Development of Durian Fiber-based Composite Material

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Abstract

This paper presents investigation on the development of durian (*Durio zibethinus*) fiber-based construction materials incorporating rice husk ash (RHA) as a supplementary cementing material. Investigation on the RHA included oxide analysis, X-Ray diffraction, surface area, fineness and particle size distribution measurements. In addition, scanning electron microscopy (SEM) of the rice husk ash was conducted. The bulk density, compressive strength and thermal conductivity of the composites at various conditions were determined. The experimental investigation reveals that the replacement of ordinary Portland cement with ground RHA of 10-30% could improve the compressive strength of the durian fiber-based construction material.

***Keywords**:* Rice Husk Ash (RHA), compressive strength, thermal conductivity

1. Introduction

Energy and environmental research are essential for sustainable development within the 21st century. Worldwide, a large amount of agricultural waste from the fruit industries can be utilized by several process. The most effective technique is to reuse this waste by processing it as a new product. Thailand produces a large quantity of durian (*Durio zibethinus*) peel annually. Khedari et al. reported [1] that durian (*Durio zibethinus*) is a most interesting product as it has low values of thermal conductivity and bulk density. Development of composite materials for buildings using durian peel with low thermal conductivity can be an alternative way to solve simultaneously energy and environmental concerns [2, 3]. However, the long term durability of natural fiber composite material is affected by long term environmental exposure. It is necessary to find ways to improve durability. To improve the durability of natural fiber reinforced composites, it is necessary to find remedial solutions to alleviate the embrittlement process of natural fiber. The alkaline pore water in the composite dissolve the lignin and the hemicellolose and thus breaks the line between the individual fiber cells. One solution is to reduce the alkalinity of the pore fluid in the cement paste. This reduction in alkalinity can be achieved by replacing a part of the ordinary Portland cement with pozzolanas such as rice husk ash (RHA), fly ash, and silica fume [4-9]. In addition, the materials studied have included high alumina cement and modified ordinary Portland cement-based materials. The replacement of the cement with natural pozzolanas such as RHA eliminated the loss in strength of the composite [10-13]. Pozzolans play an important role when added to Portland cement because they usually increase the mechanical strength and durability of concrete structures [14]. A durability study [15] of high strength concrete made with a partial replacement of cement by RHA should be conducted along with its economic aspect.

Using RHA from a power plant as a pozzolan by replacing a portion of Portland cement to improve performance and durability of durian fiber-based construction material is the main objective of this research. Reducing the embrittlement of durian fiber-based composites is needed to improve the ability to develop durable composites. These challenges include disposing agriculture waste, producing building material and conserving energy in cement industries that will help advance the economic, energy and environmental objectives of sustainability. This study will lead us to conclude that an admixture of rice husk ash may be used in the production of durian fiber-based construction material.

2. Research Methodology

2.1 Raw Materials

2.1.1 Durian peel

When natural fiber reinforced composites are used, the durability question should be raised. The reason for this is that the lignin and hemicellulose in fibers dissolves in an alkaline environment and the fibers lose their reinforcing capacity. Therefore, it is necessary to know the basic and chemical composition of durian peel. The results of chemical analysis and solubility performed on durian peel following the TAPPI standards are shown in Table 1.

It can be seen that it contains lignin and hemicellulose which is the primary cause of the change in the characteristics of the natural fibers in the composite. As mentioned in the introduction, the alkaline pore water in the composite dissolves the lignin and hemicellulose and thus breaks the link between the individual fiber cells. This issue must be, therefore, carefully considered prior to commercialization.

2.2 Rice Husk Ash and Ordinary Portland Cement

In this study, an ASTM Type I normal ordinary Portland cement was used. Its physical properties and chemical composition are given in Table 2 with different fineness. The RHA used was by-product from power plant. A preliminary test to determine the fineness of Ground RHA retained on sieve No. 325 (45 μm) revealed that optimum grinding condition for RHA required using a steel ball mill for 3 hours. The chemical and physical properties of the RHA are also given in Table 2.

Table 1 Chemical composition and solubility of durian peel

Chemical composition in Fiber	Dried Durian Peel	Standard
Ash content	5.5	TAPPI-T211-om-93
Alcohot-benzene solubility	13.4	TAPPI-T204-om-93
hot-water solubility	39.5	TAPPI-T207-om-93
1% NaOH solubility	54.5	TAPPI-T212-om-93
lignin (ash corected)	10.9	TAPPI-T222-om-98
alpha cellulose	31.6	TAPPI-T203-cm-88
beta-cellulose	6.8	TAPPI-T203-cm-88
gamma cellulose	8.7	TAPPI-T203-cm-88

Ground RHA has high fineness because 99.6 % passed the sieve No. 325. Table 2 indicated that unground RHA possesses lower specific gravity than ground RHA. This can be explained by the fact that ground RHA has high contents of Fe_2O_3, MgO and CaO since these oxides possess high molecular weights. High alumina and silica contents tend to yield lower the molecular weights. The results of particle size analysis are shown in Fig. 1 and their median particle size is tabulated in Table 2. The median particle size of unground and ground RHA are approximately 375 and 9 μm, respectively. The median particle size of cement is approximately 17 μm.

Examination of chemical compositions was performed using X-Ray fluorescence spectrometer. It can be seen that unground RHA, ground RHA and Portland cement contain different amount of oxides. Chemical analysis indicates that the material is principally composed of SiO_2 (91.6% for unground RHA and 88.2% for ground RHA), the high content of the SiO_2 plays an important role on pozzolanic properties. In addition, SiO_2 content of ground RHA is lower than unground RHA and Fe_2O_3 content of ground RHA is higher than unground RHA. The ground RHA is apparently contaminated by the steel ball in the grinding process. Therefore, it is believed that the grinding method has much effect on the chemical composition of RHA. In the hydration of Portland cement, [6] calcium silicate hydrates are formed as well as $Ca(OH)_2$. The latter reacts with the reactive, silica in the RHA to form additional calcium silicate hydrates. Replacement of the large amount of cement by RHA, lowers the alkalinity of the cement matrix. Therefore, the alkalinity of the composite pore water is reduced and the rate of decomposition of the natural fibers based composite decrease.

Table 2 Physical properties and chemical analyses of the Portland cement and RHA [7]

Properties	Unground RHA	Ground RHA	Portland cement
Physical Tests			
Specific Gravity	0.25	2.4	3.14
Fineness			
- retaining 45 μm, %	78.35	0.4	4.7
- nitrogen absorption, m^2/g	-	20.04	-
- Blaine, specific surface area, m^2/kg	-	-	330
Median Particle Size (μm)	375	9	17
Chemical Analyses, %			
Silicon Dioxide (SiO_2)	91.6	88.2	12.7
Aluminium Oxide (Al_2O_3)	0.3	0.15	2.63
Phosphorous Oxide (P_2O_5)	0.37	0.47	0.049
Potassium Oxide (K_2O)	1.61	2.08	0.59
Calcium Oxide (CaO)	0.65	0.99	63.8
Titanium Oxide (TiO_2)	0.019	0.016	0.22
Manganese Oxide (MnO)	0.115	0.13	0.052
Ferric Oxide (Fe_2O_3)	0.19	0.89	2.37
Loss on Ignition, LOI (%)	5	5	1.37

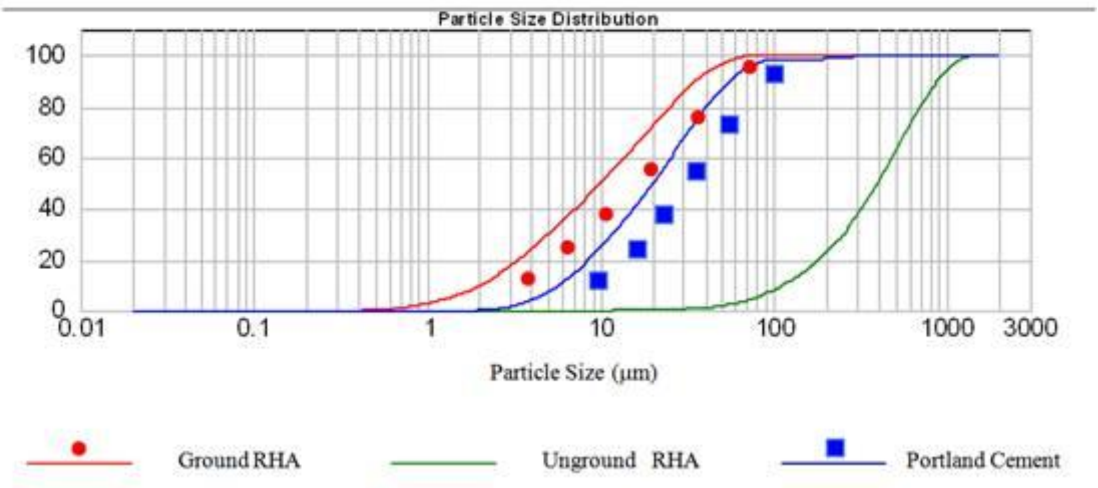

Fig. 1 Particle size distribution

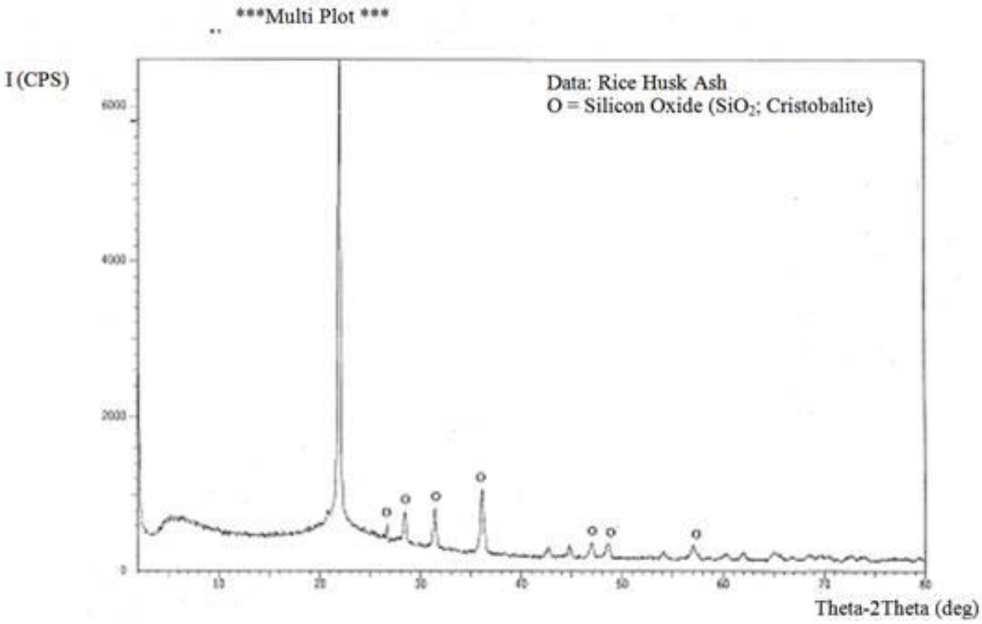

Fig. 2 X-ray Diffraction Analysis of RHA

RHA was ground to a powder and analyzed by X-ray diffraction. The diffractometer measures an angle twice that of the theta angle called the measured angle '2-theta' following in Bragg's Law. The X-Ray diffraction spectrum indicated the presence of cristobalite, as shown in Fig. 2. Cristobalite is the tetragonal polymorph of SiO_2. RHA is a by-product from a power plant. It should be noted that the rice husk is burned at temperature of 900 to 1200 $^{\circ}C$ to generate electricity. Thus, amorphous silica is gradually transformed to crystalline silica.

The electron micrographs of unground RHA and ground RHA are shown in Figs. 3 and 4, respectively. The micrographs of unground RHA showed the burnt husks and grains of quartz. The unground RHA and ground RHA are not spherical. Ground RHA has an irregular shape and possesses higher surface area than that of unground RHA. This can lead to improve mechanical properties of the composite. The electron micrographs of these grains are somewhat similar to that of grains of siliceous nature, thereby confirming the presence of quartz found in the X-Ray diffraction analysis.

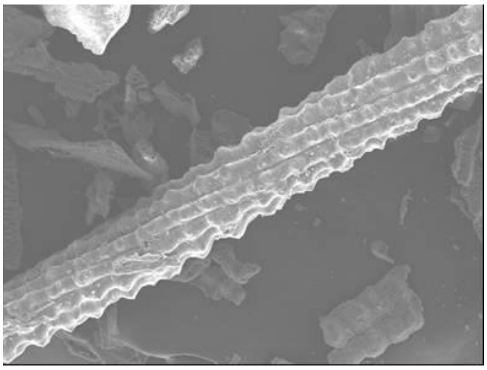

Fig. 3 SEM observation of the unground RHA (150 X)

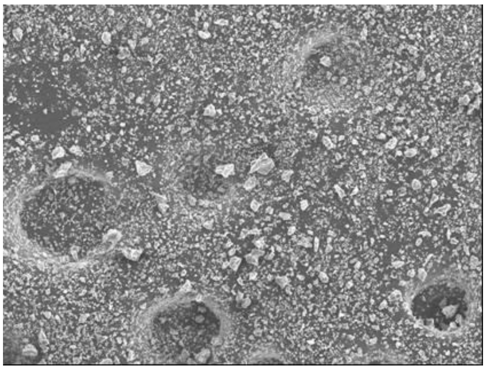

Fig. 4 SEM observation of the ground RHA (150 X)

2.2 Preparation of specimens

The fiber were prepared as follows; (i) Drying fresh durian peel, (ii) Grinding dried durian peel by hammermill and (iii) Screening to remove fines.

Mixing of the mortar and molding of the specimens were performed in accordance with ASTM C109-77, Method of Test for compressive strength of Hydraulic cement mortars. Mix proportions were cement: sand: fiber: water (1: 1: 0.1: 0.6) by weight. RHA was used to replace cement in amounts that varied from 10, 20, 30 and 40 % by weight. The dimensions of specimens were 5 x 5 x 5 cm^3. Two sizes of sand commercially available were used: < 0.71 mm and 0.855 ± 0.145 mm. Specimens were stabilized in water for 28 days.

The composite specimens were tested according to methods described in the following standards; (i), bulk density measurement performed according to ASTM C 134-88, (ii) thermal conductivity measurement performed according to ASTM C 177 and (iii) compressive strength measurement performed according to ASTM C 109-95.

3. Results and Discussion

A summery of physical property measurement citing the average results of all specimens is given in Table 3.

The bulk density of the composites is inversely proportional to the percentage of RHA content. This is due to the fact that specific gravity values of unground RHA and ground RHA are lower than Portland cement.

The Table shows the measured compressive strength of durian fiber construction specimens as a function of RHA content for different RHA types and size of sand. It was found that compressive strength of specimen containing unground RHA are lower than specimen made with ground RHA. This is due to the fact that the degree of fineness of unground RHA was not sufficient to result in the foundation of sufficient hydrate matters.With ground RHA, the fineness increased considerably so that good cement bond is achieved leading to higher compressive strength when compared to specimen manufactured without RHA. In fact as mentioned earlier, ground RHA has high surface area when compared to unground RHA. Thus, it more readily forms hydrated products generally known as Calcium Silicate Hydrate (C-S-H) gel in a pozzolanic reaction. Consequently, the compressive strength of specimen containing ground RHA are higher than specimen made with unground RHA. Replacing 30% of Portland cement type I by ground RHA gave the highest compressive strength. However, at higher RHA content (40% of cement Portland), the mix did not perform well and a decrease of the compressive strength was observed. In a similar way, it was found that using sand size < 0.71 mm enhanced the compressive strength further compared to the larger sand size of 0.855 ± 0.145 mm. Fine sand can lodge itself well into the matrix between fibers. Therefore, it reduces voids leading to high compressive strength of specimen.

The compressive strength of composites made with ground RHA and sand size of 0.71 mm is approximately 3 to 4 times higher than that of composites made with unground RHA and sand size of 0.85 ± 0.145 mm. Therefore, the use of ground RHA as a cement substitute at 30% can produce durian fiber composite with excellent compressive strength.

As expected, replacing Portland cement by RHA increases the voids in the composites and results in a lighter composite with a lower thermal conductivity. The thermal conductivity of composites is inversely proportional to the voids in the specimen. With sand size 0.85 ± 0.145 mm, the thermal conductivity of composite is lower than that with < 0.71 mm as shown in Table. Increasing the size of sand creates more void space and leads to a low thermal conductivity as specimens density decreases. This effect of size of sand is more or less similar for both ground and unground RHA.

Table 3 Summery of physical, mechanical and thermal properties measurements of composites specimens specification for unground and ground RHA [7,8]

Type of RHA	Size of sand (mm)	RHA Content (%)	Bulk density[a] (kg/m^3) ASTM C134-88	Compresssive strength[b] (MPa) ASTM C 109-95	Thermal Conductivity[a] (W/m K) ASTM C-177
Unground RHA	<0.71	0	2024 ± 12.29	8.20 ± 0.057	1.178 ± 0.017
		10	1784 ± 27.84	3.44 ± 0.027	1.088 ± 0.003
		20	1534 ± 12.17	4.37 ± 0.081	0.928 ± 0.012
		30	1386 ± 11.53	5.91 ± 0.018	0.819 ± 0.007
		40	1220 ± 12.12	3.14 ± 0.116	0.689 ± 0.018
	0.855± 0.145	0	2016 ± 21.17	6.28 ± 0.028	1.125 ± 0.021
		10	1635 ± 10.54	2.75 ± 0.004	0.986 ± 0.011
		20	1413 ± 19.47	3.95 ± 0.028	0.815 ± 0.007
		30	1284 ± 5.57	4.64 ± 0.078	0.715 ± 0.004
		40	1183 ± 12.12	2.89 ± 0.136	0.592 ± 0.011
Ground RHA	<0.71	0	2024 ± 12.29	8.20 ± 0.057	1.178 ± 0.017
		10	2020 ± 6.56	16.28 ± 0.001	1.175 ± 0.006
		20	1962 ± 5.57	18.61 ± 0.092	1.078 ± 0.016
		30	1922 ± 9.17	20.60 ± 0.008	1.052 ± 0.001
		40	1841 ± 22.11	16.77 ± 0.017	1.025 ± 0.014
	0.855± 0.145	0	2016 ± 21.17	6.28 ± 0.028	1.125 ± 0.021
		10	2016 ± 5.29	10.57 ± 0.010	1.114 ± 0.010
		20	1811 ± 8.19	17.31 ± 0.013	0.987 ± 0.006
		30	1813 ± 4.58	18.55 ± 0.079	0.865 ± 0.007
		40	1736 ± 29.46	14.75 ± 0.041	0.790 ± 0.013

Note: (a) is average of three replicate of the given conditions (b) is average of two replicate of the given conditions

4. Conclusions

The experimental investigation indicated that RHA can be used as a partial replacement for ordinary Portland cement type I in mortar mixes. The mix proportions of the specimens was cement: sand: fiber: water (1: 1: 0.1: 0.6). The maximum strength was obtained with 30 % replacement of ordinary Portland cement with ground RHA. It was found that the fineness of RHA has a significant effect on compressive strength of composites. The composites with finer rice husk ash possess higher compressive strength than those with the coarser ash. The size of sand is also significant to the structure of composites. It was found that increasing the size of sand leads to more void spaces in the specimen that decreased compressive strength, bulk density and thermal conductivity

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6. References

1. Khedari, J., Suttisonk, B., Pratintong, N., Hirunlabh, J., 2000. New lightweight composite construction materials with low thermal conductivity. Cement & Concrete Composite, Vol. 804, pp. 1- 6.
2. Khedari, J., Charoenvai, S., Hirunlabh, J., 2003. New insulating particleboards from durian peel and coconut coir, Building and Environment, Vol. 38, pp. 245-249.
3. Gram, H.E., Nimityongskul, P., 1987, “Durability of Natural Fibres in Cement-based Roofing Sheets,” Journal of Ferroncement, Vol.17, No. 4, pp. 321-327.
4. Shafiq, N.1988, ‘Durability of Natural Fibers in RHA Mortar’, *Journal of Ferrocement.,* 18[3], 249-262.
5. Filho, R. D. T., Ghavami, K., England, G. L. and Scrivener, K., 2003, Development of vegetable fibre-mortar composites of improved durability, Cement & Concrete Composites, Vol. 25, pp. 185-196.
6. Nehdi, M., Duquette, J. & Damatty, A.E. 2003, ‘Performance of rice husk ash produced using a new technology as a mineral admixture in concrete’, Cement and Concrete Research, 33[8], 215-273.
7. Charoenvai, S, , Khedari J., Hirunlabh J., Daguenet M., Quenard D .,2005, “Impact of Rice Husk Ash on the Performance of Durian Fiber-based Construction Materials”, The 10th International Conference on Durability of Building Materials and Components, Hotel HILTON, 17-20 April 2005, Lyon, France, pp.TT3-51.
8. Charoenvai, S, Khedari, J., Hirunlabh, J., Shin, U., 2004, "Investigation on Mechanical Properties of Durian Fiber-based Construction Materials Containing Rice Husk Ash (RHA)", The Third International conference on Advances In Structural Engineering and Mechanics, 2-4 September, Seoul, Korea, pp.1679-1687.