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Thermal and mechanical performance of oil palm fiber reinforced mortar utilizing palm oil fly ash as a complementary binder

Ashwin Narendra Raut *, Christy Pathrose Gomez

Department of Construction Management, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia

HIGHLIGHTS

- Focus is on utilization of oil palm industry waste in mortar.
- Thermal performance of fiber reinforced mortar being is analyzed for various fiber proportions.
- Effect of oil palm fibers on physical and mechanical properties is assessed.
- Influence of fiber incorporation on drying shrinkage examined.

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ABSTRACT

This paper provides an in-depth analysis of the recycling potential of oil palm industrial waste which is abundantly available in Malaysia that is posing serious environmental concerns. Much research has been undertaken regarding the processing of palm oil production waste, however there is lack of attention regarding the thermal performance of oil palm waste and its attended mechanical properties as fiber reinforced mortar, stifling its wide applicability within the construction industry. This paper focuses on the utilization of oil palm residue to develop thermally insulated building envelope material. The palm oil fly ash is used as a replacement for cement, and the oil palm fibers are incorporated as an additive to reduce thermal conductivity of wall systems. Various proportions of fiber reinforced mortar were prepared to study the effects of fibers on thermal and mechanical performance. Thermal performance was studied using steady state approach by using Hot Guarded Plate apparatus. The experimental findings have revealed that the porous nature of fiber makes it a suitable choice for enhancing thermal performance of mortar, with some acceptable reduction of mechanical strength and marginal fluctuations in flexural strength.

1. Introduction

The building sector is one of the largest consumers of resources causing high carbon emissions [1]. In the backdrop of environmental issues, many countries are adopting sustainable technologies and materials. Therefore, it is crucial to find surrogate materials which have sustainable features. One way to overcome this situation is to adopt natural renewable sources or non-hazardous waste materials. Implementation of sustainability features in the manufacture of energy efficient products would certainly benefit the environment. Considering hot and humid climatic aspects similar to that of Malaysia, the approach should be to develop materials that have high thermal performance. Extensive literature suggests that the incorporation of natural materials are comparable in performance with standard building materials [2]. Several types of natural fibrous materials such as hemp, coconut fibers, date palm fibers, bamboo, and sisal have been experimented and tested as fillers alongside binders (cement, clay, sand, gypsum, mortar, concrete, etc.) to develop sustainable composite building materials [3–6].

Malaysia is one of the largest producers of palm oil yielding around 17.7 million tons of crude oil every year reaching 41% of global production [7]. Generally, it is considered that every oil palm tree fruit bunch contributes, about 21% palm oil, 6–7% palm kernel, 14–15% fiber, 6–7% shell and 23% empty fruit bunch [8]. Extraction of fibers can be carried out from various parts of the oil palm tree such as trunk, frond, fruit mesocarp and empty fruit bunch (EFB). The various parts of the tree constitute approximately 73% fibers [9]. It is estimated that for about every ton of palm oil, 1.1 ton of EFB results as a waste [10]. A fraction of this EFB is used

* Corresponding author.
E-mail addresses: ashwin7588@gmail.com (A.N. Raut), cpgomez21@gmail.com (C.P. Gomez).

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Fig. 1. EFB oil palm waste at Kian Hoe Plantation Mill, Kluang, Malaysia.

as boiler fuel [11], in the preparation of fertilizers or as mulching material [12], whilst the major portion is left in mill premises itself. The burning of empty fruit bunch (EFB), fiber and oil palm shell (OPS) at temperatures of around 800 °C to 1000 °C converts it into palm oil fly ash (POFA) [13]. Traditionally, the disposal of the generated POFA, as well as rest of the leftovers in the field, remains unutilized creating environmental problems [11,14]. A view of EFB wastes piled up for disposal in a palm oil mill in Malaysia is shown in Fig. 1.

Much research has been conducted to utilize Palm Oil fly ash (POFA) as a partial cement replacement product. Tay [15] in his research identified POFA possessing pozzolanic behavior which can be used as cement replacement in concrete. He also suggested that because of its low pozzolanic reactivity it can be used only up to 10%. A similar observation was made by Tangchirapat et al. [16] and Chindaprasirt et al. [17] who recommended the use of POFA up to 10% of binder mass due to its low pozzolanic reactivity. Hence, in order to enhance the pozzolanic reactivity POFA must be ground to produce lower particle size. Chindaprasirt [17] in his research found that the compressive strength of POFA-incorporated mortar having median particle size of 7 μm (3% retained on a 45 μm sieve) to have higher values than control mortar due to the filler effect of finer particle size. Also, researchers [18–21] reported that the effect of POFA incorporation in concrete for durability performance suggests enhanced performance of concrete due to the formation of C-S-H gel caused by POFA. To be more specific, utilization of POFA improves resistance to chloride ion penetration [17,18] improves resistance to acidic environment [15] and sulphate attack [22].

Several attempts have been made to incorporate natural fibers in composites to develop lightweight thermally insulated cement composites. Composites developed from natural fibers act as an alternative building material which is energy efficient, eco-friendly, and economical as well. Natural fibers, either unprocessed or processed, have been used to reinforce cement based products in various applications globally. Natural fibers have a high variation in their properties which could affect overall fiber cement properties [23,3]. It has been reported that natural fibers behave like reinforcement, improving the mechanical properties of its composites. Researchers [25,26] have pointed to some added advantages such as increased flexural strength, post failure integrity, increased impact toughness, and improved bending strength of the composites [27]. Additionally, cement composites reinforced with natural fibers have been reported to arrest the propagation of micro cracks [28].

Natural fibers are cellular porous structures comprising of cellulose, hemicellulose, and lignin which constitute different layers [24,29]. However, natural fibers contain a high content of hydroxyl groups (-OH) which causes hydrophilic behavior, and this results in poor adhesion of fibers within the cementitious matrix [30,31]. This hydrophilic behavior can be overcome by several chemical treatments such as saline treatment, alkali treatment and treatment involving graft copolymerization of monomers. Amongst these treatments, an alkali treatment is commonly used to clean the surface of fibers. This has been reported by several researchers [30–34] who have verified interfacial adhesion improvement was observed between the fiber and cement matrix with alkali treatment.

The objective of this paper is to evaluate the thermal and mechanical performance of mortar reinforced with oil palm fiber as a sustainable alternative to conventional mortar that has better thermal insulation properties. The total amount of Palm oil fly ash (POFA) is kept up to 10%. The fiber content was varied from 0 to 1.5 wt.% of binder (cement + POFA) to observe its effect on the strength development and thermal behavior.

2. Materials and methods

The constituent materials of the fiber reinforced mortar (FRM) are as follows:

2.1. Raw materials

2.1.1. Cement

An Ordinary Portland cement of Lafarge Holcim brand, type Portland cement CEM I 52.5 N was used as a binder. Chemical properties and physical properties are shown in Tables 1 and 2.

Table 1
Chemical composition of cement and POFA.

Chemical composition	SiO_2 (%)	Al_2O_3 (%)	MgO (%)	Na_2O (%)	CaO (%)	Fe_2O_3 (%)	Cl (%)	P_2O_5 (%)	K_2O (%)	LOI (%)
Cement (OPC)	20.0	5.1	0.8	0.34	63.9	3.4	0.05	–	0.75	6.66
POFA	61.66	5.13	4.17	0.49	9.86	5.29	0.162	3.71	8.42	1.07

Table 2
Physical properties of POFA.

Sr. No.	Physical Properties	POFA	Cement	Standard
1	Specific gravity (g/cm^3)	2.21	3.15	ASTM C188 [36]
2	Soundness			
	Le Chatellier Expansion (mm)	1.2	–	
	Autoclave Expansion (%)	0.06	0.35	IS 4031:1988 [37] and IS 1727:1967 [38]
3	Setting Time			
	Initial Setting Time (Minutes)	166	120	
	Final Setting Time (Minutes)	274	185	