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OIL PALM TRUNK FIBER AS A BIO-WASTE RESOURCE FOR CONCRETE REINFORCEMENT

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ABSTRACT

This paper reported the investigation on the potential of oil palm trunk fiber as concrete reinforcement by determining the physical, mechanical and chemical composition of the fiber and also the effect of different volume percentages of oil palm trunk fiber (OPTF) on the physical, mechanical and durability properties of Grade 30 concrete. Oil palm trunk fiber was found to possess high tensile strength (300-600 N/mm^2), high density (1200kg/mm^3) and high content of lignin (23.03%). Hence OPTF is suitable as reinforcement. The compressive, tensile and flexural strength properties of the concrete improved by the addition of 1% OPTF and the OPTF have acted as crack arrester. The low dosage of OPTF improves the resistant against NaOH and NaCl attack but concrete with high dosage of OPTF have good resistance against the HCl attack.

***Keywords*:** Concrete, Mechanical properties, Oil palm trunk fiber, Brittleness.

I. INTRODUCTION

The versatility in formulation of concrete led to wide acceptance in construction industry. New developments continue in the application of concrete materials. But concrete has one main drawback: its considerable brittleness, which results in poor fracture toughness, poor resistance to crack propagation, and low impact strength. This inherent brittleness has limited their application in fields requiring high impact, vibration and fracture strengths Therefore, in the last few decades; much attention has been given to improve the mechanical properties of concrete, especially in making them tougher. One of the ways to enhance the toughness properties of the concrete is by the addition of fibers. Fibers are used in cementitious matrices primarily to modify the tensile and flexural strengths, toughness, impact resistance, and fracture energy (Balaguru and Shah, 1992). Cellulose–cement composites are mainly used for two reasons: (i) they are light at high volumes of fibers, and (ii) they can be manufactured with cost–performance ratios comparable to other building materials (Vinson and Daniel, 1990). A variety of fiber types, including man-made fibers or synthetic fibers such as steel, glass, polypropylene and natural cellulose fibers are available. Natural fibers like jute, coir, bamboo and sisal have already been used as reinforcement materials in cement matrices for many years, especially in developing countries (Balaguru and Shah, 1992, Wolfe and Gjinolli, 1996). The trunk of oil palm tree can also be processed to form a good source of fiber. The process of extraction of fiber does not require a sophisticated engineering process like the synthetic fiber. With regard to the previous research on oil palm trunk fibers (OPTF), MDF board from OPTF was stronger and had better fiber-to-fiber strength recorded than the frond and empty fruit bunch (EFB) MDF (Lionel,1996). Important properties of the hardened natural fiber reinforced concrete (NFRC) are strength, deformation under load, crack arrest, durability, permeability and shrinkage. In general, the strength is considered to be the most important property and the quality of NFRC is judged mainly by their strength. The ultimate strength depends upon fiber type, fiber form, fiber geometry, mix design, mixing method, curing method, casting technique, etc. Among the many factors, the two most important factors, which influence the maximum loads, are the volume percentage of fibers and aspect ratio. That's why many studies on NFRC used only a few significant parameters (fiber content, fiber length and fiber type) for the performance predictions of NFRC (Ramirez-Coretti, 1992, Jorillo and Shimizu, 1992). The use of fiber reinforcement has been reported to increase the flexural strength in dry condition and decrease it in wet condition (Vinson and Daniel 1990), while the compressive strength is frequently reported to decrease with increase in fiber content (Wolfe and Gjinolli, 1996, Wolfe and Gjinolli, 1996, Blankenhorn 2001). Considerable research has already been done in investigating the properties of natural-fiber reinforced cement or concrete products using fibers such as coconut coir, sisal, sugarcane bagasse, bamboo, jute, wood and vegetables in more than 40 countries (Mansor *et al*, 1982). Currently, Malaysia is the largest palm oil producer and contributes about 57.6% of the total supply of palm oil in the world. The increase in housing development also causes a lot more plantations being cleared. A large supply of elemental fragments of oil palm biomass can also be found through oil palm replanting. Tremendous amount of trunks and fronds are generated during the replanting since the economic life span of oil palm tree is about 25-30 years. Apart from trunks and fronds, empty fruit bunches is another important fibers component generated during the extraction of oil palm fruit into palm oil. Therefore, there should be an effort to fully utilize the oil palm waste such as its leaves, trunks and bunches significantly to the other industry.

Therefore this study investigated the behavior of concrete reinforced with oil palm trunk fiber (OPTF).

2. MATERIALS AND EXPERIMENTAL METHODS

2.1 Oil palm trunk fiber

The OPTF were taken directly from the plantation when the trees are newly fallen using special excavator machine. Freshly shredded fibers were obtained at random from trees aged between 20-30 years. After that, the fibers were undergone cleaning process to remove the parenchyma, as this parenchyma contains carbohydrates, which can retard the concrete hardening process. However after cleaning them using shredder machine, the parenchyma cannot be removed 100% and the fiber produced became very light, too small in diameter and short. It cannot meet the requirement as stated by ACI 544 where the length of natural fiber to be added in concrete may vary from 25-300 mm. The processed fiber is more suitable for manufacturing the cement particle/fiber board and medium density board. Therefore, in this study, the OPTF was processed manually. This process can be improved later especially when there is collaboration work with other company to invent such machine.

2.1.1 Determination of Physical Properties and Chemical Composition of OPTF

Preliminary measurements on the fibers were made e.g., bulk density of the fibers, diameter of the fiber, fiber morphology study and chemical analysis. Natural fibers come in varying sizes and textures to the extent that it becomes very difficult to determine a proper estimate for their dimensions. Different methods have been used to obtain approximate values for the diameters of such fibers. Eichorn and Young (2004) measured the diameter of hemp fibers using a calibrated FEG-SEM at an excitation voltage of 2 keV. An assumption was made by the authors that the fibers had a circular cross section. Devi *et al* (1997) used a stereo microscope to obtain diameters of pineapple fibers based on a similar assumption of circular cross-section. Mwaikambo and Ansell (2006(b)) used SEM and image analysis techniques to obtain the diameters of sisal fiber bundles, assuming they had circular cross-sections.

i. Determination Cross-sectional area and bulk density

In this work, the diameters and the density of the fibers were determined by

a. six readings were taken along the fiber length and the average was used as the diameter due to the variability of the fiber cross-section using Scanning Electron Microscopy (SEM).

b. The density of the fibers was determined from $\rho = \frac{m_f}{V}$ and $V = Al_f$. The expression for cross section area, A can be written as,

$$A = \frac{m_f}{\rho l_f} \quad [1]$$

where ρ is the apparent bulk density of the fiber, m_f is the mass of the fiber, V is the volume of the fiber and l_f is the length of the fiber. The apparent bulk density of the as received oil palm fiber bundles was determined using the Archimedes principle. A bundle of oil palm fiber bundles was weighed and its weight recorded as M_{fa} . The bundle was then immersed in benzene (a solvent which has density 875 kg/m3) until wetted. The weight of oil palm fiber bundles in benzene was recorded as M_{fs} . The apparent bulk density of oil palm fiber bundles is subsequently computed as,

$$\rho_b = \rho_s \frac{M_{fa}}{M_{fa} - M_{fs}} \quad [2]$$

where ρ_b is the bulk density of oil palm fiber bundles, ρ_s is the density of the solvent (benzene) M_{fa} is the weight of the fiber in air and M_{fs} is the weight of the fiber in solvent.
The tensile strength of the sisal fiber bundle is determined using the cross-sectional area obtained from the weight of the fibers and the density as shown in Equation [3].

$$\sigma_T = \frac{F_{\max}}{A} \quad [3]$$

Substituting for area A in Equation [3].

$$\sigma_T = \frac{\rho F_{\max} l_f}{m_f} \quad [4]$$

ii. Determination of tensile strength of oil palm fiber

The oil palm fiber bundles were cut to lengths of approximately 70 mm, weighed and finally mounted on manila-card coupons using EVO-STIK super strong standard heavy-duty epoxy adhesive from Evode Industries. Figure 1 shows a typical mounting of the fiber on the coupon. The tensile test was conducted according to ASTM D885(1995) using an Instron machine with a crosshead speed of 1mm/min. Twenty specimens were used The ends of the manila-card coupons were gripped by hydraulic clamps to align the fiber with the machine axis. The sides of the hole on the coupon were cut with a pair of scissors to allow load transfer to the fiber during tensile testing. The maximum load from this tensile test was substituted into Equation [4] for the fiber tensile strength.

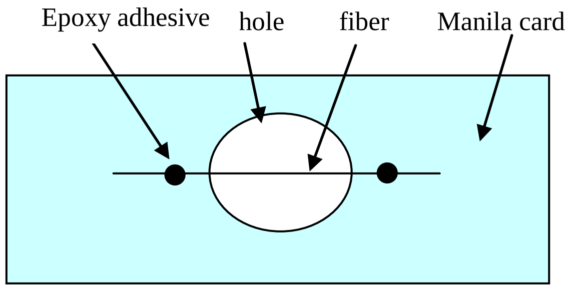


Figure 1: Mounting of fiber for tensile testing on coupon

2.1.2 Determination of chemical composition of oil palm trunk fiber

The chemical composition was performed according to TAPPI standards (1985). Hollocellulose determination was carried out in the same manner as described by Wise *et al*, (1946).

2.2 Concrete

2.2.1 Binders and Aggregates

The concrete constituents used were ordinary Portland cement, fine aggregate, coarse aggregate and OPTF. The fine and coarse aggregate used satisfied the sieved analysis grading in accordance with BS 882:1992. Coarse aggregate has maximum size of 20 mm. The relative density for aggregate was assumed to be 2650 kg/m^3.

2.2.2 Concrete mix, casting and batching

Design Grade 30 concrete was employed. The ratio of coarse aggregate and sand to cement was set at 1.5 and 3 respectively. Water-cement ratio was kept constant at 0.5. Length of OPTF used was 25 mm since from the previous studies by the author (Jelani et al, 2004), for grade 30 concrete the optimum length of OPTF is 25 mm. The detail of mix proportion is shown in Table 1.

Table 1: Mix Design (kg/m^3)

Mix	Fiber by volume	Cement	Water	Coarse Agg[a]	Fine Agg[a]
1	0%	360	180	1075	530
2	1%	358	179	1061	522
3	2%	355	176	1046	515
4	3%	350	175	1037	511

Note:
[a] aggregate
Batch quantities: kg/m^3
Assume R.D(relative density) for aggregate = 2650 kg/m^3
Cement: Sand: Coarse aggregate (1:1.5:3)
Maximum size: 20mm
Water cement ratio : 0.5 (constant)

The mixing method is critical to the properties of oil palm trunk fiber reinforced concrete (OPTFC). The addition of fiber has to be uniformly dispersed in the concrete in order to obtain homogenous concrete mixture. Therefore the consistency of the matrix needs to be neither too stiff nor too wet to ensure that the fibers can be uniformly dispersed in the mixture. The detailed procedures are described in Figure 2.

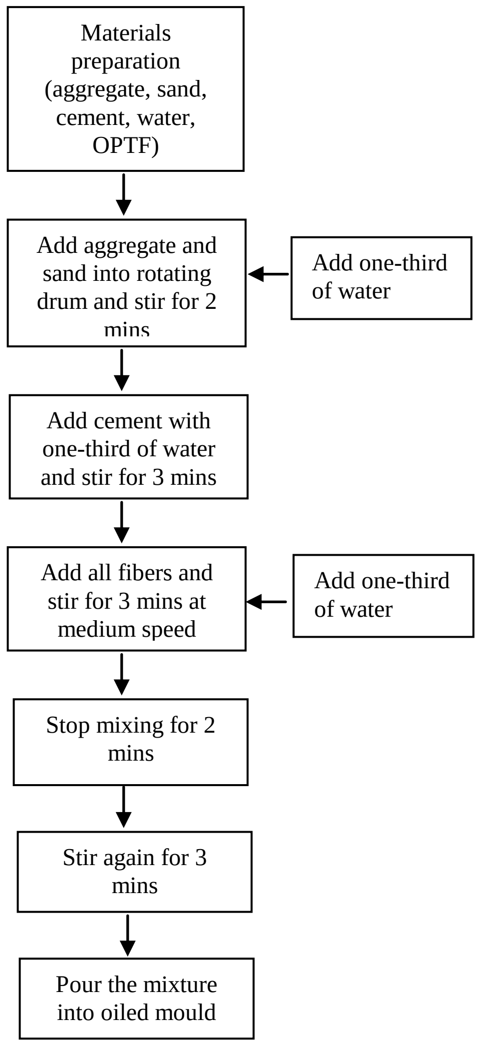


Figure 2: Simplified mixing flow chart

When pouring the mix into the mould, the mix was compacted by external vibration as recommended by AS 1012.1-2000 and 1012.8.2-2000. After that the specimens were allowed to settle over night at room temperature. After 24h, specimens were removed from the moulds and placed in water tank at room temperature to cure for the next 28 days. Then they were removed from the tank, air-dried and tested at the requested date.

In this study, superplasticiser was not incorporated in the concrete to improve the workability since the aimed of this paper is to determine the effect of OPTF on the properties of the concrete. However similar study was conducted with the addition superplasticiser (Ahmad *et al*, 2002).

2.3 Specimen preparation and test methods

2.3.1 Workability test

Fresh plain and fibrous mixes were tested for workability by slump (BS 1881: Part 102: 1983), compacting factor (BS 1881: Part3 and VeBe (BS 1881: Part 104: 1983) test methods.

2.3.2 Mechanical test

For mechanical testing, the relevant samples were cast in

i. cylinder of 150 mm height and 150 mm diameter cross-section for splitting tensile test.
ii. cube mould of size 100 mm x 100mm x 100mm for compression test.
iii. rectangular mould of size 150 x 150x 750 mm for flexural test.

At least 7 specimens were prepared for each parameters tested. The mechanical properties of hardened concrete namely tensile strength, Modulus of Elasticity, compressive strength and flexural strength were determined in accordance with BS 1881.

2.3.3 Durability test

For durability testing, four cylinders have been prepared. After curing at 28 days, every one cylinder was cut into three slices of 50 m length. So each mix produced 12 slices. From these 12 slices, 6 slices were chosen at random for immersion in water, 5% sodium chloride (NaCl) with pH8, 0.2M natrium hydroxide (NaOH) with ph 12 and 2% hydrochloric acid (HCl) solution with pH 2. The specimens for each mixes were weighted to get their weight before immersion. Then the specimens were immersed in three different tanks containing different solution with solution at least 124 mm deep. The specimens was removed from the tank every 24 hours immersion, dried and measured the weight. The procedure was repeated every day for 26 days.

The weight change is calculated using the following equation:

$$\% \, WL = \frac{M_i - M_f}{M_i} X \, 100 \qquad [5]$$

Where;
WL = percentage weight change/weight loss
M_i = mass of the surface-dry before the test
M_f = mass of the surface-dry after test

2.3.4 Scanning Electron Microscopy

The OPTF and the fracture surfaces of concrete were inspected using Scanning Electron Microscopy (SEM) at Metal Performance Technology Center, SIRIM Berhad in a JEOL JSN6310 scanning electron microscope (SEM) equipped with a computer image analysis system, after gold coating.

3. RESULT AND DISCUSSION

3.1 Fiber

The physical and mechanical properties and chemical composition of oil palm trunk fiber are shown in Table 2. The fibre bundles are of varying cross section with cross-sections ranging from 0.3 – 0.6 mm in diameter. In terms of color, the vascular bundles of OPTF were light yellowish in fresh state and turned to dark grey when dried.

Table 2: Properties of Oil Palm Trunk Fiber

Properties	Values
Bulk density	1100 kgm^{-3}
Tensile strength	300 – 600 N/mm^2
Modulus of Elasticity	15-32 GPa
Hollocellulose	72.12
Lignin	23.03
Alpha-cellulose	46.58

In this study the tensile strength of OPTF was found to be 300-600 N/mm^2 which is considered high when compared with other natural fiber such as sisal (280-568 N/mm^2) and Jute (250-350 N/mm^2) (Aziz *et al*, 1984). Bulk density of fibers is 1100kg/m^3. Fibres that currently dominate the composite material industry are aramid fibers with E=120 GPa, carbon fibers with E=220-700 GPa and glass fibres with E=70-80 GPa (Curtis 1989). Of these, glass fibres are the most widely used due to their low cost and good mechanical properties (Wambua, 2003).

One of the criteria for a fiber to possess high tensile strength is that the fiber has thick wall (Fordos, 1988). Therefore, the high tensile strength value of the OPTF may be due to the thick wall and it was found that OPTF is not easily collapse even though the fiber lost moisture. By looking at the SEM photo on the fiber structure as shown in Figure 3, the node like cell material indicated by the arrows holds adjacent ultimate fibers together which makes the fiber stiff and as compared to other fiber such as wood fiber (Coutts, 1988). The other advantage of OPTF is that it possesses high density (1200 kg/m^3). The high density also indicates that the fiber is strong. The high content of lignin in OPTF (23.03%) also gives extra merit to the fiber because lignified cellulose fibers retain their strength better than delignified fibers when exposed to moisture (Fordos, 1988). With all these reasons, oil palm trunk fiber was found to have the potential as concrete reinforcement.

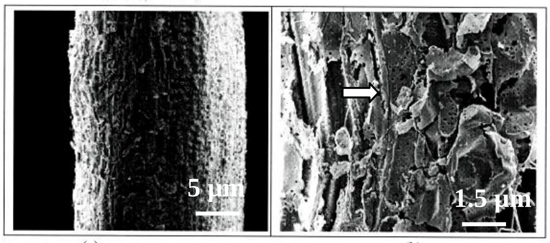
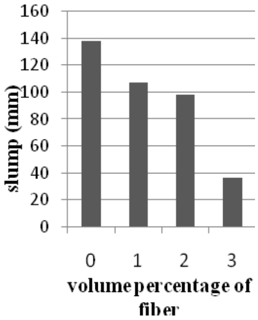
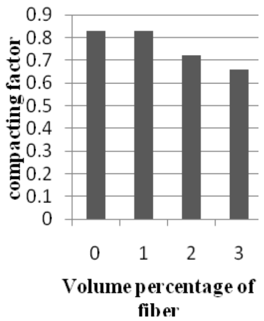


Figure 3: SEM micrograph showing the OPTF fiber at different magnification; (a) 65x and b) 1500x

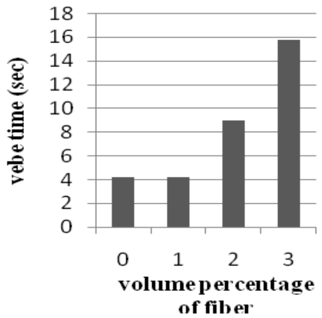
3.2 Workability

It was observed that the inclusion of OPTF in fresh concrete significantly altered the rheological behavior in terms of its mobility. Addition of fibers decreases workability due to an increase in surface area. Since it is difficult to measure the workability of natural fiber reinforced concrete, three different workability tests were performed namely slump test, compaction test and Vebe test. Figure 4 presents the results of workability study on the concrete reinforced with OPTF. ACI 116R-90 describes slump test as a measure of consistency rather than workability. Therefore the slump test will be useful in detecting variations in the uniformity of mix consistency among the different percentages of fiber additions. From Figure 3a, the reduction in workability is evident with the increasing of fiber content. The slump shows loss of about 73% from 130 mm to 30 mm (100 mm loss) when fiber is included in concrete for 3%. This indicates that the moisture content of the mixture has decreased. When adding 1 to 2% fiber, the slump loss is not so significant. The inclusion of fiber stiffened the mixture resulting in an increased stability or cohesion but also to an apparent reduction of workability (Jorillo and Shimizu, 1992). The compaction factor is defined as the ratio of the mass of the concrete compacted in the compaction factor apparatus to the mass of the fully compacted concrete. From Figure 3b, the compacting factor of the fresh concrete without fiber and 1% fiber has a same value (0.83). Adding the fiber by 2% and 3% reduce the compacting factor (CF) to 0.7 and 0.65 respectively. Neville (1995) categorized 0.85 and lower value as low workability and corresponding to 25-50 mm slump and 2-6 sec of Vebe time (VB) (Figure 3c). The results of the compaction factor test can be correlated to slump, although the relationship is not linear. However in this case, the CF value does not corresponding to the slump value. Compaction is achieved using vibrating table. It is assumed that the input of energy required for compaction is a measure of workability of the mix and this is expressed as the time in seconds (*Vebe time*). From Figure 3c, the VB shows that the fresh concrete with 3% and 2% fiber has higher time to spread compared to that with 1% and without fiber. ASTM C995 recommended that the time of flow for fiber reinforced concrete is 8-15 sec (Naik, 2004). Therefore concrete with 3% and 2 % fiber has good workability.





(a) (b)



(c)

Figure 4: The workability of concrete with different addition percentage of OPTF; (a) slump test, (b) compacting factor and (c) vebe time

Based on the CF and VB results, the concrete mixes can be stated to be dry mixes. However, based on the slump test, it can be said that the concrete mixes have high workability. VB is reported to be more suitable to measure workability for dry mixes (Neville, 1995). which is also found in this study.

3.3 Effect of Different Volume Percentage of OPTF on the mechanical properties of concrete

Table 3 shows the summary statistics of mechanical properties of concrete reinforced with OPTF. An analysis of variance was performed to determine if there were differences in mean flexural strength values among the different volume of fiber tested. F-test indicated that there were significant differences in the mean flexural strength [p value = 0.02] at 5% significant level, which indicates that the different volume of OPTF influenced the flexural strength properties of OPTF reinforced concrete. From Table 3, it can be seen that flexural strength of concrete with fiber addition increased the flexural strength at the lower dosage especially for 1% fiber. Comparison between 1% OPTF and plain concrete indicated that 1% OPTF gave higher MOR strength. Concrete with 2% and 3% OPTF have no significant difference but the value is less than concrete with 1% OPTF. This result suggests that the volume of fiber not only influenced the concrete strength properties but also have the possibility of interfering with other basic properties of concrete.

Table 3: The mechanical properties of concrete with various volume percentages of OPTF

Vol. of fiber (%)	Flexural strength (MPa)	Compressive strength (MPa)	Splitting tensile (MPa)	MOE (GPa)	Possion's Ratio
0	27.2 ±2.2	30.5±3.4	1.6±5.2	10.0	0.18
1	32.2 ±1.6	39.6±2.1	2.0±2.4	14.1	0.21
2	22.3±4.3	27.3±3.7	1.5±1.4	10.4	0.18
3	23.8±2.5	22.3±4.1	1.7±2.8	9.7	0.10

The flexural strength obtained with 1.0 percent volume fraction OPTF is 18.35 percent greater or 2.2 times the corresponding properties of plain concrete. It was also observed that while the unreinforced specimen specimens broke suddenly into two, the fiber reinforced specimens remained in one piece even when the maximum load was applied. In this case, the fibers can acts as crack arresters as shown in Figure 5(a).

(a) (b)

Figure 5: Concrete reinforced with OPTF; (a) specimen under bending showing OPTF as crack arrester and (b) broken specimen showing uniformly distributed OPTF in concrete.

The maximum load carrying capacity of the reinforced concrete is controlled by pullout of the fiber strand from the concrete matrix because fiber reinforcing does not have a deformed surface like larger steel reinforcing bars and this can limits the performance.

It is usually assumed that the fibers do not influence the tensile strength of the matrix, and that only after the matrix has cracked do the fibers contribute by bridging the cracks (Surenda, 1991). Therefore the length of the fiber has to be sufficient in order to mobilize the interfacial bond face. In fact after the concrete specimen has broken the fiber does not collapse which can be seen from Figure 5(b). In this figure, it also shows that the fiber is well dispersed which can indicate the right mixing technique. This is important because the strength can be affected by the distribution of the fibers in the concrete.

In fact, the fiber also increase the significant amount of energy being absorb which makes the concrete tougher as can be seen from the area under the graph of the stress-strain graph for concrete with 1% OPTF (Figure 6). This also may be due to the significant considerable proportion of the fibers are pulled out from the matrix. The addition of 1% fiber also improves the Poisson ratio (Table 3).

From Figure 6, the stress increases linearly as strain increases. It is obvious that for plain concrete, it failed abruptly which indicates that non-reinforced concrete is more brittle than reinforced concrete. Thus, the addition of fibers converts the brittle matrix into ductile material. The ultimate tensile strength at 1% fiber is also higher than 0% fiber. The ultimate tensile strength for 1% OPTF is 27.7% higher or 1.3 times higher than plain concrete.

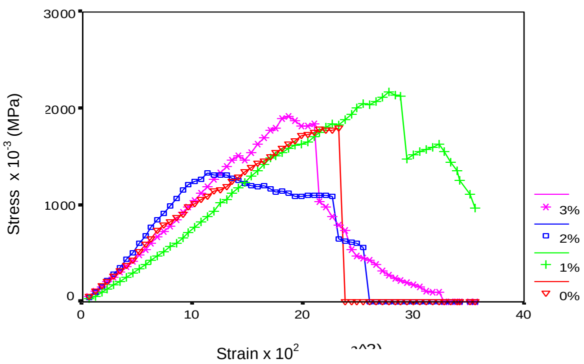


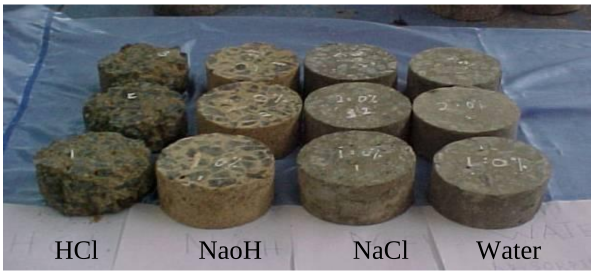
Figure 6: Stress versus strain

It can be seen that the ultimate tensile strength decreases with the increased in fiber content. This is because of the high addition of fiber reduced the workability, therefore the concrete was not well placed and compacted. The addition of fiber can also prevent the escape of air bubbles and increase the porosity which explains the drop in compressive strength observed when fiber content increased.

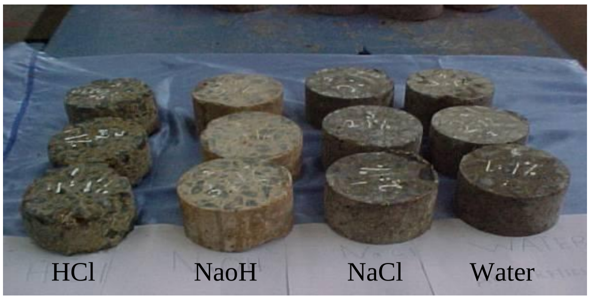
The MOE is also the highest at 1% addition of OPTF. This means that the addition of OPTF does improve the stiffness of the concrete at low dosage.

3.4 Effect of Different Volume Percentage of OPTF on the Concrete Ability to Resist Water and Chemical Attack

A series of experiment was conducted to determine the effect of two independent variables namely OPTF content and types of solution to the durability of the concrete in terms of weight change. Figure 7 shows the photographs of concrete after immersion. The different solutions and different volumes of fiber give different effects to physical appearance of the concrete. The differences are in the shapes and color of the concrete. OPTF reinforced concrete after being immersed in the water, there is not much change in the size of the specimens. However, when the specimen immersed in HCl solution, the concrete specimen deteriorated. The aggregate started to peel off around the side of the specimen which indicates the lost of bonding. The color of the specimens varied when immersed in different solutions.



(a)



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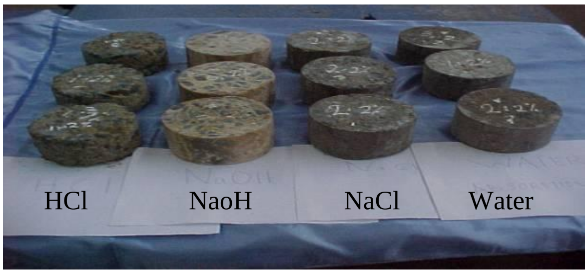

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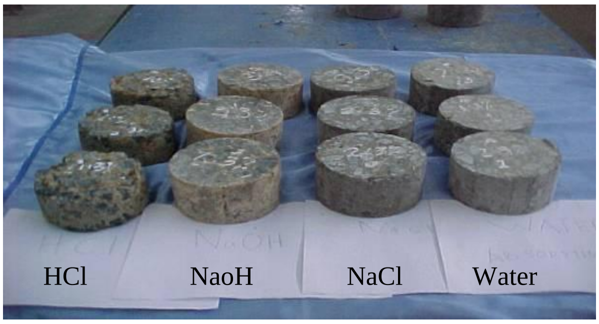

(d)

Figure 7: Concrete specimen with different percentage of OPTF; (a) 0%, (b) 1%, (c) 2% and (d) 3%, after 30 days immersion in water and chemical solutions

For concrete specimens immersed in the water, there was no changed in color. For the specimens immersed in NaCl, the color became a little bit lighter when compared to when immersed in water. The specimens immersed in NaOH were found to turn to reddish in color. As the amount of fiber increases, the specimens immersed in NaoH tend to crack. In contrast, specimens immersed in HCl, the aggregate became darker in color while the mortar became reddish as if corrosion occurs. The specimens also chipped off more and more as the amount of fiber increased. Figure 8 provides the mean percentage weight change of concrete reinforced with different volume percentages of fibers in response to different solution used after 30 days immersion.

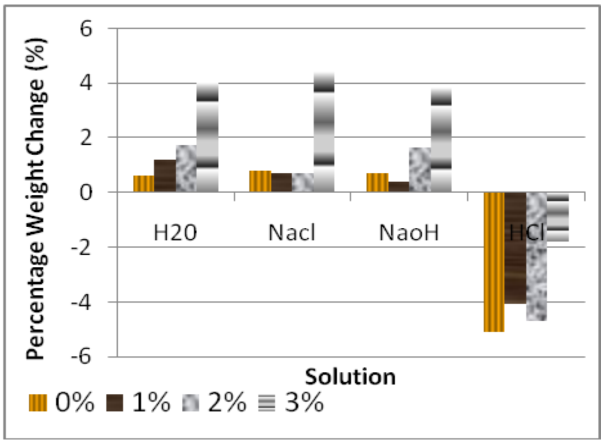

Figure 8: Percentage weight change of OPTF reinforced concrete when immersed in different solution

The positive change in weight increased, this means more absorption, therefore not good indication for durability. Even for negative change in weight i.e in HCl solution, it's still not a good indication. When the negative change in weight increased, it means that the specimen deteriorated. When immersed in water, the addition of fiber increases the water absorption. This may be due to the fact that OPTF absorbs water due to the pores in the fiber (Figure 3b).

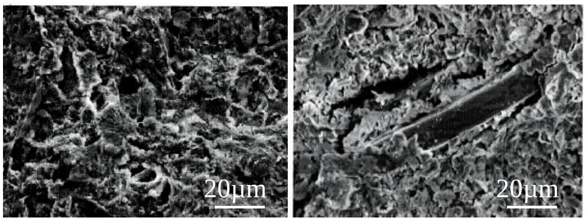

Figure 9: SEM micrograph of concrete; (a) without fiber and (b) with fiber

The total cellulose in the fiber including hemicellulose, is about 72.12%, which is higher than the international value of 53%. This indicates that the fiber structure is not very closed. That's why there is tendency for the fiber to absorb water. Concrete contains 3% OPTF has the highest increased in weight change but still considered lower when compared with the specified values for building board in ASTM (208-72), where the maximum allowable water absorption is 7%. Figure 9b shows the SEM micrograph of concrete specimens with OPTF which did not immersed in any solution. It indicates that the fiber is still intact and in good condition. It also shown that there is no weak transition zone between the cement matrix and the fiber when compared to the micro-structural of the concrete without OPTF (Figure 9a) which explained the improvement in the strength properties of OPTF reinforced concrete. There was no significant difference in the weight change due to immersion in NaCl solution except when using 3% OPTF. The concrete with 1% OPTF was found to have the least change in weight when immersed in NaOH solution and even was lower than the plain concrete. Natural fibers are known to possess poor resistance to alkalis. They get damaged in the alkaline environment of the cement matrix. When further immersed in alkaline solution, the situation got worse. The deterioration of the fibers is considered to be due to the composition of cellulose, hemicelluloses and lignin by the reaction with alkalis in the cement matrix (Rehsi, 1988). In this case the fiber is no longer flexible and may lose its reinforcing capacity. Adversely, NaOH may have reacted with the cement component and produced the crystalline formation which makes concrete denser as shown in SEM micrograph (Figure 10a). The formation of salt crystalline may occupied the pores and consequently improves the durability of the specimens. However, the effect of this solution on the strength was not measured in this study.

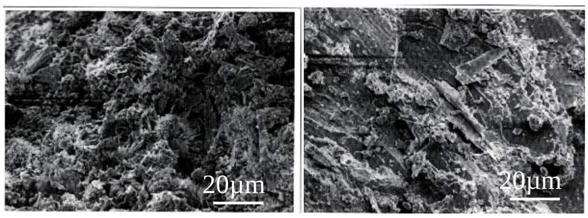

Figure 10: SEM micrograph of concrete after immersion in; (a) NaOH and (b) HCl.

From Figure 8, the entire concrete specimens immersed in HCl were reduced in weight instead of increased in weight which explained by the deterioration of the concrete specimens shown in Figure 7. The SEM micrograph as in Figure 10b also shows the degradation of OPTF and the concrete. However, the trend in weight change for concrete immersed HCl is different than when immersed in other solution where the concrete suffered less deterioration when the amount of fiber increases, and concrete with 3% OPTF found to be able to resist better against the acid attack as the weight lost is the least.

4. CONCLUSION

The mechanical properties and microstructure of concrete reinforced with OPTF have been investigated with the following outcomes

a. Oil palm trunk fiber was found to be suitable as reinforcement because it possesses high tensile strength (300-600 N/mm^2) which is considered high when compared with other natural fiber, high density (1200kg/mm^3) where the high density also indicates that the fiber is strong and high content of lignin (23.03%) as lignified cellulose fibers retain their strength better than delignified fibers.

b. The workability using slump, compacting factor (CF) and vebe test (VB) were not consistent. However the slump test was found more suitable in measuring the workability of OPTF reinforced concrete.

c. The mechanical properties of concrete are improved by the addition of 1% OPTF and the OPTF has acted as crack arrester.

d. 1% OPTF improves the durability of the concrete due to NaOH and NaCl attack but concrete with 3% OPTF has good resistance against the HCl attack.

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