm^3 and 3.13 MPa. The increasing addition of rice husks until 15 wt% decreased the thermal conductivities of the geopolymer composites at about 0.297 W/m-°K. The higher addition of rice husks than such amount does not significantly decrease the thermal conductivity of the composite. Lastly, large-sized wall-panel boards can be solidified by the geopolymerization of a geopolymer paste with an increasing amount of rice husks.

For future research, it is recommended to study the different sources of red clays in Mindanao. The different sources of red clays provide different mineral compositions that strongly influence the reactivity of the geopolymer paste. Accordingly, different combinations of alkali-activators are worthwhile for investigation. A microwave heating process can possibly enhance the reactivity of geopolymer to shorten the solidification time.

5. Acknowledgement

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