PROPERTIES OF FOAMED CONCRETE INCORPORATING PALM OIL BIOMASS ASH AS A PARTIAL CEMENT REPLACEMENT

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Abstract - Palm oil biomass has been used as fuel in producing electricity distributed to the masses or for limited usage at the palm oil mills for their internal energy needs. Palm oil biomass ash (POBA) is the result of the incineration process of palm oil biomass. For the sake of reducing the ash's negative impact on the environment, several studies have endeavoured on incorporating this waste into the production of concrete, mortar and paste. However, all these studies have used it after excessive processing. In this study, POBA sieved through a 300µm sieve will be used to partially replace cement in foamed concrete. Compressive strength, drying shrinkage as well as porosity will be determined for foamed concrete mixes having constant filler to binder ratio of 1.0 and a density of 1300kg/m^3 at ages from 7 to 90 days. Results show that with the aid of a superplasticiser dose, coarse oil palm ash can be used as a partial cement replacement in producing foamed concrete without any negative effect on the properties.

Index Terms - Foamed concrete, Palm oil, Properties, Replacement

I. INTRODUCTION

The palm oil industry is a thriving industry in Malaysia. As a result of this developing industry, the amount of produced waste is increasing. For a single hectare of palm oil plantation, 70 tonnes of biomass are produced [1]. About 90 million metric tonnes of biomass is produced in Malaysia annually [2]. This biomass residue consists of empty fruit bunch, fibre, shell, wet shell, palm kernel, fronds and trunks. It has been a common practice for palm oil mills to burn their biomass instead of using conventional fossil fuels for heating up their boilers and generate steam [3, 4]. More than 300 palm oil mills are operated by self-generated electricity using palm oil biomass in Malaysia [1]. In addition, the generated electricity is not only used for their internal use in crude palm oil extraction but also providing the surrounding remote areas with electricity. Due to the abundant amounts of biomass produced, Malaysia has the potential to utilise these quantities in power generating. Using such alternative fuels to partially or fully replace fossil fuels used in all Malaysian industries to generate energy, will result in a significant drop in CO_2 emissions, achieving the vision to be a developed country without degrading the environment and promoting the utilisation of renewable energy in power generating [5]. However, the process of burning palm oil biomass will result in a new type of waste. This waste is called palm oil biomass ash (POBA) which is causing numerous problems to the environment. POBA quantities are expected to increase due to the increasing demand for energy and the thriving palm oil industry.

POBA is created through the incineration of palm oil biomass. OPA is produced at a percentage of 5% by weight of palm oil biomass [6]. In Malaysia alone, nearly four million tonnes of oil palm ash is produced annually [7]. To this date, due to the huge amounts produced, it is commonly practiced that oil palm waste is disposed of by uncontrolled dumping and tipping methods. This operation is conducted by spreading the waste over the vicinity of the mill or dumped to fill up low economic value dumps on pieces of land that are selected previously (inundated swampland, abandoned sand mines and quarries) [8]. The uncontrolled disposal of such waste, especially ash, will lead to the deterioration of the environment due to the fact that they are rich in organic substance [9]. Another issue with improper disposal of oil palm ash is that the ash particles, due to their light weight, will be carried by winds creating smog on a humid day [10, 11].

Recycling of POBA is receiving increasing attention because of its huge potential in improving economic benefits and environmental awareness [12]. As an alternative to POBA disposal, recycling of this residue is a good method to decrease its environmental impact. Although POBA is considered to be a newly introduced pozzolanic material, numerous studies have incorporated it in the production of concrete [13], mortar [14], cement pastes [15], high-strength concrete [16], and aerated concrete [17]. However, the incorporation of POBA into foamed concrete as a partial cement replacement has not yet been investigated. Using POBA as a partial cement replacement in producing foamed concrete will increase the possibility of creating a more environmentally friendly foamed concrete and decreasing the amount of cement used in its production. These studies have used this waste after

further processing it by either enhancing its physical and/or chemical properties. Despite the positive results that these enhancements showed on the performance of POBA, they do apply considerable cost [18, 19]. In addition to the applied cost, the further processing procedures hinder the utilisation of POBA and confine it to laboratory conditions.

Foamed concrete is a type of lightweight concrete. It is known to be highly flow-able, possesses low self-weight, has a minimal aggregate consumption, controlled low strength and superior thermal insulation properties [20]. Controlling the quantity of foam can produce foamed concrete with densities ranging from 500kg/m^3 to 1600kg/m^3 [21]. Foamed concrete is considered to be an environmental friendly material due to its limited use of aggregate because of the absence of coarse aggregate and its high capacity in incorporating waste materials [22]. A number of waste materials have been used as cement and sand replacements in its production. They have been used to enhance the properties of foamed concrete and to reduce its cost.

Against all the mentioned issues, this study utilised coarse POBA sieved through a 300µm sieve to partially replace cement in producing foamed concrete. The uniqueness of such incorporation lies in the type of POBA used in this study. The POBA is produced by incinerating palm oil biomass at temperatures exceeding 1000ºC. As a result of such high temperatures, the POBA produced has a reduced carbon footprint and has a finer particle size distribution. Hence, eliminating the need for further processing methods to be conducted on the POBA. In addition, POBA is used to partially replace cement in producing foamed concrete where the effect of such incorporation on the properties of foamed concrete is studied. As a result of this utilisation, the prospect of broadening the recycling methods of such waste is increased.

II. EXPERIMENTAL PROGRAMME

The materials used in this study are ordinary Portland cement (OPC), fine sand as filler, potable water, protein based foaming agent which was diluted in water at a ratio of 1:30 then aerated to produce pre-formed foam having a density of 68kg/m^3, and a naphthalene based super-plasticiser (PS-1) having a PH of 7.5. The POBA was collected from a nearby palm oil mill which was dried at 105 ±3ºC for 24 hours then sieved through a 300µm sieve. The passing through the 300µm sieve will be used as a partial cement replacement. Table 1 shows the properties of both cement and POBA used in this study. A total of six mixes were conducted for this study. These mixes had a mix ratio of equal amounts of both binder and filler. Water to binder ratio (W/B) of 0.45 was chosen for design purposes. POBA is used to replace cement at replacement levels of 25-65% with 10% increments. A pure cement foamed concrete mix is prepared for the sake of comparison with POBA foamed concrete. Binder and filler materials are mixed using an inclined rotary drum mixer until a homogeneous dry mix is obtained. Water is added gradually until the required consistency is achieved; in this case 240mm. the density of the base mix is determined by weighing a 1litre cup of the mortar then the amount of foam is calculated then added until the required design density is obtained (1450kg/m^3 ±3%). Specimens are removed from the moulds after 24 hours the sealed cured until the testing date. Table 2 shows the mix composition of these mixes. Properties to be tested are compressive strength according to BS12390-3 [23], and porosity using the vacuum saturation apparatus and the following formula:

$$porosity = \frac{W_{sat} - W_{dry}}{W_{sat} - W_{wat}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, W_{sat} : weight in air of the saturated sample, W_{dry} : weight of oven dried sample and W_{wat} : weight in water of the saturated sample. The tests were conducted on 7, 28 and 90 days of age and each given reading is the average of three samples.

Chemical Composition (%)	OPC	POBA
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+ K_2O)	--	0.15+4.24
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	3.15	1.65
Loose bulk density (kg/m^3)	1180	833.6
Blaine surface area (cm^2/g)	3924	1952

Table 1 Properties of OPC and POBA

Mix	OPC	POBA	S	W	PS-1	Foam
I-0	583.6	0.00	583.6	204.3	-	0.37
I-25	437.7	145.9	583.6	174.7	5.8	0.34
I-35	379.4	204.3	583.6	264.3		0.26
I-45	321.0	262.6	583.6	301.4		0.22
I-55	262.	321.0	583.	361.		0.16

	6		6	8	
I-65	204.3	379.4	583.6	385.0	0.13

S: sand, W: actual water quantity needed to achieve the required consistency of 240mm

Table 2 Mix proportions (kg/m^3)

III. RESULTS

A. Water and Foam Quantities

Actual water quantities applied to the mixes to achieve the 240mm consistency reading are listed in Table 2. Water quantities increased with increasing the POBA content in the foamed concrete mix. This is reasoned to the fact that POBA particles are porous in nature and are irregularly shaped [24]. This makes the mix containing the POBA particles need more water to achieve the required consistency. However, mix I-25 showed decreased tendency to need water due to the effectiveness of the PS-1 dose.

Foam quantities decreased with increasing POBA content in the foamed concrete mix. The low specific gravity of the POBA particles reduces the weight of the base mix when used as a cement replacement. This reduction in weight will decrease foam quantity required to achieve the design density of the foamed concrete mix.

B. Compressive Strengths

Fig. 1 shows the compressive strength as a function of age. A reduction in compressive strength is shown by the foamed concrete mixes with increasing the POBA content beyond 25% by weight of OPC. Mix I-25 exhibited superior compressive strength readings at all ages in comparison to that of its control mix I-0.

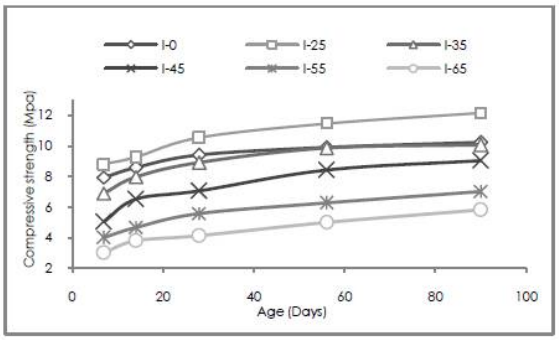

Fig. 1 Compressive strength

This is due to the reduced amount of both foam (due to the application of the POBA) and the water (due to the effectiveness of the PS-1 dose). The reduction of water and foam create a foam concrete mix that has a strong and less porous paste. When the POBA content increases beyond 25% by weight of OPC, it increases the water demand for the mix despite the reduced amount of foam. Increased water demand produce a foamed concrete mix with a porous paste. However, all mixes showed strength development with age hinting the existence of a pozzolanic reaction occurring between the silica oxide (SiO_2) in the POBA particles and the calcium hydroxide ($Ca(OH)_2$) produced by cement hydration, hence, creating increased amounts of calcium silicate hydrates (CSH) within the paste.

C. Flexural Strength

The flexural strengths were determined at the ages of 7, 14, 28, 56 and 90 days. The flexural strengths reduced with increasing UOPA replacement levels beyond 25%. I-25 exhibited higher flexural strengths than their correspondent control mixes at all ages. Flexural strengths at 90 days of age is higher than those exhibited by their correspondent control mixes by 12.6%. The super plasticiser dose of 1% by weight of binder is effective to reduce the water demand even with a 25% replacement level of cement by UOPA. This created a stronger paste due to the decreased amount of micro-pores in the paste. In addition, the existence of UOPA reduced the demand for foam and as a result decreased the artificial pores within the mixes microstructure. Decreased artificial pores create a stronger mix that requires increased amounts of force to break the specimen.

Mixes with higher UOPA replacement levels than 25% showed that they were weak in resisting the flexural stress. Although increasing the UOPA replacement level would reduce the foam quantity (reduced artificial pores), the water demand increased and as a result the micro-pores increased within the paste of the mix making it weaker in resisting the flexural load.

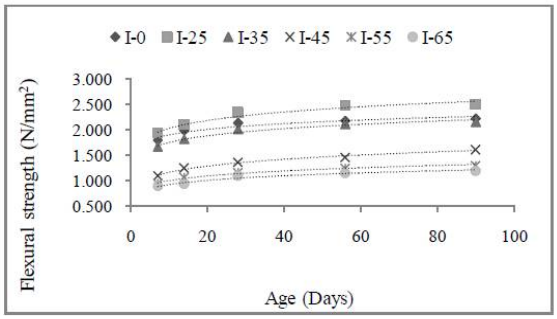

Fig. 2. Flexural strength

Fig. 2 shows the flexural strength as a function of age. The figure shows that flexural strengths increase with age. The development in flexural strengths for foamed concrete with UOPA content is due to a pozzolanic reaction occurring between the silica oxides in the OPA and the calcium hydroxide emitted by the cement hydration process. This pozzolanic ration creates extra calcium silicate hydrates making the paste stronger in withstanding the flexural stress imposed on the specimen.

D. Porosity

Fig. 3 shows the porosity readings as a function of age for all the foamed concrete mixes. The results show

that porosity readings increased with increasing POBA content beyond 25% by weight of OPC. The increase in porosity is due to the ineffectiveness of the PS-1 dose, which increased the water demand with increasing POBA content.

The increased water quantity produces a foamed concrete mix with a porous paste. This increased porosity would reduce the strength of the paste and produces a weak mix. Similarly to the compressive strength, mix I-25 showed lower porosity readings at all ages in comparison to those shown by its control mix I-0. The reduced porosity is due to the reduced amount of artificial pores within the paste (due to the reduction in foam quantity) and to the reduced amount of water content due to the PS-1 dose. Fig. 3 also shows that the all the mixes, especially the mixes containing POBA replacement levels, showed a decrease in porosity readings with age. This is due to pozzolanic reaction that was mentioned earlier.

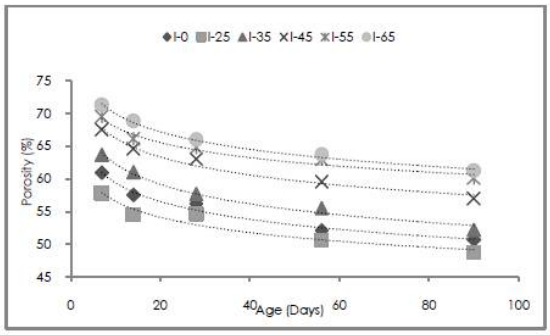

Fig. 3 Porosity readings

From the previous results and analysis, it can be stated that porosity has a strong effect on the compressive strength of the foamed concrete mix. Increased porosity hints to a weak paste that reduces its ability to withstand increased amounts of loading. Fig. 4 shows compressive strength as a function of porosity at the age of 28 days.

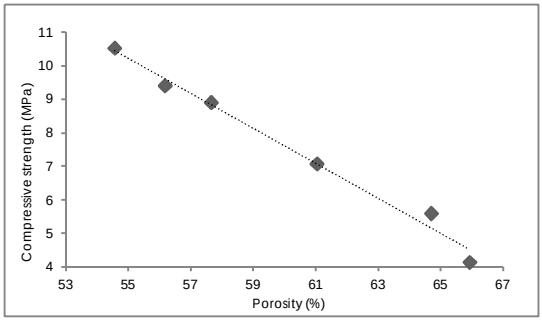

Fig. 4 Compressive strength as a function of porosity at the age of 28 days

The relationship shown in Fig. 3 is written as follows:

$$f_c = -0.5222\,\rho_{28d} + 38.944 \quad \text{..... (2)}$$

The best fit correlation between the compressive strength and the porosity of the foamed concrete mixes is a linear relationship. Regression analysis has been conducted between the actual compressive strength reading and the values obtained from Equation 2 yielded an R^2 value of 98.7%. this high value indicates a rather strong relationship between the two variables.

E. Water Absorption

Water absorption is proportionate to increasing UOPA content inside the foamed concrete mix. Foamed concrete mixes showed an increase in water absorption readings beyond the 25% UOPA replacement level. The decrease in water absorption readings exhibited by mixes is because of the effectiveness of the superplasticiser dose. The 1% superplasticiser dose effectively reduced the water demand and as a result reduced the amount of pores existing in the paste. Therefore, increasing pore content inside the foamed concrete would increase its tendency to absorb more water. In other words, increasing UOPA content would increase the paste volume in the mix; hence, increasing the amount of micro-pores which have the tendency in taking in water when submerged. It has been proven that increasing paste volume would increase water absorption[25].

Mixes in all six replacement level experienced lower water absorption readings with increasing age. This reduction in water absorption is occurring regardless of the existence of UOPA content in the foamed concrete mix. The decrease in water absorption readings is a result of the reduced amount of pores within the paste of the foamed concrete mix. This reduction in pore quantity is due to the pozzolanic reaction occurring between the silicate oxides and the calcium hydroxide. These calcium silicate hydrates are known to occupy the empty voids between the pores and as a result, densifying the paste. Fig. 5 illustrates water absorption as a function of age for the foamed concrete.

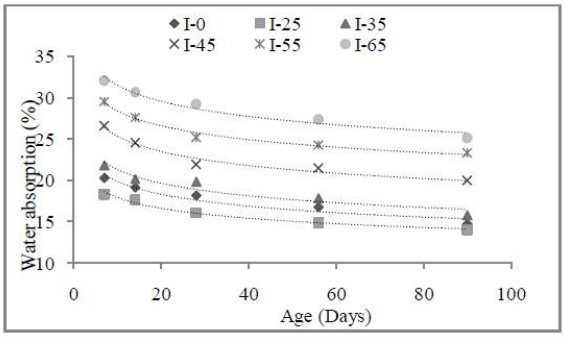

Fig. 5 Water absorption as a function of age

F. Drying Shrinkage

Foamed concrete suffers from the high shrinkage because of the increased cement content and the lack of coarse aggregates. Due to the importance of drying shrinkage to foamed concrete, the shrinkage readings were taken until the age of 365 days. Fig. 6 illustrates

the drying shrinkage for the mixes with a design density of 1300kg/m^3

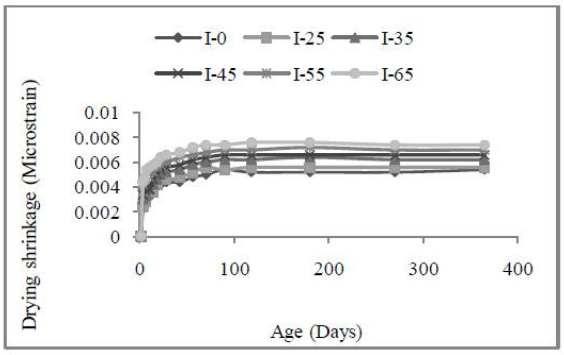

Fig. 6 Drying shrinkage as a function of age

Increasing OPA replacement levels have a negative effect on drying shrinkage. Drying shrinkage increased with increasing OPA content. Foamed concrete mixes containing UOPA replacement levels showed increases in drying shrinkage readings in the range of 3.7-37%. The same observation was reached by Tay [10] when replacing cement by OPA sieved through a 150µm sieve; and by Awal and Nguong [26] when replacing cement by OPA passing through a 45µm sieve in conventional concrete.

Drying shrinkage occurs when absorbed water is removed from the surface of the gel pores resulting in a change in volume of unrestrained hydrated cement paste [27]. Increased water demand that accompanies UOPA content would contribute to this change in volume. Since it has been shown that UOPA particles are porous in nature, they taken more water. In the case of foamed concrete, the increase in drying shrinkage is attributed to the increase in paste volume. When replacing cement by UOPA, the foam demand decreases, hence, increasing the paste volume. Increasing the paste volume increases the amount of pores contributing to the drying shrinkage. As confirmed by Nambiar and Ramamurthy [28], drying shrinkage of foamed concrete is a function of paste volume.

CONCLUSION

This study investigated the possibility of utilising coarse POBA as a partial OPC replacement in producing foamed concrete. Replacement levels of 0, 25, 35, 45, 55 and 65% by weight of OPC were used to incorporate POBA into a foamed concrete mix with equal amounts of filler and binder with a design density of 1450kg/m^3. POBA's incorporation reduced the foam quantity required to achieve the design density and increased the water demand to achieve the required consistency. POBA replacement levels beyond 25% reduced the compressive strength and increased the porosity of the foamed concrete mix. However, mix I-25 showed superior compressive strength and exhibited

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