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THE EFFECT OF OIL PALM ASH INCORPORATION IN FOAMED CONCRETE

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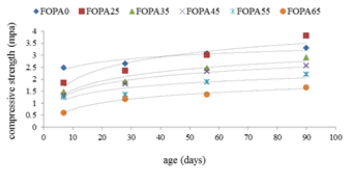
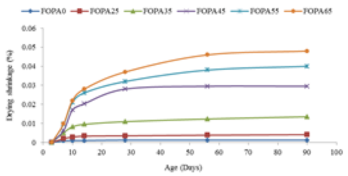
Graphical abstract





Abstract

This paper investigates the effect of replacing different portions of cement by fine oil palm ash (FOPA). A target density of 1000 kg/m^3 was used for the foamed concrete mixes. A foamed concrete mix of 1 part binder, 2 parts filler and 0.45 part of water has been used. Cement was replaced at levels of 25, 35, 45, 55 and 65% by weight of binder. The compressive strength, density, water absorption, drying shrinkage and sorptivity were tested at different ages. The mix containing 25% of fine OPA showed enhanced properties in comparison to the control mix at the age of 90 days. The mixed showed higher compressive strength, less water absorption, increased density and lesser sorptivity. However, the same mix showed higher shrinkage readings than that of the control mix.

Keywords: Foamed concrete, oil palm ash, cement replacement

Abstrak

Kajian ini kesan pengabungan abu kelapa sawit yang halus sebagai pengantian separa untuk simen dalam menghasilkan konkrit berbusa (FOPA). Sasaran densiti yang digunakan bagi campuran konkrit berbusa adalah 1000 kg/m^3. Campuran konkrit berbusa dengan 1 bahagian pengikat, 2 bahagian pengisi dan 0.45 bahagian air telah digunakan. Simen telah digantikan pada tahap 0, 25, 35, 45, 55 dan 65% daripada jumlah berat pengikat. Kekuatan mampatan, densiti, penyerapan air, pengeringan pengecutan dan sedutan kapilari telah diuji pada usia yang berbeza. Campuran yang mengandungi 25% abu kelapa sawit halus telah menunjukkan penambabaikkan dalam ciri-ciri berbanding dengan campuran kawalan pada hari ke-90. Campuran tersebut menunjukkan kenaikkan dalam kekuatan mampatan, pengurangan dalam penyerapan air, peningkatan density dan pengurangan dalam sedutan kapilari. Namun demikian, campuran yang sama telah menunjukkan bacaan pengecutan yang lebih tinggi berbanding dengan campuran kawalan.

Kata kunci: Konkrit berbusa, abu kelapa sawit, gentian simen

1.0 INTRODUCTION

After water, concrete is the most widely used material on earth [1]. It is widely exploited due to its versatility, availability of raw materials, economy, durability and strength [2]. However, due to this extensive use of concrete, raw materials are growing seldom. The annual consumption of concrete world-wide by the construction industry reaches 1.6 billion tonnes of ordinary Portland cement (OPC), 10 billion tonnes of sand and rock, and 1 billion tonnes of water, thus making the concrete industry the largest consumer of natural resources on the planet [1]. Another issue arises from this extensive use of concrete is its large contribution to global warming. Cement manufacturing contributes about 5% of the total CO_2 emissions [3]. In addition, the manufacturing of a single tonne of OPC produces a tonne of CO_2 emitted into the atmosphere [4]. Therefore, a number of studies have pursued the goal of fabricating other types of concrete that possess the same desirable properties but are more environmentally friendly and more economical. It has been found that reducing the self-weight of any construction can be advantageous. This type of reduction can be done by either reducing the cross sections used or by using lightweight concrete. Lighter concrete when used can reduce the weights induced on the foundations hence, reducing their size; furthermore, reducing the weight of materials handled by that increasing the productivity and also, its low thermal conductivity.

Foam concrete, is one of these types of lightweight concretes that was first produced in Sweden by Axel Eriksson [5]. Foam concrete is a homogeneous material due to the absence of large aggregates when compared to conventional concrete. The most attractive properties that this type of concrete has are its self-compacting and self-leveling nature, flow-ability, its ability to be produced with very low densities [6] and its low weight leading to designing more economical supporting structures such as foundations, walls and floors [7]. Furthermore, foam concrete is considered to be an environmentally friendly product because it uses less natural resources and the ability to incorporate larger amounts of waste materials within its mix [8]. Such wastes include fly ash, rice husk ash and blast furnace slag. The air content of a foamed concrete mix is more than 25%. In its basic form, foam concrete is a mixture of sand, cement, water and pre-formed foam which is a combination of water and a foaming agent either synthetic or protein based. The application of pre-formed foam into mortar (a mix of cement, sand and water) will lead to the reduction of the mix density, but at the same time increasing the yield [5]. Foam concrete is a very fluid and self-leveling concrete that can flow for long distances and has the ability to fill difficult shaped voids, it is bleed and settlement free, has a range of strengths form 0.5MPa to 10MPa and due to its low strength and high air entrainment, it is possible to remove foam concrete from the place it was poured into for future purposes [9]. In addition, foam concrete is produced at densities ranging between 300 to 1800 kg/m^3. Oil palm ash is a by-product produced by the palm oil industry. It is generated from the incineration of oil palm shell (OPS) and oil palm empty fruit bunch (EFB) at 800-1000C°, for heating up the mill's boilers instead of using conventional fuels.

The resulting ash is produced at about 5% by weight of the incinerated solid fuels [10]. In Malaysia alone, the quantity of oil palm ash produced annually reaches 4 million tonnes [11]. It has been common practice to dispose of the resultant ash by dumping into landfills or spread on the premises of the oil palm mill without any consideration to its environmental effects. A number of studies focused on the OPA's utilization in concrete manufacturing. Studies have proved that OPA is a pozzolanic material that can be used in concrete as a cement replacement in order to enhance the properties of concrete.

Palm oil ash (OPA) or palm oil fuel ash (POFA) is a greyish coloured ash that tends to get darker with the increasing amount of unburned carbon [12]. In its normal state, as received from the source, the original OPA is a large particle sized substance having a porous texture. Grinding of OPA will produce particles that have a smaller particles size. In addition, the grinding process will increase both the fineness of the OPA particles and also its specific gravity [13]. OPA is a throw away product that is produced abundantly. Common practices for disposing of this by-product were either by tipping or dumping. Hence, the waste is either spread over the premises of the mill or dumped to fill in low economic value dumps or selected types of land such as swamplands, abandoned sand quarries [11]. These disposal methods were conducted without taking into consideration the surrounding environment or taking precautions to compact, cover and prevent the spreading of pollutants into the ground water levels [14]. In addition, due to its fine particles, OPA can be easily carried away by wind by that causing smog on a humid day [15]. Therefore, the utilization of OPA in concrete production has a number of environmental benefits such as reducing the amount of OPA that is disposed of into landfills, reducing the amount of energy used and the emitted greenhouse gases when OPA is used to replace manufactured cement and the conservation of other natural resources when OPA is used as filler replacement.

OPA has been extensively used as a cement replacement in conventional concrete. Using ungrounded OPA as a cement replacement proved to have reduced effect on the compressive strength of concrete only when used at a 10% replacement level [15, 16]. Increasing the levels of replacement of cement by OPA will increase the concrete's ability to suppress the alkali-aggregate reaction [12]. High strength concrete was obtained when replacing cement with OPA at a level of 30% achieving higher compressive strengths than the control mix; however, increasing the replacement levels reduced the modulus of elasticity and also reduced the heat of hydration for the mix [10]. A 20% replacement of cement by ground OPA (particle size of 7.4µm) achieved the same sulfate resistance of conventional concrete mix using cement [17]. High strength concrete with a replacement level of 20% of cement by OPA achieved a compressive strength reaching 95% of that of a 10% silica fume concrete at the age of 180 days [18]. Cement was replaced by OPA at a replacement level of 20% and achieved a compressive strength higher than that of the control mix used; however, permeability was observed to be higher than the control mix when using OPA as cement replacement [19]. OPA was used at replacement levels of 20% and 40% by weight of cement in a mortar mix of (1:2.75) and the compressive strengths obtained by these mortars were higher than that of the control mortar; also, the chloride penetration was lower when compared to the control mortar [20]. However, the authors concluded that using a blend of pozzolanas having equal amounts such as OPA and fly ash will not only improve the mortar strength but also in terms of chloride penetration. When grinding OPA to have a 10.1μm and used as a cement replacement in high strength concrete, drying shrinkage was observed to be the lowest at a replacement level of 30% by weight of binder; also, lower permeability was achieved with the sample containing ground OPA achieving half the permeability that of the control mix [13]. Mortars achieved higher compressive strengths when cement was replaced with fine OPA (5+2% retained on a 45μm sieve) at a replacement level of 40% than that of the control mortar when studying the filler effect and the pozzolanic reaction of ground OPA in mortar [21]. Treated ultra-fine OPA with a median particle size of 2μm can be used in large volumes (up to 60%) for the production of high strength green concrete [22].

2.0 MATERIALS AND MIX PROPORTION

2.1 Materials

The materials used in this study were cement labeled under the name castle cement produced by YTL, fine sand which Figure 1 shows its sieve analysis according to BS 882 [23], protein based foaming agent produced by DRN SDN. BHD. labeled as (PA-1) and it is diluted in water at a ratio of (1:30) and is aerated to produce preformed foam with a density of 65kg/m^3, potable water, and fine OPA. The raw OPA was collected from a palm oil mill near Nibong Tibal. The ash was produced by incinerating the biomass at temperatures greater than 1000°C. The raw OPA was oven dried for 24 hours then sieved through a 300μm sieve to remove any unburned shell and fibres and eliminate the presence of larger OPA particles. The sieved OPA was then ground using a ball mill for 1 hour to obtain fine OPA with 100% passing through a 45 μm sieve.

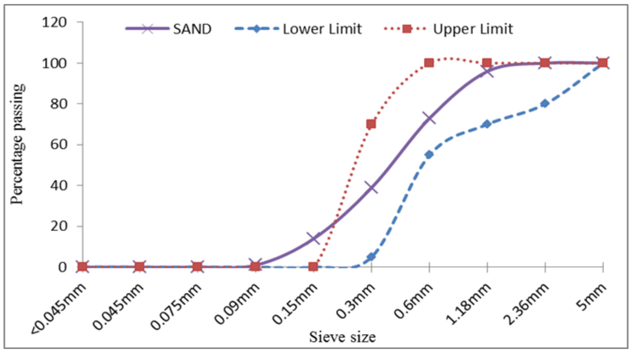


Figure1 Sieve analysis of the sand used in this study

2.2 Mixing Procedure

The dry materials (cement, OPA and sand) are placed inside a concrete mixer and then mixed until a homogeneous mix is obtained. The water is then added gradually until the required consistency of 220 mm is obtained. The density of the base mix is then determined by weighing a 1 litre cup of the mix. The quantity of foam is then calculated and then added gradually to the mix. Foam is added to the mix until the design density is obtained (1150±50 kg/m^3). Then the fresh mix is poured into the moulds then covered with a plastic sheet to prevent any loss of moisture. After 24 hours, the samples are de-moulded, weighed and cured until the date of testing. The type of curing used is sealed curing because it reflects what is used in the industry [24]. The samples are wrapped with plastic film then kept until the testing date. Table 1 shows the calculated materials to be used in the six mixes.

Table 1 Calculated mix composition (kg/m^3)

Mix	cement	OPA	sand	water
FOPA0	324.81	0.00	649.62	146.16
FOPA25	243.61	81.20	649.62	146.16
FOPA35	211.13	113.68	649.62	146.16
FOPA45	178.65	146.16	649.62	146.16
FOPA55	146.16	178.65	649.62	146.16
FOPA65	113.68	211.13	649.62	146.16

2.3 Testing Programme

2.3.1 Compressive Strength

The compressive strength was conducted on 100mm cubes. The cubes were tested using an ELE testing machine with a capacity of 3000 kN. The compressive strength is taken at the ages of 7, 28, 56 and 90 days.

2.3.2 Water Absorption

Water absorption is determined at the ages of 7, 28, 56 and 90 days of age. The water absorption is determined using 100 mm cubes using the same procedure stated by Nambiar and Ramamurthy (2006). The water absorption results are taken as the difference in weight per unit of volume (kg/m^3).

2.3.3 Sorptivity

The sorptivity test measures the water absorption rate via capillary suction of unsaturated concrete placed in contact with water without the existence of a water head. Sorptivity was determined using cylindrical specimens of a 100 mm diameter and 200 mm length. The procedure used to test soprtivity is the same stated by [25].

2.3.4 Drying Shrinkage

The drying shrinkage was determined using rectangular specimens of 75×75×280 mm. Drying shrinkage was tested according to the procedure specified by [26]. Drying shrinkage readings were taken at the age of 3, 7, 10, 14, 28, 56 and 90 days.

3.0 RESULTS AND DISCUSSION

3.1 Water and Foam Requirements

Table 2 shows the quantities of the materials used in this study for all six mixes. Water demand increased with increasing OPA content. The control mix needed less water to achieve the required consistency of 220 mm. with increasing OPA content, the mix required additional water to achieve the same consistency. This is reasoned to the shape and nature of the OPA particles. The OPA particles are angular and irregular shaped particles which require increased amounts of water to lubricate its surface [27].

Table 2 Mix contents and obtained densities (kg/m^3)

Mix	cement	OPA	sand	Act. water	Mortar density	Foam (m^3)	Fr. density
FOPA0	324.81	0.00	649.6	132.70	2208	0.499	1165
FOPA25	243.61	81.20	649.6	159.76	2148	0.472	1175
FOPA35	211.13	113.7	649.6	162.16	2118.4	0.463	1180
FOPA45	178.65	146.1	649.6	164.62	2098	0.457	1175
FOPA55	146.16	178.7	649.6	167.66	2087	0.453	1180
FOPA65	113.68	211.1	649.6	173.86	2085	0.449	1185

The foam requirements decreased with increasing OPA content. As it is shown in Table 2, the mortar density decreases with increasing OPA content; hence, requiring lesser amounts of foam to achieve the design density. This is reasoned to the lightweight OPA particles.

3.2 Compressive Strength

Figure 2 shows the compressive strengths of the six mixes as a function of age. In general, compressive strengths decreased with increasing OPA content. This is true until the age of 56 days. At the age of 56 days, FOPA25 exhibited a compressive strength which is 98% of FOPA0's compressive strength. At the age of 90 days, FOPA25 obtained a higher compressive strength than the control mix FOPA0. This is due to the pozzolanic reaction occurring between the OPA and cement creating extra CHS compounds which creates a denser paste. The decrease in compressive strengths seen with foamed concrete mixes containing OPA replacements beyond 25%, is due to the increased water demand which in return creates a porous paste.

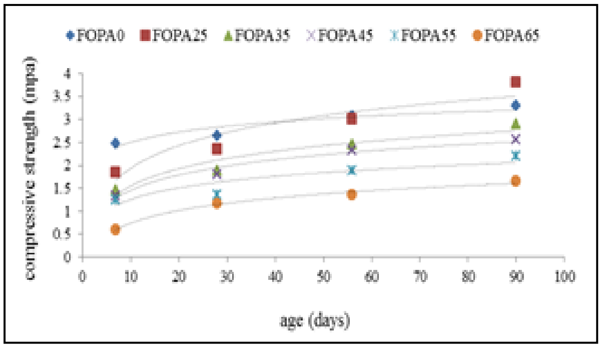


Figure 2 Compressive strength readings with age

In addition, the decrease in cement content also decreases the compressive strength. However, Figure 2 also shows that all foamed concrete mixes undergo strength development with age. This is due to the cement hydration process and due to the pozzolanic reaction occurring between OPA and cement.

3.3 Water Absorption

Water absorption readings are illustrated in Figure 3. FOPA25 exhibited lower water absorptions than the control mix. This is reasoned to the filler effect that the OPA particles induce in the paste where it reduces the amount of pores within the paste. Water absorption readings increased with increasing OPA content beyond 25%. This increase is due to the increased water demand which results in increasing the pores within the paste. In addition, the paste volume is larger due to the addition of OPA which reduces the artificial pores in the paste. However, in general water absorption readings reduced with age due to the pozzolanic reaction between OPA and cement particles resulting in a denser paste and a less porous paste.

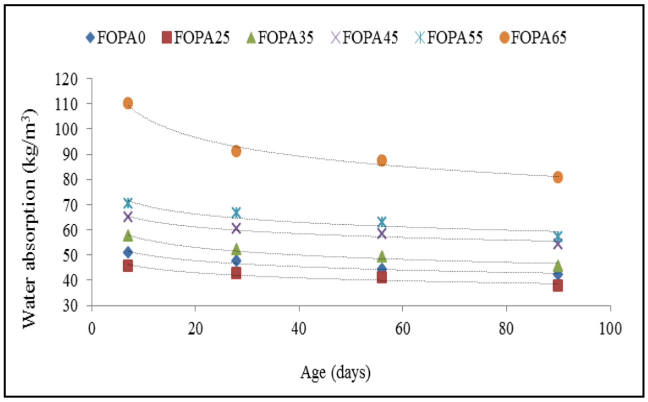


Figure 3 Water absorption readings with age

3.4 Sorptivity

The sorptivity test was conducted at the age of 28 days. Figure 4 shows the readings achieved for the six foamed concrete mixes. The figure shows that

FOPA25 showed less sorptivity reading than the control mix. This means that the water intake through the face immersed in water was too slow to be taken by the capillary pores.

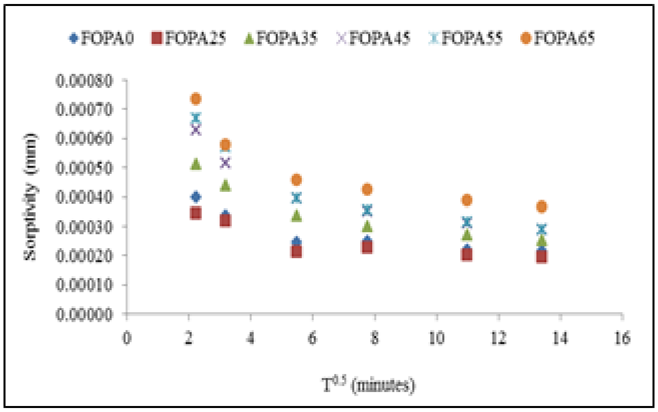


Figure 4 Sorptivity readings with the square root of time

Due to the filler effect of the fine OPA and pozzolanic reaction occurring between OPA and cement created a denser paste with no continuous pores creating channels through the paste which absorb the water. Increasing OPA content increases the sorptivity readings. It seems that increasing OPA content beyond 25% disturbs the pore structure of the foamed concrete mix; hence, creating continuous pores.

3.5 Drying Shrinkage

The drying shrinkage readings are illustrated in Figure 5. All mixes with OPA replacements showed higher drying shrinkage readings than the control mix FOPA0. It clearly shows that the loss of moisture from the samples containing OPA is higher than the control mix. Therefore, it is required to use plastic fibres when using OPA as a cement replacement to decrease the drying shrinkage of the foamed concrete mix.

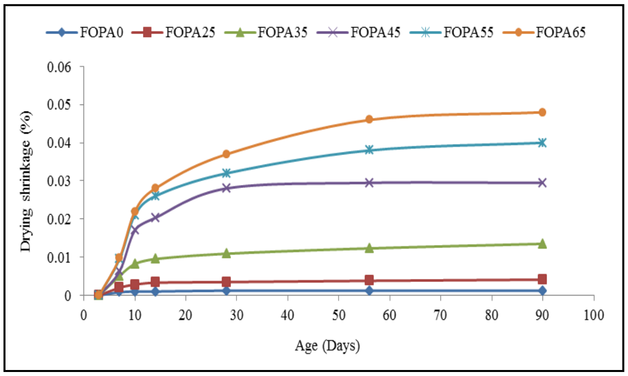


Figure 5 Drying shrinkage readings

4.0 CONCLUSION

This study investigated the effect of replacing cement with fine OPA on the properties of 1000 kg/m^3 foamed concrete mix. The following are the conclusions that were drawn from this study:

- The inclusion of OPA into the mix as a cement replacement increased the water demand and reduced the amount of foam required to achieve the needed design density.
- FOPA25 achieved a higher compressive strength than the control mix after 56 days. This is due to the pozzolanic reaction occurring between OPA and cement particles. Increasing OPA content beyond 25% decreased the strength.
- FOPA25 exhibited lower water absorption readings and lower sorptivity than the control mix. Increasing OPA content beyond 25% increased the water absorption readings and increased sorptivity. Higher OPA contents disrupt the pore structure of the foamed concrete mix; hence, creating a more porous paste than that of the control mix's paste.
- Drying shrinkage readings increased with increasing OPA replacement levels. This is reasoned to the increased moisture loss from the samples when OPA is used in the mix.
- As a recommendation, it is desirable to use a water reducing agent to reduce the foamed concrete mix's water demand when OPA is used as a cement replacement. This would help in controlling the water and hence creating a denser, less porous foamed concrete. In addition, for the sake of reducing drying shrinkage, plastic fibres should be added as a percentage of binder materials' weight.

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