World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:10, No:3, 2016

Utilising Unground Oil Palm Ash in Producing Foamed Concrete and Its Implementation as an Interlocking Mortar-Less Block

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Open Science Index, Civil and Environmental Engineering Vol:10, No:3, 2016 publications.waset.org/10003993.pdf

Abstract**—**In this study, the possibility of using unground oil palm ash (UOPA) for producing foamed concrete is investigated. The UOPA used in this study is produced by incinerating palm oil biomass at a temperature exceeding 1000ºC. A semi-structural density of 1300kg/m3 was used with filler to binder ratio of 1.5 and preliminary water to binder ratio of 0.45. Cement was replaced by UOPA at replacement levels of 0, 25, 35, 45, 55 and 65% by weight of binder. Properties such as density, compressive strength, drying shrinkage and water absorption were investigated to the age of 90 days. The mix with a 35% of UOPA content was chosen to be used as the base material of a newly designed interlocking, mortar-less block system.

Keywords**—**Foamed concrete, oil palm ash, strength, interlocking block.

I. INTRODUCTION

FOAMED concrete is a type of lightweight concrete produced by introducing air voids into cement slurry or a mortar base mix [1]. The air voids are produced by aerating a foaming agent to produce pre-formed foam having a specific density into the base mix. Foamed concrete can be produced with a broad spectrum of densities ranging from 400 to 1600kg/m^3 [2]. It is considered to be an economical and an environmental friendly material providing superior thermal and acoustic insulation properties as well as fire and termite resistance to buildings [3]. Due to its versatility, foamed concrete is used in a wide range of applications such as roof and floor fills, engineered fills and highway reinstatement uses [4], [5]. The cost of foamed concrete is determined by its ordinary Portland cement (OPC) content and by its foam quantity [6]. Therefore, a number of studies have endeavored on the utilisation of a number waste materials such as fly ash [7]-[11], blast furnace slag [12] and silica fume [3], [13] as partial OPC replacements. Such utilisation of waste materials aimed at the reduction of cost and to create an environmental friendly foamed concrete with enhanced properties.

Oil palm ash (OPA) is a newly introduced waste material to the construction industry. It is produced by incinerating palm oil biomass for the purpose of producing electricity to fulfil the mill's energy needs. This type of waste is a throw away material that is causing environmental problems if not dealt with properly. Although it is a newly introduced material to the construction industry, research has been undergone to utilise this waste in producing concrete [14], [15], mortar [16], [17], high strength concrete [18], [19] and aerated concrete [20]. The majority of these studies have used OPA after it had undergone further processing such as grinding to achieve a finer particle size or/and heat treatment to reduce its carbon content. These studies have come up with replacement level recommendations ranging from 10 to 30% by weight of cement to be replaced by the processed OPA [21].

Although these further processing procedures are beneficial in creating a new pozzolanic material, they do add considerable cost [22]. Hence, these further enhancements hinder the utilisation of OPA into real life construction works and restrain it to laboratory conditions. This study will aim on the utilisation of unground OPA with passing through the 300μm sieve (UOPA) in the production of foamed concrete. The study is based on the belief that utilising OPA produced by incinerating palm oil biomass at temperatures greater than 1000ºC will achieve the same recommended replacement levels by studies using processed OPA. However, the main issue with OPA is its increased water demand; therefore, this study will use a dose of a water reducing agent to counter this issue. Such utilisation will not only be cost efficient, but produce a greener foamed concrete.

This greener foamed concrete will be implemented as the base material for a newly designed interlocking mortar-less block system. The newly designed block system will be called the BTechLiTe block. The BTechLiTe block will be a good economical option because it eliminates the need for experienced labour due to its easy interlocking mechanism, it reduces material consumption due to the absence of mortar and it uses foamed concrete that uses a low cost waste material.

II. MATERIALS AND METHODS

A. Materials

The materials used in this study are OPC type I complying with BS EN 197-1, fine sand complying with BS 882, potable water, a protein based foaming agent diluted in water at a rate of (1:30) and when aerated produces stable pre-formed foam having a density of 65kg/m3, a naphthalene based water reducing agent with a pH number of 7 and UOPA. The raw

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OPA was collected from a nearby palm oil mill which incinerates its palm oil biomass at temperatures greater than 1000ºC for producing 21MWa of electricity for its energy needs. The raw OPA was dried in an oven for 24 hours at a temperature of 100ºC, then, the dried OPA is sieved through a 300µm sieve to remove any larger particles and any unburned fibres and shell. Table I lists the chemical composition and physical properties of the OPC and UOPA used in this study.

TABLE I
PROPERTIES OF BOTH OPA AND UOPA

Chemical Composition (%)	OPC	UOPA
Carbon (C)	--	9.31
Silicon Dioxide (SiO_2)	19.98	66.64
Aluminium Oxide (Al_2O_3)	5.17	3.82
Iron Oxide (Fe_2O_3)	3.27	3.69
Calcium Oxide (CaO)	63.17	5.23
Magnesium Oxide (MgO)	0.79	2.29
Sulphur Trioxide (SO_3)	2.38	0.43
Alkalis (Na_2O)	--	0.15
Loss on Ignition (LOI)	--	6.09
SiO_2+Al_2O_3+Fe_2O_3	--	74.15
Median particle size d_{50} (µm)	5.73	101.81
Specific gravity	2.85	1.65
Loose bulk density (kg/m^3)	1180	833.6
Blain surface area (cm^2/g)	3924	1952

B. Specimens and Mix Design

The foamed concrete mixes prepared for this study have a target density of 1300kg/m3. A 1.5 sand to cement ratio is used with 0.45 as the preliminary water to binder ratio. UOPA partially replaces OPC at levels of 0, 25, 35, 45, 55 and 65% by weight of binder. The design density is determined using the formula specified by [23]:

$$\gamma_{design} = 1.034\gamma_{target} + 101.96 \quad (1)$$

where, γ_{design} is the design density and γ_{target} is the target density (1300kg/m^3). Using the above formula, the calculated design density is 1441kg/m^3. The authors determined a design density of 1450 to ensure the obtained dry densities are within the spectrum of the target density. Table II lists the mixes and their constituents used. A 1% by weight of binder materials dose of a water reducing agent (WRA) is used with mixes containing UOPA replacements. The required consistency for the base mix is chosen as 220mm. The consistency is checked using the Brewer test specified in [24].

TABLE II
CALCULATED MIX CONSTITUENTS (KG/M^3)

Mix	Cement	UOPA	Sand	WRA	Water
I-0	484.71	-	727.06	-	218.12
I-25	363.53	121.18	727.06	4.85	218.12
I-35	315.06	169.65	727.06	4.85	218.12
I-45	266.59	218.12	727.06	4.85	218.12
I-55	218.12	266.59	727.06	4.85	218.12
I-65	169.65	315.06	727.06	4.85	218.12

C. Mixing Procedure and Curing Regime

The dry materials (OPC, sand and UOPA) are placed inside the mixer and mixed until a homogeneous mix is obtained. The water is then added gradually to the mix until the required consistency is obtained. A litre of the base mix is then weighed to determine the mix's density. From the determined base mix density, the quantity of foam to be applied is calculated then added to the base mix. Until there is no trace of foam in the mix, a litre of the foamed concrete is then weighed to determine the achieved wet density. The achieved density should be within the range of ±30kg/m3 of the design density. The obtained mix is then poured into the moulds and cured until the day of testing. The type of curing chosen is sealed curing, where the demoulded specimens are wrapped in plastic film then left until the day of testing [7]-[11]. This type of curing is reflective of what is done in the industry [5].

D. Testing Programme

Density: The consistency and stability of the fresh and hardened foamed concrete mixes are investigated as well as their oven dry densities. Consistency is defined as the ratio of the obtained fresh density to the design density (1450 and 1150kg/m^3). Stability is defined as the ratio between the obtained fresh density and the hardened density. Both consistency and stability ratios should be near to unity [25]. Oven dry densities are obtained by placing the samples for 24 hours in an oven at a temperature of 105±3ºC.

Drying shrinkage: Drying shrinkage is determined using the procedure described by BS ISO 1920-8 [26]. The readings were taken at the ages of 7, 28, 56 and 90 days of age.

Compressive strength: The compressive strength is determined using the procedure stated by BS 12390-3 [27]. The test is conducted a universal testing machine with a maximum capacity of 3000kN. The listed reading is the average of three samples. Compressive strength readings are determined using 100mm cubes at the ages of 7, 28, 56 and 90 days.

Water absorption: Water absorption is determined according to BS 1881-122 [28]. The water absorption readings were determined at the ages of 7, 28, 56 and 90 days. Each listed reading is the average reading of three samples.

III. RESULTS AND DISCUSSION

A. Water and Foam Requirements

Table III lists the water and foam requirements used in achieving the required consistencies and the design densities. Water demand to achieve the 220mm consistency increased with increasing UOPA replacement levels beyond 25%.

The increased water demand is attributed to the shape and the porous nature of the UOPA particles. UOPA particles are angular and irregularly shaped particles; hence, demanding increased amounts of water to lubricate its surface and achieve the same consistency as the control mix. The same observation was observed when replacing OPC with finely ground OPA in concrete [14], [15].

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TABLE III
ACTUAL MIX CONSTITUENTS (KG/M^3)

Mix	Cement	UOPA	Sand	WRA	Actual Water	Foam (litres)
I-0	484.71	-	727.06	-	167.78	372.1
I-25	363.53	121.18	727.06	4.85	153.06	347.0
I-35	315.06	169.65	727.06	4.85	196.89	302.6
I-45	266.59	218.12	727.06	4.85	218.11	270.5
I-55	218.12	266.59	727.06	4.85	251.00	244.0
I-65	169.65	315.06	727.06	4.85	283.94	202.3

Foam quantities decreased with increasing UOPA quantity in the foamed concrete mix. The decreased foam amounts are due to the low specific weight that UOPA possesses in comparison to OPC. When replacing OPC with UOPA, the weight of the base mix reduces; hence, requiring a lesser amount of foam to achieve the required design density. Similar observations were noted when replacing OPC and sand with fly ash [5], [8], [29].

B. Density

Table IV lists the fresh density, hardened density, mix consistency reading and stability readings achieved for the conducted foamed concrete mixes. Fresh densities achieved were in the range specified earlier as ±30kg/m^3 of the design density. Consistency ratio readings obtained are near to unity. This indicates that the difference between the fresh obtained density and the specified design density is insignificant. Hardened density readings obtained by UOPA foamed concrete mixes were lower than their correspondent control mixes. This is true for mixes containing UOPA replacement levels beyond 25%. This is due to the increased water quantities existing in these mixes, and as a result, they lose water quantities proportional to the amounts existing within their matrix. Mix I-25 showed a higher hardened density than its corresponding control mix due to the reduced amounts of water that went in its mixing in comparison to the amounts needed by the control mix I-0. Although hardened densities were reduced with increasing UOPA content, the stability numbers were near to unity indicating that the amounts of water and the fresh obtained densities were adequate in achieving stable foamed concrete mixes.

TABLE IV
DENSITIES, MIX CONSISTENCY AND STABILITY READINGS (KG/M^3)

Mix	Fresh density	Hardened density	Consistency	Stability
I-0	1460	1453.2	1.01	1.00
I-25	1480	1454.6	1.02	1.02
I-35	1475	1451.4	1.02	1.02
I-45	1480	1447.4	1.02	1.02
I-55	1480	1442.7	1.02	1.03
I-65	1485	1441.5	1.02	1.03

Oven dry densities are found to be inversely proportional to UOPA content. Fig. 1 shows the oven dry densities as a function of age. Increasing the UOPA content in the foamed concrete mix is accompanied by increasing water quantity. As a result of drying the samples, most of the water is evaporated leaving behind pores spread in the paste of sample; hence, reducing its oven dry density. I-25 has a lower quantity of water to begin with; therefore, when the samples were dried, the minimised water quantity leaving the paste leaves behind reduced amounts of pores. Although a drop in oven dry density is witnessed with increasing UOPA content, oven dry densities are developing with age. This is an indication that the pores within the paste are decreasing in quantity. This is due to a pozzolanic reaction occurring between the calcium hydroxide produced by the dement hydration process and the silica oxide which UOPA particles are rich with. This pozzolanic reaction is producing extra amounts of calcium silicate hydrate compounds (CHS) filling the pores left behind by the water evaporation.

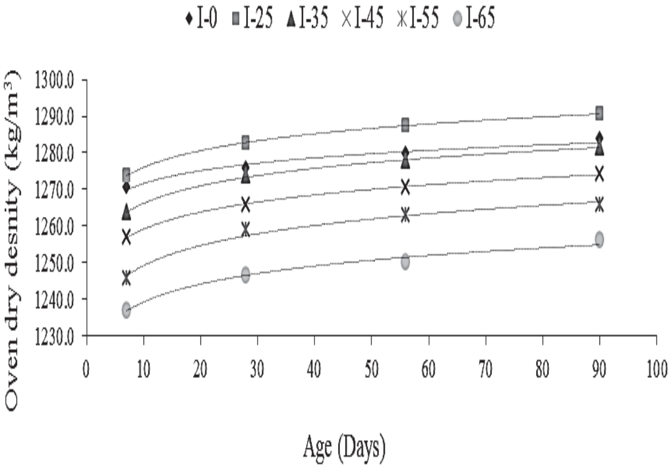

Fig. 1 Oven dry density as a function of age

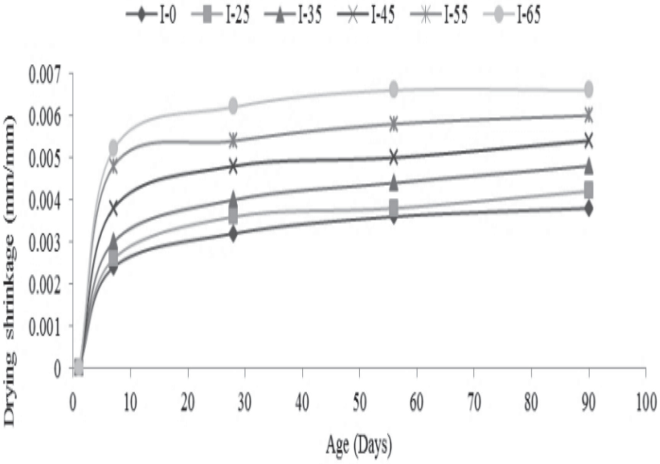

Fig. 2 Drying shrinkage as a function of age

C. Drying Shrinkage

Drying shrinkage readings are shown in Fig. 2. It is obvious that drying shrinkage readings are proportional to UOPA content. The same observations were reported when replacing OPC with fine OPA in producing conventional concrete [30]. The increase in drying shrinkage readings can be reasoned to the increase in water content accompanied by the UOPA content, and as a result, increasing the amounts of water

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leaving the samples causing the shrinkage. However, it has been noted that even mix I-25 which showed lower water demand than its corresponding control mix has a higher drying shrinkage. Therefore, there is another factor causing the increase in drying shrinkage other than water content. In foamed concrete, the drying shrinkage is found to be a function of paste volume [31]. It was mentioned earlier, that foam quantity decreases with increasing UOPA content; hence increasing paste volume. This explains I-25's increased drying shrinkage readings in comparison to its corresponding control mix I-0.

D.Compressive Strength

Compressive strength readings are listed in Table V. Foamed concrete mixes containing UOPA beyond 25% exhibited lower compressive strengths than their corresponding control mix. Reduced compressive strengths are due to the increased water to binder ratios accompanying the increased UOPA content. The increased water content will produce a more porous and weak paste that cannot withstand additional load. Mix I-25 showed higher compressive strengths than those exhibited by its corresponding control mix I-0 at all ages. The superior compressive strengths even at the early age are due to effectiveness of the WRA dose which causes the water to binder ratio to drop. Decreased water in the mix will cause the increase of strength at an early age. When comparing strength development, the control mixes showed lower strength development after 28 days of age in comparison to mixes containing UOPA where they continue to increase in their development.

TABLE V
COMPRESSIVE STRENGTH (MPA)

Mix	Age (Days)			
	7	28	56	90
I-0	6.88	8.33	8.74	9.04
I-25	7.25	9.59	10.41	11.16
I-35	5.57	7.28	8.48	8.72
I-45	4.53	6.01	7.14	8.03
I-55	3.01	4.41	5.18	6.04
I-65	2.6	3.57	4.09	4.96

The continuous development of the UOPA foamed concrete mixes is due to the pozzolanic reaction occurring between the silica oxide in the UOPA particles and the calcium hydroxide emitted by the cement hydration process. This reaction produces extra CSH compounds which fill up the pores densifying the paste making it stronger.

E. Water Absorption

Water absorption readings are listed in Table VI. Increasing the UOPA content beyond 25% in foamed concrete increased the water absorption readings. Mix I-25 achieved a lower water absorption reading than its control mix by 9% and 8% at the ages of 28 and 90 days respectively. The decreased water absorption exhibited by I-25 is reasoned to a less porous paste. The decreased amount of water that went in creating this mix resulted in a lower amount of micro-pores within the paste. All foamed concrete mixes showed lower water absorption readings with age.

TABLE VI
WATER ABSORPTION READINGS (%)

Mix	Age (Days)			
	7	28	56	90
I-0	16.67	14.17	13.09	11.62
I-25	15.43	12.95	11.92	10.72
I-35	18.81	16.27	14.9	13.65
I-45	20.49	17.22	15.64	14.74
I-55	23.26	20.34	19.03	17.24
I-65	30.24	25.76	24.29	22.57

IV.FOAMED CONCRETE MIX SELECTION FOR THE BTECHLITE BLOCK

From the listed results, it is obvious that mix I-25 showed superior properties than its control mix I-0. However, mix I-35 seems to be a better option although achieving readings lower than both the control mix and I-25. Looking back at the results, I-35 achieved 86% and 96% of I-0's compressive strength at the ages of 28 and 90 days. Oven dry density readings achieved by I-35 were about 0.011% and 0.01% lower than that achieved by I-0 at the ages of 28 and 90 days respectively. In addition, water absorption readings at the ages of 28 and 90 days were 14.5 and 17.5% higher than the readings achieved by I-0 respectively. In regards to drying shrinkage, foamed concrete is known for its high drying shrinkage in comparison to conventional concrete; therefore, using foamed concrete in the fabrication of smaller building elements would mitigate this increase in shrinkage [32]. Above all, I-35 is a more economical and greener option in comparison to both I-0 and I-25. It uses a lower quantity of cement at 315.06kg/m^3 lower by 35% than the cement quantity in I-0; and it uses a foam quantity which is 22.7% lower than I-0. Furthermore, it incorporates a larger waste quantity than I-25. For all the mentioned reasons, I-35 is chosen to be the mix to fabricate the newly designed interlocking block.

V.BTECHLITE BLOCK

The design philosophy that the authors followed for coming up with the BTechLiTe block design is that it should have an interlocking mechanism that allows self-alignment and mortar-less, has dimensions that agree with the modular system and can be used to build none, semi and loadbearing walls. The interlocking mechanism depends on intrusion and protrusions on the upper and lower face of the block. To achieve a staggered alignment, a half block is also designed. In addition, the block should be perforated to reduce its mass and allow for reinforcement, piping and grouting. Fig. 3 shows the BTechLiTe block system.

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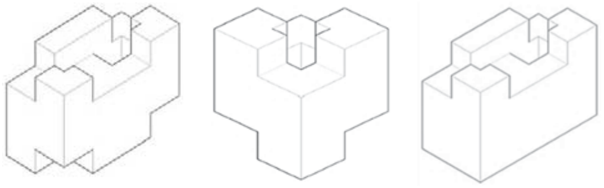

(a) (b) (c)

Fig. 3 BTechLiTe blocks; (a) Stretcher Block, (b) Half Block and (c) Base Block

The stretcher block is the main block used in the wall construction. The half block will be used to achieve staggered joints when erecting a wall. The base block will be used at the base and at the top to finish up the wall. Table VII shows the dimensions and mass of each of the blocks shown in Fig. 3.

TABLE VII
DIMENSIONS AND MASS FOR BTECHLITE BLOCK COMPONENTS

Property	Stretcher Block	Base Block	Half Block
Length (mm)	300	300	150
Height (mm)	200	200	200
Width (mm)	150	150	150
Bearing Area (mm^2)	37500	37500	20000
Volume (m^3×10^{-3})	5.56	6.50	3.00
Average Mass (kg)	7.72	9.14	4.22

VI.STRENGTH OF BTECHLITE BLOCK

As mentioned earlier, the BtechLiTe block is made out of the foamed concrete mix I-35. To determine the block's strength, a universal testing machine with a loading cell of 500kN capacity was used. The blocks were loaded until failure. The strength reading for each type of block is the average of five blocks. The blocks were tested at the age of 28 days. The stretcher, base and half blocks achieved an average strength of 3.75, 3.00 and 4.29MPa respectively. These strengths are higher than the minimum strength for a concrete hollow block indicated by BS 5628 [33]. Therefore, it is possible to use the BTechLiTe block in the construction of walls to achieve a greener a more and cost effective construction.

VI. CONCLUSIONS

In this study UOPA was used to partially replace cement for the sake of producing foamed concrete and then use it in the fabrication of a newly designed interlocking block. Five different replacement levels were used from 25 to 65% by weight of cement to produce a foamed concrete mix having a target density of 1300kg/m^3 using a filler to binder ratio of 1.5. Results show that mix I-25 exhibited superior properties than the control mix at all testing ages. However, eying the prospect of achieving a cost effective foamed concrete mix with properties similar to that of the control mix, mix I-35 was chosen to fabricate the BTechLiTe block. The BTechLiTe block provides lightweight, dimensions that agree with the modular system and an interlocking mechanism that allows self-alignment as well as a mortar-less construction scheme. Using mix I-35 in the fabrication of the BTechLiTe block, made it achieve an average mass of 7.72kg and strength of 3.75MPa; hence, achieving a higher strength than the specified minimum strength of 2.8MPa by BS 5628.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support of Universiti Sains Malaysia under USM RUI Grant (Ref. No. 1001 / PPBGN / 811234).

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