Utilization of Baggase Waste Based Materials as Improvement for Thermal Insulation of Cement Brick

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Abstract. Building materials having low thermal load and low thermal conductivity will provide thermal comforts to the occupants in building. In an effort to reduce the use of high energy and waste products from the agricultural industry, sugarcane bagasse and banana bagasse has been utilize as an additive in the manufacture of cement brick. The aim of this study is to investigate the insulation and mechanical properties of brick that has been mixed with bagasse and its effectiveness as thermal insulation using heat flow meter. Waste bagasse is being treated using sodium hydroxide (NaOH) and is characterized using SEM and XRF. The samples produced with two different dimensions of 50 mm x 50 mm x 50 mm and 215mm x 102.5mm x 65mm for thermal conductivity test. Next, the sample varies from 0% (control sample), 2%, 4%, 6%, 8% and 10% in order to determine the best mix proportion. The compressive strength is being tested for 7, 14 and 28 days of water curing. Results showed that banana bagasse has lower thermal conductivity compared to sugarcane bagasse used, with compressive strength of 15.6MPa with thermal conductivity 0.6W/m.K.

1 Introduction

In recent years, various studies have been conducted to produce the bricks which having a comparative strength and durable when applying to agricultural waste. In Malaysia, agricultural by-product produces in large quantities especially from oil palm, banana, pineapple, paddy and sugarcane.

Sugarcane bagasse for instance, produces 1 tonnes of sugarcane which generally generate around 280 kg of bagasse for one cycle [1]. This fibrous is remaining by-product after extracted from sugarcane. It is about 54 million dry tonnes of bags are produced annually through the world [1]. Sugarcane bagasse is potentially strong in displacing fossil fuels and can be extensively used in boilers, turbines and furnaces for power generation [2].

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Other applications of sugarcane bagasse are as sources of animal feed, energy, pulp, paper and boards [3].

Another type of by product from agriculture is bananas. Bananas are found abundance in tropical areas particularly. Normally restricted to tropical country, since the banana needs a climate mean temperature about 26.67°C and mean rainfall of 4 in. [6]. The total planted area of banana in Malaysia reached 33,704.2 ha in 2001 [7]. There are 25–80 species of banana in tropical areas, depending on the taxonomist according to [6]. Besides that, this by product fiber bagasse materials is practical to be used since it is renewable, low in cost, density, as well as satisfactory mechanical properties make them attractive and more environmentally friendly to be used as by product not only in the field of construction (partition boards, ceiling panelling), packaging, consumer products but also in transportation (automobiles, railway coaches). Reuse of this wastes as sustainable construction material appears to be viable solution not only to pollution problem but also to the problem of the land-filling and high cost of building materials [8]. Increase of population growth and urbanization, has raise standards of living due to technological innovations which contributed to an increase in the quantity and variety of solid wastes generated by industrial, mining, domestic and agricultural activities [9]. According to [4], improper treatment of sugarcane bagasse causes similar problems. The excess bagasse accumulation presents a waste problem for the sugar industry [2]. Therefore, this study investigated the application of modified sugarcane bagasse with the comparison of banana bagasse as thermal improvement for building brick. The physical and chemical properties of brick containing the sugarcane and banana bagasse are determined and discussed.

2 Literature review

2.1 Development of construction material from agro-waste

Agriculture waste has been used widely especially in construction materials as additive materials in concrete. Marwan [17] produces cement bricks that contain banana fiber as intermixture. Building using the natural fiber brick has become more popular since it is low in cost, readily available raw materials, produces faster and easier construction and economically friendly. Natural fiber bricks offer a competitive alternative to conventional building materials because they utilize local resources that can be both cost effective and energy efficient, and closely follow existing masonry construction practices. It shows that these traditional binders can be replaced by environmentally friendly and sustainable alternatives from unutilized waste [10].

Typically, cement bricks are formed using a mixture (by weight) of angular sand aggregate (40%-70%), clayey soil (30%-60%), cement (4%-10%) and water (8%-12%) [11]. Having a compressive strength in between (4-5 MPa) it has become a basic and universally accepted unit of measurement to specify the quality of the masonry units which restricts their applications to only one-story buildings.

Over 10 million hectares of banana plantation, of an average of 1500 plants per hectare, exist in more than 160 countries globally. It has cause to left over decompose besides creating tons of banana waste, emitting a huge amount of methane gas and carbon dioxide. These emissions have a negative impact on the environment, which increases global warming every year. Every ton of banana waste emits, on average, a half-ton of carbon dioxide per year. This study advances the utility of the cement bricks by adding banana fibers, thereby creating an innovative Green Cement Brick that further improves the mechanical properties of cement brick. Sugarcane bagasse is a fibrous residue produced in large quantity by the sugar industrials. Generally, sugarcane bagasse residue is produced about 32% of every tons of sugarcane after juice extraction [5]. Sugarcane bagasse is a fibre material which is easy to absorb and release water. Sugarcane fibre can absorb water by 78.5%. When the fibre is dry, the water will come out through vaporization process without damaging the cell structure.

The use of fresh untreated fiber in cement brick commonly results in very slow setting and abnormally low strength because of interference with normal setting and hardening processes by carbohydrates, tannins and possibly other substances in the fibers [8]. Pre-treatment is required to disrupt the structure of lingo cellulosic materials during cellulosic ethanol production, because the extensive interactions among cellulose, hemicelluloses and lignin, and the barrier nature of lignin minimize enzyme access to the carbohydrates and result in poor yields of fermentable sugars [9]. Fig. 1, vegetal fibre structure is formed by a central channel called as lumen, responsible for water and nutrients transportation, and by the cell wall. The cell wall of each fibre is composed by several layers such as middle lamella, the thin primary wall, and the secondary wall with is subdivided into external secondary wall (S1), middle secondary wall (S2) and internal secondary wall (S3). These layer are composed of microfibrils oriented into space in defined (angles) form, according to the each layer [13].

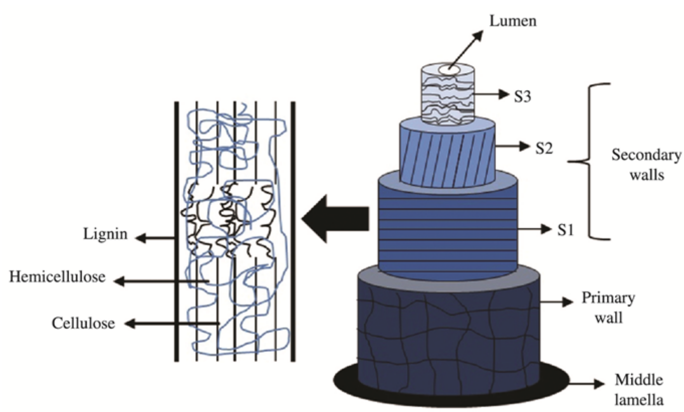


Fig. 1. Schematic representation of plant fiber structure [13].

The primary wall, initially deposited during the growth of cells, consists in a disordered arrangement of cellulose fibrils placed in a matrix of pectin, hemicellulose, lignin and protein [14]. Secondary walls consist of crystalline cellulose microfibrils organized in a spiral arrangement, where the middle layer (s2) determines the fibre mechanical properties. This is consisted by an amount of microfibrils, in a helical conformation of long chains of cellulose. The middle lamella, that is outer layer of cell, is composed predominantly by pectin that acts as cement between fibres [14].

A low thermal conductivity and a low specific heat are required to have a good thermal insulation of buildings. Many studies have shown that, regarding the mechanical behaviour, vegetable fibres are an interesting alternative to asbestos in fibre reinforced cement products manufactured by the Hatcheck process [15,16]. Besides that, the fiber has essentially due to its capability of enhancing the load carrying capacity and ductility of the concrete structures [18]. Study done by [17] shows that percentage of POFA which an agro waste based can lower the thermal conductivity value. Many studies had done which demonstrated the low thermal conductivity of such vegetable/agriculture fibre based composite cement materials but only few resulting from effect of the mixture fibre/matrix.

3 Materials and methods

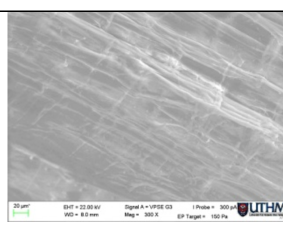
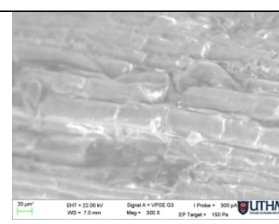
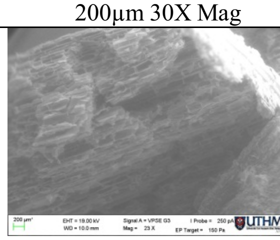
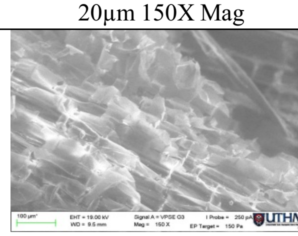
The materials used in this study are cement, sand, banana trunk fiber, sugarcane bagasse and water. Both fibers are treated using water boiling containing sodium hydroxide (NaOH). Then the fibers are tested with SEM and XRF in order to identify the surface and the chemical composition respectively. For the sample preparation, the mix ratio used was 1:3 which represent cement to sand and water cement ratio of 0.45% for cement brick production. However, both fibers introduced into mortar mix are varied from 0%, 2%, 4%, 6%, 8% and 10%. This is to ensure the optimum results based on the most favourable result. The 0% served as control for other sample. Samples with dimension of 50mm × 50mm × 50mm were produced for compressive strength test. While a dimension of 102.5mm × 215mm × 65mm were used to test the thermal conductivity of samples.

4 Results and Discussions

4.1 Microscopic Analysis (SEM) with the comparison of untreated and treated fiber

Table 1 shows the SEM image of untreated banana trunk fiber and sugarcane fiber with the comparison of treated using NaOH. Comparison between both figures, it shows that surface of treated banana trunk fiber more rough compared to untreated banana trunk fiber. Hence, the bonding between treated fiber and cement would come out with better result in strengthening the brick. On top of that, the presence of pores at the surface of treated banana trunk fiber would result in reducing the thermal conductivity [10].

Table 1. Comparison of microscopic analysis of banana and bagasse fiber before and after treatment.

	Before treatment	After Treatment with NaOH
Microscopic analysis (SEM) of banana trunk fiber	 200µm 30X Mag	 20µm 150X Mag
Microscopic analysis (SEM) of sugarcane bagasse	 200µm 30X Mag	 20µm 150X Mag

4.2 Chemical compound of ordinary portland cement, treated banana trunk fiber and sugarcane bagasse

Table 2 shows the XRF result of Ordinary Portland cement, banana trunk fiber and sugarcane bagasse sample respectively. These show the various chemical compounds present in both samples. From Table 2, the top three highest concentration of chemical composition found in Ordinary Portland cement are calcium oxide, CaO with 58.9%, silicon dioxide, $SiO_2$with 16% and aluminium oxide, Al_2O_3 with 4.32%. The other chemical compound found in Ordinary Portland cement such as carbon dioxide, potassium oxide, magnesium oxide, iron oxide and sulphur trioxide ranging from 0.10 to 3.61% of concentration. The percentage of concentration of all chemical compound found in the treated banana trunk fiber sample is quite similar with Ordinary Portland cement. The result shows that the highest percentage of chemical content in banana trunk fiber is potassium oxide with 10.7%. The concentration of the other chemical was from range 0.1% to 3.9%., especially in silicon dioxide, calcium oxide, and ferric oxide. Hence, the overall chemical compounds make the banana trunk fiber and sugarcane bagasse potential to be used as additional fiber in cement brick.

Table 2. Chemical compound of ordinary portland cement, treated banana trunk fiber and sugarcane bagasse.

Chemical compound	Formula	Portland Cement Concentration (%)	Treated Banana Trunk Fiber Concentration (%)	Treated Sugarcane Bagasse Concentration (%)
Carbon dioxide	CO_2	0.10	0.1	0.1
Calcium oxide	CaO	58.90	3.9	2.55
Silicon dioxide	SiO_2	16.00	2.3	0.87
Aluminium oxide	Al_2O_3	4.32	0	0
Sulfur trioxide	SO_3	3.61	0.3	0.51
Iron oxide	Fe_2O_3	3.47	0.7	0.48
Magnesium oxide	MgO	1.81	0	0
Potassium oxide	K_20	0.52	10.7	0.76

4.3 Compressive strength

From the results of sugarcane bagasse fiber as addition in mortar concrete, the results of compressive strength for 28 days of curing are 13.29 MPa for 0%, 15.13 MPa for 2% and 17.23 for 4%. However, the strength started to decrease by 14.42 MPa for 6% of sugarcane bagasse and continuously drop from 8% and 10% which is 13.80 MPa, and 12.01 MPa respectively.This concludes that the additional percentage of more than 4% of sugarcane bagasse will result in decrease of the strength of the sample. It was due to poor workability and less bonding between sugarcane bagasse and mortar. This finding was supported by previous study [12]. The author reported that, even compressive strength is decreased by the incorporation of the waste, but it is producing adequate brick which is comply with the standard for non-load bearing purpose. According to Oyekan, mortar contains about 1% of air voids. Air-entrainment is known to improve the properties mortar in both the fresh and hardened states. In fresh mortar, the minute air bubbles act as small ball-bearings and greatly improve the workability of the mortar. But the more workable mortar loses about 20% of its strength because every 1% of air entrapped produces about 4% loss in strength.

As for banana fiber, the result of compression strength for mortars with 28 days of curing shows that 4% of banana trunk fibers having a higher compressive strength with 15.6 N/mm². It was increased from 14.12 N/mm² and 14.78 N/mm² which were the control sample and 2% of banana trunk fibers. The compression strength was slightly decrease as the content of banana trunk fibers as intermixture in cement brick was increased which were 15.584 N/mm² for 6%, 15.58 N/mm² for 8% and 13.05 N/mm² for 10%. According to Uddin [11], the brick with highest percentage of banana trunk fiber recorded the highest compressive strength. As a conclusion, the workability between fibers and concrete were good as the percentage of fibers increase up to 2% and 4% and has the highest compression strength. Unfortunately, the strength continued to reduce for cement bricks with percentage of 6%, 8% and 10% of banana trunk fibers as intermixture because of the poor bonding between fibers and concrete. Fig. 2 illustrates the compressive strength against percentage with comparison to banana trunk fiber and sugarcane bagasse.

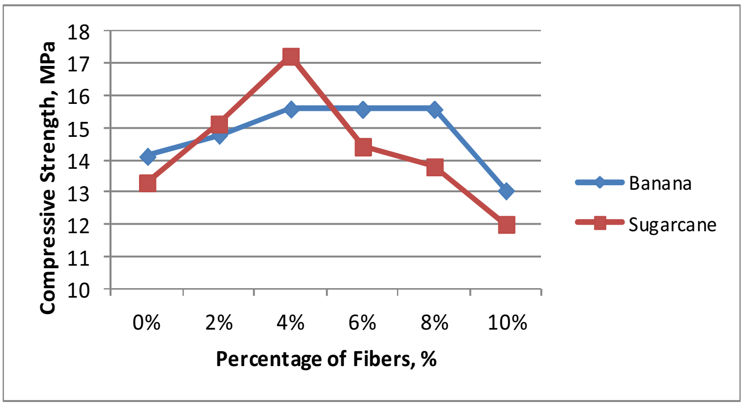


Fig. 2. Compressive strength against percentage with comparison to banana trunk fiber and sugarcane bagasse.

4.4 Correlation between compressive strength and thermal conductivity

The result of thermal conductivity test for the samples of 28th day with different sugarcane bagasse content were shown in Table 3 and Fig. 3 below.

Table 3. Data of thermal conductivity test

Type of fiber during 28days curing age	Thermal conductivity of different sawdust and sugarcane bagasse in different percentage (W/m.K)			
	0%	4%	8%	10%
Sugarcane baggase	0.69	0.68	0.65	0.62
Banana trunk fiber	0.69	0.60	0.63	0.58

Table 3 show the result for thermal conductivity test of all samples. Percentage of sugarcane bagasse found that the graph line for thermal conductivity was lower than the graph line for the compressive strength except for 0% of sugarcane bagasse content. It was obviously seen that the thermal conductivity for 0% of sugarcane bagasse content was higher while, the compressive strength was lower compared to 4% and 8% of sugarcane bagasse content. Even though, the 10% of sugarcane bagasse content gives the best result in reducing thermal conductivity, the strength is less than the required strength so it cannot be used for permanent constructions. Compared with banana fiber thermal conductivity test for cement brick with 10% additive show a good result (0.58 W/m-K) where it is lower

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compared to the control sample (0.59 W/m-K). Meanwhile, the cement brick with percentage 8% of banana trunk fiber as intermixture recorded the highest thermal conductivity which is 0.63 W/mK and followed by 0.60 W/mK for percentage of 4%.

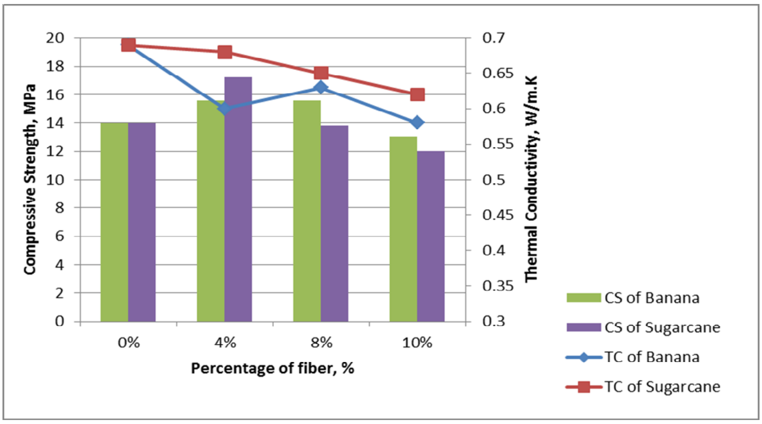

Fig. 3. Relationship between compressive strength (CS) and thermal conductivity (TC).

It can be concluded that the characteristics of banana trunk fiber has a potential to be as thermal improvement in cement brick. In other words, it is suitable to use as intermixture in cement brick and applicable in the construction industry [11]. However, based on both fiber, it can conclude that banana bagasse fiber have a good strength of 15.6MPa with low thermal conductivity 0.6W/m.K comparatively with other percentage and fibers.

5 Conclusion

The chemical composition of sugarcane baggase and banana trunk fiber is suitable and has the potential as an addition in producing cement brick. The bonding between treated both fibers gave better result in strengthening the brick as the treated fibers has a rough surface. Overall, the cement brick with percentage 4% of banana trunk fiber gives the highest value of compressive strength which is 15.59 N/mm² at the age of 28 days of curing. Although the highest value of compressive strength for 28 days of curing is 4%, the optimum mix design is 8% because there is an intersection between compressive strength and thermal conductivity lines. The value at the intersection is compatible with ASTM C207 Type N masonry cement. However, based on both fiber, it can conclude that banana bagasse fiber have a good strength of 15.6MPa with low thermal conductivity 0.6W/m.K comparatively with other percentage and fibers.

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