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# ENGINEERING PROPERTIES OF HIGH VOLUME BIOMASS WASTE MORTAR

Habeeb Lateef Muttashar[a*], M. W. Hussin[b], Jahanger Mirza[b], Nor Hasanah[a], Ghasan Fahim Huseien[a]

[a]Department of Structure and Materials, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

[b]Department of Structure and Materials, Faculty of Civil Engineering & UTM Construction Research Centre Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

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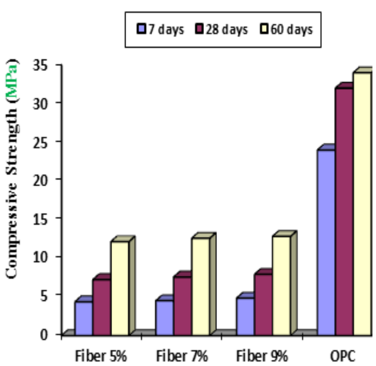
*Corresponding author
Lmhabeeb2@live.utm.my

## Graphical abstract




## Abstract

This paper represents the effects of using waste generated from palm oil industries like ash, shell and fibre on the engineering properties of mortar. Palm Oil Fuel Ash (POFA) was used as cement replacement up to 60% and Oil Palm Kernel Shell (OPKS) as sand replacement in mortar mixture. The Oil Palm Fibre was added to increase the strengthening performance of mortar. The method used to find the water binder ratio was by trial and error method with 1:3 ratio of cement to sand. The cubes size of 70mm x 70mm x 70mm, beams size of 40mm x 40mm x 160mm, and cylinders size of 70mm diameter and 150mm height, were cast and tested for compressive strength, flexural strength and splitting tensile strengths of mortar. Samples were cured in water before testing it at 7, 28, and 60 days. Also, the water absorption of mortar was tested at the age of 28 days. The results showed that oil palm fibre provided more advantages and increase the strength properties especially in the flexural and tensile strength. The addition of Oil Palm Kernel Shell reduced the density of mortar and it can be used for lightweight application. The test results also showed that as the POFA ratio increased, the compressive strength of mortar decreased. However, as OPKS ratio increased, the density was found to be decreased. The mix proportions using 60% POFA and 20% OPKS was considered as the optimum mix design. The mortar showed optimum strength at 9% with the addition of fibre.

*Keywords*: Palm Oil Fuel Ash, biomass waste, Oil Palm Kernel Shell, Oil Palm Fibre, mortar

## Abstrak

Kertas kerja ini membentangkan kesan penggunaan sisa daripada industri minyak sawit termasuk abu, tempurung dan gentian terhadap ciri-ciri kejuruteraan mortar. Abu terbang kelapa kelapa sawit (POFA) digunakan sebagai pengganti simen sehingga 60% manakala tempurung sawit (OPKS) digunakan sebagai pengganti pasir dalam campuran mortar. Gentian kelapa sawit ditambah untuk meningkatkan prestasi kekuatan mortar. Kaedah yang digunakan untuk mencari nisbah pengikat kepada air adalah secara cuba jaya dengan nisbah simen kepada pasir, 1:3. Kiub bersaiz 70mm x 70mm x 70mm, prisma bersaiz 40mm x 40mm x 160mm dan silinder dengan saiz diameter 70mm and tinggi 150mm dibuat dan diuji bagi kekuatan mampatan, kekuatan lenturan, dan kekuatan tegangan pemisahan mortar. Sampel-sampel diawet dalam air sebelum diuji pada hari ke 7, 28 dan 60. Serapan air pada mortar juga diuji pada usia rendaman mortar 28 hari. Keputusan jangka pendek menunjukkan OPF mempunyai banyak kelebihan dan meningkatkan ciri-ciri kekuatan terutamanya dalam kekuatan lenturan dan tegangan. Penambahan OPKS mengurangkan ketumpatan mortar dan boleh digunakan dalam aplikasi mortar ringan. Keputusan ujian menunjukkan apabila nisbah POFA bertambah, kekuatan mampatan mortar berkurang. Walaubagaimanapun, ketumpatan berkurang apabila nisbah OPKS bertambah. Nisbah campuran menggunakan 60% POFA dan 20% OPKS dianggap sebagai rekabentuk campuran optimum. Mortar menunjukkan kekuatan optimum pada 9% penambahan OPF.

*Kata kunci*: Abu terbang kelapa sawit, bahan buangan biomas, tempurung kelapa sawit, gentian kelapa sawit, mortar



## 1.0 INTRODUCTION

These days, Portland cement has gained popularity due to the fact that it is generally utilized as a part of cement industry as more structures are developed. In any case, it discharges greenhouse gasses, carbon dioxide ($CO_2$) into the air during its production. There has been numerous trial works directed by presenting another material or reused waste materials as a substitution of cement or aggregate in cement [1]. The utilization of these reused materials is progressively created on account of natural sustainability. One of these new waste materials is Palm Oil Fuel Ash (POFA) which is generally utilized as a part of land filling. It is a rural waste and one of the pozzolanic materials as demonstrated by past examination and has been effectively utilized as cement replacement in mortar. POFA is a by-product of palm oil industry. The ash remains is delivered as a result of firing the palm oil shell and husk as fuel in palm oil plant boilers to create steam for power production during the extraction process of palm oil. Malaysia is the world biggest maker of unrefined palm oil. Palm oil farms expanded considerably from 400 hectares in 1920 to around 3.6 million hectares in 2002, and are anticipated to extend to 5.2 million hectares in 2020 [2]. Then again, the rich accessibility of Palm Oil Fuel Ash (POFA) makes chance to use this by-product of firing the palm oil shell and husk, as a substitute for OPC to make concrete. In addition, Malaysia has a high creation of Palm Oil Fuel Ash which is for the most part utilized as a part of land filling. It is a horticultural waste and one of the pozzolanic materials as demonstrated by past analysts and has been effectively utilized as a part of changing the durability and strength of cement. The pioneer in POFA examination has left on concentrating on agricultural ash remains in Malaysia lastly recognized that POFA is a pozzolanic material and ready to replace cement substitution up to 35% in mortar blend that could deliver comparative quality as typical mortar [3]. It was accounted for that the advancement and utilization of palm oil fuel ash concrete, which permitted the surrogate of OPC up to 40% with no adverse impact on the quality of cement [4].

## 2.0 MATERIALS AND METHODS

### 2.1 Palm Oil Fuel Ash (POFA)

POFA was obtained from the mill of Pertubuhan Peladang Negeri Johor at Kahang mill near Kluang Johor, Malaysia and air dired in oven at 110°C ± 5 for 24 hours to remove moisture. Now it was ground using the modified Shimpo Ball Mill PTA-01 test machine, consisting of 45 porcelain balls as shows in Figure 1. These balls help to crush materials into finer particles and it was further sieved through a 300μm sieve for removing the bigger size ash particles and imperfections. Only the fine ashes passing the sieve was collected and used in the mixing Figure 2 shows the collected POFA. However the chemical composition of POFA is shown in Table 1.

**Table 1** Chemical composition of pofa [5]

| Elements | Pofa (%) |
|---|---|
| SiO2 | 53.5 |
| Al2O3 | 1.9 |
| Fe2O3 | 1.1 |
| CaO | 8.3 |
| MgO | 4.1 |
| Na2O | 1.3 |
| K2O | 6.5 |
| P2O5 | 2.4 |
| LOI | 18.0 |

### 2.2 OPKS and OPF

OPKS was ground using modified Los Angeles abrasion test machine as shows in Figure 3 consisting of 10 stainless steel bars (12mm diameter and 800mm long) instead of steel balls inside to obtain similar properties for replacing sand.

**Figure 1** Grinding machine (Simpo's PTA-01)

**Figure 3** Los Angeles abrasion test machine


**Figure 2** Palm Oil Fuel Ash (POFA)


**Figure 4** Oil Palm Kernel Shell (OPKS)

The use of OPKS was to reduce the density of high volume biomass waste mortar. Now, the OPKS was kept in air-tight plastic bag as shown in Figure 4 and stored in a humidity-controlled chamber. The palm oil fiber used in study was obtained from Kahang Palm Oil factory located at Kluang, Johor, Malaysia. The fibers produced from Empty Fruit Bunch (EFB) of oil palm tree The fiber was also subjected to further treatment such as sieving and heating, in order to improve strength in terms of flexural and tensile strength the Fiber was kept in air-tight plastic bag as shown in Figure 5.

## 2.3 Cement

Ordinary Portland cement (OPC) obtained from (Tenggara cement manufacturing sdn bhd) was used during this study.


**Figure 5** Oil Palm Fibre (OPF)

## 2.4 Fine Aggregate

Locally obtained sand with specific gravity of 2.62[5] under saturated surface dry condition was used as to ensure that water cement ratio is not affected. In this study, sand replacing ratio with OPKS was 20%.

### 2.5 Water

Water is one of the most important materials required to produce normal mortar mix. In general water acceptable for drinking purpose is considered suitable for the manufacturing of mortar. As impurities in water may influence the setting time of cement and also it can affect the strength of concrete or can cause staining at its surface [6].

## 3.0 MIX PORPORTIONS AND SAMPLES PREPARATION

In this study POFA was used as a partial substitute of OPC on mass-for-mass basis where the replacement ratios 60%, 80% and 100% While OPKS replacement ratio was 20% only. This was carried out as to ensure that any change resulting in the properties of high strength mortars is due the partial substitution of OPC with higher volume biomass POFA. Owing to the lower specific gravity of POFA in comparison to OPC, high strength mortar mixes are expected to have greater powder volume and binder paste volume in particular at higher biomass POFA content [7]. The mix proportion of biomass waste POFA mortar is shown in Table 2. Therefore, OPKS was used to replace sand, since it has lower specific gravity and helps to reduce the density of biomass waste mortar. The use of Oil Palm Fiber varied from (wt.5%, wt.7%, wt.9%) for the formulation of binder. This is to study the effect of OPF on the higher volume biomass waste mortar. The mortar specimen preparation includes 70mm standard cubes, 70mm (diameter) by 150mm (height) standard cylinders and 40x40x160mm standard beam. Mixing of mortar was carried out using a Hobart mixer and casting of samples was done in the form of three Layers; each layer was compacted using a vibrating table as to achieve maximum compaction. After casting, the samples were cured in water maintained at room temperature until for the requirement of further testing. The process of mixing the mortar started after the preparation of all the materials. Firstly, the wall surface of mortar mixer was moistened with water, to reduce the losses of water cement ratio in the mix which is 0.45 so that water measured. The sand was put into the machine and OPKS was transferred using a spade. Sand and OPKS were mixed together for one minute until homogeneity. Now, as much as 1/5 of total amount of water was added and the process of mixing continued. POFA was added slowly after the addition of OPC in the mixture. The remaining water which is 4/5 of the total amount of water was further added during the mixing process. Mixing time was around 15 minutes after regular mixing was achieved, until the machine was halted.

**Table 2** mix design for raw materials

| POFA:OPC % | OPC Kg | SAND Kg | POFA Kg | OPKS Kg | OPF Kg | | |
|---|---|---|---|---|---|---|---|
| | | | | | 5% | 7% | 9% |
| **0:100** | 511 | 1534 | 0 | 0 | 0 | 0 | 0 |
| **60:40** | 204.4 | 1227 | 306.6 | 306.8 | 25.5 | 35.7 | 45.9 |
| **80:20** | 102.2 | 1227 | 408.8 | 306.8 | 25.5 | 35.7 | 45.9 |
| **100:0** | 0 | 1227 | 511 | 306.8 | 25.5 | 35.7 | 45.9 |

## 4.0 RESULTS AND DISCUSSION

### 4.1 Analysis of Compressive Strength

The compressive strength of the mortar cubes was determined according to ASTM C109/C109M-12 "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars". The formula for compressive strength test:

$$\text{Compressive strength} = P/A \quad (1)$$

Where:

P = the load when samples failed (KN)

A = Area of mortar ($mm^2$)

The compressive strength for the control samples (OPC) for 7, 28, 60 days was 24 $N/mm^2$, 32 $N/mm^2$, 34 $N/mm^2$ respectively. From the analysis of compressive strength results for mortar the mixing ratios selected were 60% POFA as cement replacement, 20% OPKS as sand replacement, different ratios of fiber added as extra weight was (wt., 5%, wt.7%, wt.9%) with the measuring fiber length between (16-20)mm. The results obtained for the 7 days test were 4.379 $N/mm^2$, 4.506 $N/mm^2$, and 4.843 $N/mm^2$, respectively as shown in Figure 6. In the same context, the outcomes of 28 days tests are 7.250 $N/mm^2$, 7.583 $N/mm^2$, and 7.928 $N/mm^2$. The results of 60 days were found to be 12.151 $N/mm^2$, 12.589 $N/mm^2$, and 12.824 $N/mm^2$. The results show that the use of fiber increased the compressive strength of mortar. This increase in strength may be due to the linking present in between the components of mortar, resulting from the fiber particles, which works as reinforcement [8]. Figure 7 show the compressive strength samples.

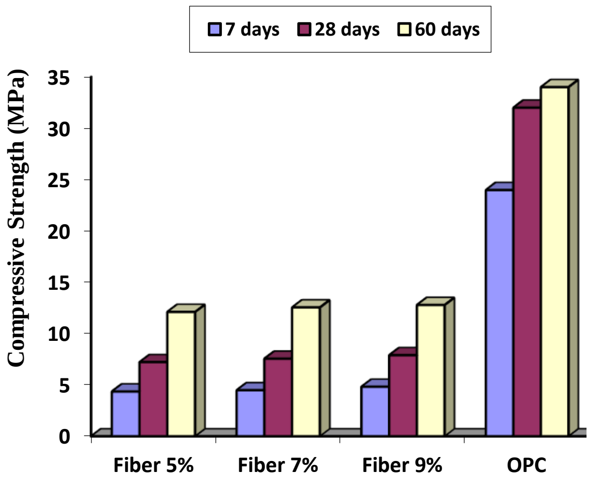



**Figure 6** Bar chart of Compressive strength

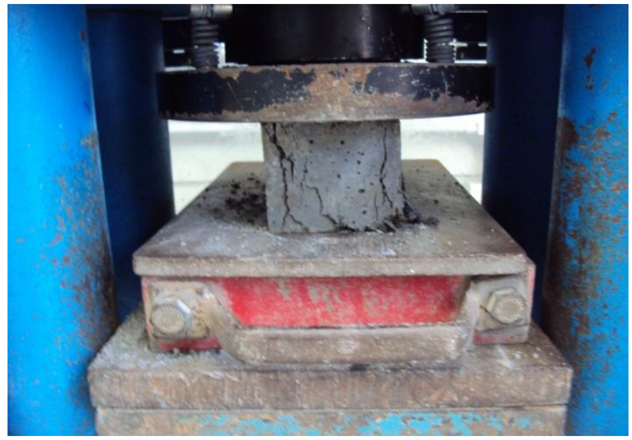


**Figure 7** compressive strength samples

## 4.2 Analysis of Flexural Strength

Flexural strength is the ability to resist an applied bending force such as encountered by concrete pavements or other slabs on ground. A determination of the flexural strength is frequently necessary as part of the design of concrete mixtures to check compliance with established specifications or to provide information necessary to the design of an engineering structure. Flexural analysis was carried out at room temperature as specified in ASTM D790, using laboratory equipment. The formula for compressive strength test:

$$\sigma = 3FL/\ (2bd^2) \qquad (2)$$

Where:
F is the maximum load (force) at the fracture point (KN)
L is the length of the support span (mm)
b is width of sample (mm)
d is thickness of sample (mm)

The results for flexural strength of 7 days were found to be 0.861 N/mm$^2$, 1.684 N/mm$^2$, and 2.714 N/mm$^2$. However the outcomes of 28 days test are 1.243 N/mm$^2$, 1.815 N/mm$^2$, and 3.320 N/mm$^2$, respectively. It can be concluded that flexural strength obtained for mortar with 60% POFA as cement replacement and 20%OPKS as sand replacement was different in comparison to the control samples of OPC as shown in Figure 8. The flexural strength for biomass waste mortar is lower than the flexural strength of OPC mortar it could be due to the decreasing in cement and sand ratios in the mortar. However the outcomes obtained have shown that use of fiber in the mortar increased the flexural strength in the sample. This might be due to the ability of fibers to withstand stress after cracking and fiber present in the samples acted as reinforcement [9].

Fibers in mortar also resulted in the bridging of cracks and holding the cracked Parts together or limiting the area of crack initiation. Similarly, the outcomes for 60 days test were found to be 1.768 N/mm$^2$, 2.084 N/mm$^2$, and 3.753 N/mm$^2$, respectively. It is due to the higher diameter of palm oil fiber length. Moreover, the increase in the length: diameter ratio of fiber usually augments the flexural strength and toughness of mortar. Figure 9 shows the deformation in the samples under the Flexural test.

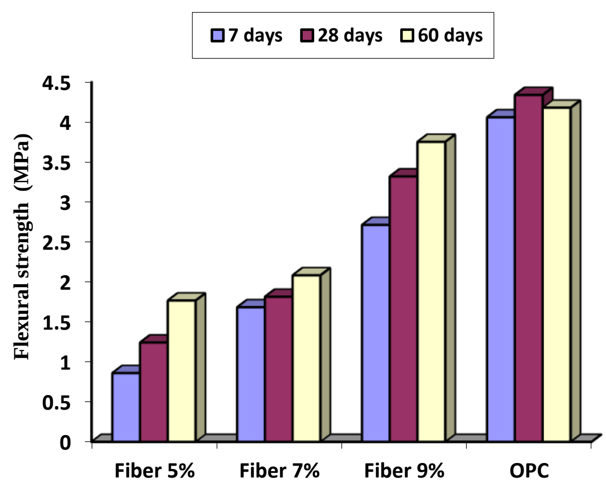



**Figure 8** Bar chart of Flexural strength

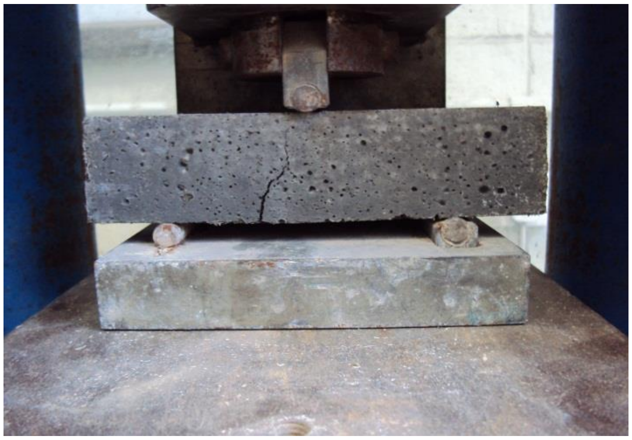


**Figure 9** Flexural strength samples

### 4.3 Analysis of Tensile Strength

Cylindrical test is required to determine the indirect tensile strength of concrete. Cylindrical test is based on ASTMD 3039. For tensile strength test is calculated using the formula 3:

$$Ft=2P/\pi DL \quad (3)$$

Where:
P = maximum load apply to sample (KN)
D = diameter of the cylinder (mm)
L = the length of the cylinder (mm)

The results show that the selected ratios for biomass waste mortar have higher tensile strength in comparison to OPC. The average tensile strength for control samples OPC was found to be 1.87 N/mm$^2$, 2.35 N/mm$^2$, and 2.40 N/mm$^2$, respectively. Whereas the results of 7 days test were found to be 1.26 N/mm$^2$, 2.44 N/mm$^2$, and 4.58 N/mm$^2$, the outcomes of 28 days test result are 2.45 N/mm$^2$, 3.57 N/mm$^2$, and5.76 N/mm$^2$, as shown in Figure 10. It can be seen that biomass waste mortar has higher tensile strength when compared to OPC. It is due to the fact that tensile strength of mortar can be improved to some extent with the inclusion of fibers. Tensile strength is considered to be an increased strength obtained with the implication of continuous fibers in the cement paste. The advancement is due to the existence of fibers. It is because of the ability of fibers to withstand stress after cracking and the presence of fiber in the samples act as reinforcement [10] as show in Figure 11. The tensile strength of palm oil fiber was found to be as 21.2 MPa [11]. If the modulus of elasticity of fiber is high in respect to the modulus of Elasticity of concrete or mortar binder, the fibers help to carry the load, thereby increasing the tensile strength of the material. Fibers in continuous or discontinuous form as a reinforcement has been seen to endow fiber reinforced concrete with real and significant improvement in the tensile properties, when compared to unreinforced matrix [15].

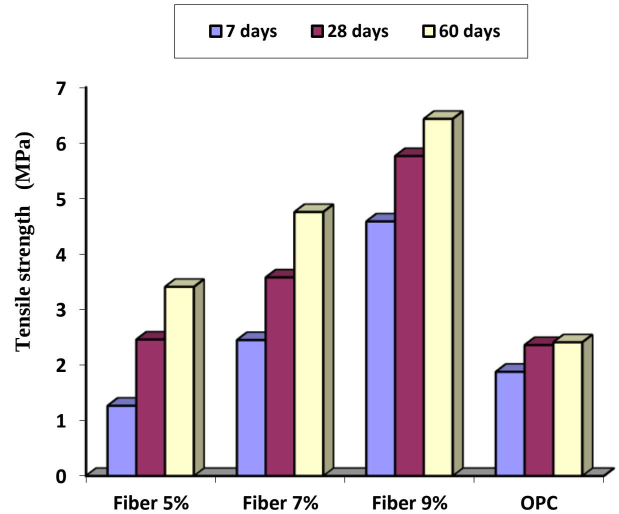



**Figure 10** Bar chart of tensile strength

**Figure11** Tensile strength samples

### 4.4 Water Absorption

Water absorption for mortar is important in order to get the rate of water absorb by the mortar. Mortar who have high water absorption may not be good in quality to be use since the mortar will tends to absorb much water during construction works. Water absorption test was conducted according to the ASTM C140 - 07 at 28 days by using three specimens and average value was taken to calculate the water absorption. Water absorption was determined by using equations (4) and (5). In Figure 12 the results obtained shows that the use POFA as cement replacement and OPKS as sand replacement showed higher water absorption, when compared to the control samples of OPC. It is due to the fact that higher ratio could be to the presence of large amount of bigger particles in POFA and the properties of OPKS as an organic aggregate, as it contains many pores and hence the water absorption is high [12].

That is why the mortar samples of the mix contain more voids thus results in affected capillary pores of the mortar that later absorbed more amount of water. Outcomes shows that when the fiber ratio increased the water absorption decreases, it due to the ability of fiber in filling the voids.

Absorption, kg/m³ = ((Ws-Wd))/ (Ws-Wi) x 1000 (4)
Absorption, % = ((Ws-Wd))/Wd x 100 (5)
Where:
Ws = saturated weight of specimen (kg)
Wi = immersed weight of specimen (kg)
Wd = oven-dry weight of specimen (kg)

### 4.5 Density

The mortar mix was designed for the density of 2200 kg/m³ the obtained results shown that the samples provided density lowers than the design mix. The reduction in density depends on the difference in the mix proportion and the type of materials. Used POFA as cement provided lower density. This was expected, as the specific gravity of POFA mortar is much lower than that of OPC mortar [13]. OPKS as sand replacement with 20% ratio in biomass waste mortar reduced the weight of the mix, at the same time directly showed effect on absorption of water in sample during the process of water curing, Specific gravity of OPKS varied but did not exceed the value of 2.0 [16].The Palm oil fiber as further addition of weight with the constant percentage for 60% POFA, 20% OPKS, showed higher reduction for cube 1690 kg/m³,1767 kg/m³,1791 kg/m³ respectively for density. Also with beam and cylinder samples, mortars with Palm oil fiber provided higher reduction of density after curing in water, for beam 1758 kg/m³,1816 kg/m³,1894 kg/m³ and for cylinder 1582 kg/m³,1816 kg/m³ 1894 kg/m³ as show in Figure 13. This could be due to the additional weight in mortar after the addition of Palm oil fiber to the mix and also for the absorption of water with the particles of OPKS and pores in the mortar, which was filling with water during the time of curing [14].

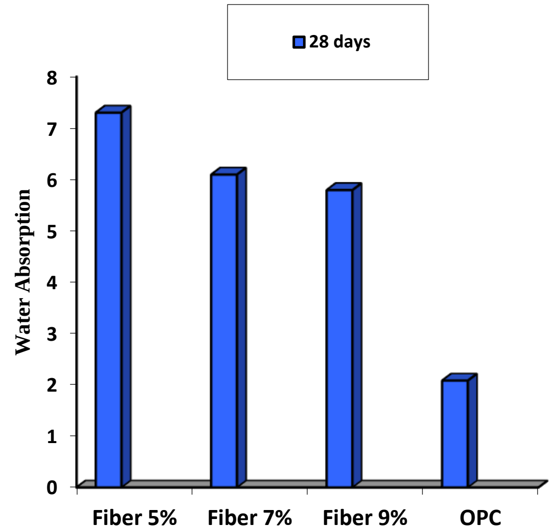



**Figure12** Water absorption capacity

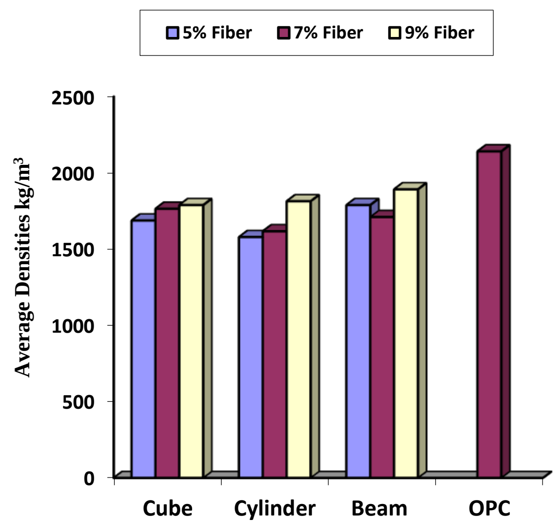



**Figure 13** Bar chart average densities

## 5.0 CONCLUSIONS

In this study the effects of using higher volume biomass waste POFA as an alternate for cement, also the use of crushed Oil Palm Kernel Shell to replace sand for reducing the density of mortar and the effects of palm oil fiber on the strength properties was investigated. The use of POFA with 60% percentage in the mortar reduced the compressive strength in mortar when compared to the control samples of OPC because the size of POFA particles is bigger than the cement particles .However OPKS reduced the density in mortar when used as sand replacement by reducing the weight of mortar samples, which is due to the lower specific gravity of OPKS, which was found to vary, but it never exceed the value of 2.0 [16] in comparison with sand.

Fibres in mortar have showed improvement in flexural and tensile strength as compared to the compressive strength, which is found to be affected to a lesser extent in the presence of fibers. It was found that nearly up to 60% of waste materials can be used for replacing the materials in biomass mortar

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