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Development of thermally efficient fibre-based eco-friendly brick reusing locally available waste materials

Ashwin Narendra Raut [a,*], Christy Pathrose Gomez [b]

[a] Department of Construction Management, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia
[b] Department of Construction Management, Universiti Tun Hussein Onn, Malaysia, 86400 Batu Pahat, Johor, Malaysia

HIGHLIGHTS

- Focus is on development of thermally efficient wall material for hot and humid climate.
- The bricks were developed utilizing locally available sustainable waste material.
- Physical, mechanical and thermal performance of newly developed bricks is assessed.
- Effect of oil palm fibres on physical and thermal properties is assessed.
- Microstructural examination is performed to understand interaction between the raw materials.

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ABSTRACT

Currently there are several kinds of building wall thermal insulation materials commercially available in Malaysia, however the issue with all these materials is that they are not eco-friendly. This paper attempts to reduce the dependence on non-eco-friendly insulation material by developing thermally efficient eco-friendly bricks. The prototype brick developed by incorporating locally available sustainable waste material was subjected to initial investigation on physical, mechanical, thermal and microscopic studies. The investigations revealed that the thermally efficient prototype mix design using glass powder and palm oil fly ash along with lime as binder is able to provide strength to the bricks. Also, usage of oil palm fibres were beneficial in lowering the thermal conductivity of bricks. At incorporation of 1% wt of OPF, compressive strength was found out to be 7.21 MPa and thermal conductivity was 0.39 W/mK, which indicates the proposed bricks can be an alternative to non-eco-friendly commercial common bricks. The advantage of the proposed bricks is two-fold: having low thermal conductivity will make it an energy efficient option, second is the usage of sustainable resources makes it an eco-friendly product.

1. Introduction

The building sector consumes a significant amount of energy during its operational stage contributing to an ever increasing amount of greenhouse gas emissions. A key consideration in order to improve the energy efficiency of the building sector is to provide thermal insulation to the building envelope for the purpose of lowering its heating/cooling load. There are several kinds of insulating materials commercially available in Malaysia such as Fibreglass–urethane, Fibreglass (rigid), Urethane (rigid), Perlite, Extruded Polystyrene and Urethane [1]. But the problem with all these materials is that they are not eco-friendly materials. Due to the environmental concerns, there is an urgent need to develop and utilize materials that have eco-friendly features. A material having sustainable features along with optimum insulating properties can eventually contribute to addressing key environmental concerns, such as leading to reduction in greenhouse gas emissions. In addition, better insulation of the building envelope reduces mechanical energy dependency for cooling and heating purposes, eventually contributing to the betterment of the environment.

The amount of raw materials consumed by the construction industry is approximately 24% of the global raw material resource [2]. Thus, for achieving the goal of sustainable development in the construction industry, the selection of building material plays a pivotal role. There have been continuous efforts to research on the viability of reusable waste materials as alternative building materials. Efforts have been ongoing to utilize demolition waste, municipal solid waste, agricultural waste and industrial waste in

* Corresponding author.
E-mail addresses: ashwin7588@gmail.com (A.N. Raut), cpgomez28@gmail.com (C.P. Gomez).

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building materials [3–6]. However, most of the studies while studying the incorporation of waste material have failed to address the thermal insulation characteristics of such material for improving energy efficiency needs and mechanical performance.

To a great extent the solid waste industrial by-products have been researched for more than a few decades as a form of pozzolanic material. Glass powder is one of such materials having pozzolanic behaviour because of its high silica content. In Malaysia, waste glass amounts for 3% of total municipal solid waste generated every year causing serious environmental concerns [7]. In 2008, for supporting recovering activity in Malaysia, 119 solid waste recyclers were licensed. These companies provides alternative resources by recovering solid waste and reduce dependency on natural resources. There is scope of utilizing recycled glass from recovered solid waste and incorporate it as a supplementary cementiotious material [8]. There are various types of glass based on its chemical composition: soda-lime glass, vitreous glass, borosilicate glass, lead glass, barium glass, etc. Most commonly used glass is soda-lime glass consisting of approximately 73% SiO_2, 13–18% Na_2O and 10% CaO [9]. Thus, based on chemical composition powdered glass can qualify as pozzolanic material as per ASTM C618 [10]. There has been much research undertaken with encouraging results regarding mechanical performance and durability criteria for construction materials while incorporating glass powder [11–13]. However, high amount of alkali makes it vulnerable to alkali silica reaction if it is used as a supplementary cementiotious material [13,14]. Several studies suggest that grounded fine glass powder which has a particle size below 300 μm shows very good pozzolonic reactivity without ASR expansion [15,16]. Also, to reduce the chances of disruption due to alkali silica reactivity, Byars et. al. [17] in his research has suggested the combined use of supplementary cementitios material such as fly ash, silica fume, etc.

Palm oil fly ash (POFA) is available in abundance in Malaysia and possesses pozzolanic behaviour [18]. Each oil palm fruit bunch produces 21% palm oil, 6–7% palm kernel, 14–15% fibres, 6–7% shell and 23% empty fruit bunch on an average [19]. It is estimated that, a single kilogramme of palm oil results in 4 kg of dry biomass [20]. The Malaysian oil palm industry generates 3 million tons of POFA in the year 2007 and it is estimated that production rate will increase due the expansion of oil palm sector [21]. Several researchers [22–24] have studied the usefulness of POFA as a supplementary cementitious material for enhancing mechanical performance as well as durability of concrete products. Thus, the combined use of glass powder along with POFA as pozzolonic materials can be treated as a sustainable step within the local construction industry.

Enhancement of thermal performance can be done by introducing pores in the matrix of the material. Studies have found that fibrous material possesses cellular pores structure which can reduce the heat transfer rate significantly [25–27]. Coconut coir fibre, durian fibre, straw bale, cotton stalk fibre, and bamboo fibre has been tried and tested before for developing thermally insulated composites. Also, studies there have been conducted on oil palm fibre for insulating applications [28]. On the backdrop of waste disposal issue of Malaysian oil palm industry as discussed earlier, oil palm fibres can be utilized as a pore forming agent in proposed material.

The objective of this research is to understand the physical, mechanical and thermal performance of bricks developed from the locally available waste material which can be procured easily. The research in more inclined towards the thermal performance of bricks as the proposed material is supposed to be thermally efficient. As all the raw materials are mostly by-product of industrial & municipal activity, the proposed product provides a sustainable alternative to existing energy consumptive fired clay bricks.

2. Prototype development

The constituent material for developing thermally efficient bricks are glass powder, palm oil fly ash, oil palm fibres, crusher dust, lime, and water.

2.1. Raw materials

(i) *Glass powder:* Scrap of broken glass were procured from local dump yard. This broken glass was brought for preconditioning where it was crushed for in a ball mill for 2 hours at 60 rpm speed to form a finely grounded glass powder. Furthermore, it was sieved using 90 μm sieve to keep its particle sizes in check. Chemical composition by using X-ray Florescence (XRF) technique is shown in the Table 1. Physical properties such as specific gravity, fineness, soundness, initial and final setting time, drying shrinkage, and determination of flow were determined and it is shown in the Table 2. The scanning electron microscopy (SEM) image of powdered glass is shown in Fig. 1(a). Also, X-ray diffraction (XRD) was carried out which points out to the fact that no substantial crystalline phase was detected as shown in Fig. 3.

(ii) *Palm Oil Fly ash:* The palm oil fly ash was collected from oil palm industry located at Kluang, Johor, Malaysia. The ash collected was having a certain percentage of moisture content, to remove moisture it was subjected to oven drying at 110 °C. The dried ash was further sieved using 90 μm sieve size. Furthermore, physical, mechanical and chemical characterization of palm oil fly ash were conducted similarly to that of glass powder (GP). The XRD pattern shown in Fig. 2 suggests the presence of quartz mineral which is rich in silica, also proven by chemical composition represented in Table 1.

(iii) *Oil palm fibres:* The oil palm fibres were also collected from same company from where palm oil fly ash was procured. As the fibres were in hydraulic compressed form,

Table 2
Physical properties of POFA and glass powder.

Sr. No.	Physical properties	POFA	GP
1.	Fineness (cm^2/g)	1348	1862
2.	Specific gravity	2.21	2.67
3.	Soundness		
	Le Chatellier expansion (mm)	1.2	0.8
	Autoclave expansion (%)	0.06	0.05
4.	Setting time		
	Initial setting time (min)	166	144
	Final setting time (min)	274	268
5.	Drying shrinkage (%)	1.805	1.801
6.	Determination of flow (cm)	15.5	19.6

Table 1
Chemical composition of glass powder and palm oil fly ash.

Chemical composition	SiO_2 (%)	Al_2O_3 (%)	MgO (%)	Na_2O (%)	CaO (%)	Fe_2O_3 (%)	Cl (%)	P_2O_5 (%)	K_2O (%)	LOI (%)
Glass powder (GP)	68.89	4.147	2.717	16.938	5.904	0.52	0	0	0.568	0.316
Palm oil fly ash (POFA)	61.663	5.13	4.17	0.49	9.869	5.299	0.162	3.716	8.427	1.074
Lime	3.94	1.37	0.32	0.01	88.7	0.09	–	–	0.02	3.53