Effect of lye alkaline solution treatment on engineering properties of oil palm empty fruit bunches (EFB) fiber strengthen foamed concrete

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Effect of lye alkaline solution treatment on engineering properties of oil palm empty fruit bunches (EFB) fiber strengthen foamed concrete

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Abstract. Natural fibers have become attention-grabbing and interesting these days to be employed as an industrial material and structural material for rehabilitating of structures. Nevertheless, the natural fibers to matrix interface interactions with cement matrix remain a key issue in getting the desired mechanical properties. Treatment of natural fibers is crucial in improving matrix to filler adhesion, thus improving its mechanical properties. In this study, oil palm empty fruit bunches (EFB) fiber was studied for use as reinforcement materials for cementitious composites in foamed concrete. The effect of fiber treatment on mechanical properties of EFB fiber reinforced foamed concrete was investigated comprehensively. For lye-treated EFB fibers, these fibers were washed three times with tap water to eliminate unwanted debris, dusts and impurities and dried at room temperature for 48 hours. Lye chemical solution of 2%, 4%, 6%, 8% and 10% wt. concentration were prepared using distilled water and lye chemical pellets. For the 2% wt. concentration, 2 grams of lye chemical was dissolved in 100ml of distilled water which is equivalent to 100 grams. For the 4, 6, 8 and 10% wt. concentrations, 4 grams, 6 grams, 8 grams and 10 grams of lye were dissolved in 100ml of distilled water respectively. The EFB fibers were soaked in the prepared solutions for a period of 24-hours after which they were removed and thoroughly rinsed until a neutral pH of the rinsing solution was attained. A pH meter was used to determine the pH value of the solution after rinsing. Finally, the dried fibers were sealed in a plastic bag before the composite manufacturing to avoid atmospheric moisture contamination. From the results obtained through experimental works, it can be concluded that the lye treatment of the EFB fibers modifies the fibers adequately causing a variation in the axial compression and flexural properties of the foamed concrete. Above all, 6% lye concentration gave better mechanical properties and therefore is considered a better treatment concentration value in the range of 2% to 10% wt. for improving the mechanical properties of EFB reinforced foamed concrete.

1. Introduction
Cement industry is one of the major contributors to the emission of the greenhouse gasses like carbon dioxide which is about 1.35 billion tons annually [1]. The production of Portland cement increases with the increasing demand from the construction industry which has been over one thousand million tons per year [2]. The construction industry in recent years has shown a significant interest in lightweight foamed concrete as a building material. Lightweight concrete is the combination of cement, fine aggregates, water and foam. There is no coarse aggregates involve in this type of concrete...
The lightweight foamed concrete are consists with the entrapped bubbles that act as the aggregate in order to make it better in the terms of workability, flowability, thermal properties and lighter in weight [4]. Even though it increases the workability, flowability, thermal properties of the concrete and lighter in weight but foamed concrete are considerable brittleness, results in low flexural strength, poor fracture toughness, poor resistance to crack propagation and low impact strength.

Natural fibers are widely used in the cementitious matrices to modify the tensile and the flexural strengths and increase the toughness, impact resistance and the fracture strength of the lightweight foamed concrete. Malaysia is currently heading towards the biotechnology hub area thus there will be billion tons of palm oil by-products will be produced and this oil palm by-product are treated as waste disposal. In this era, the growing need for sustainable development is increase in demand. This motivated scientist to perform researchers on the use of industrial by-products for other application [5]. From the researches that have been conduct, oil palm empty fruit bunches fibers has the potential to be developed as the alternative fibers in the fiber reinforcing concrete. There are three types of fiber that comes from oil palm tree. The oil palm frond fibres come from the oil palm frond or the leaf like part of the palm. The empty fruit bunch fiber comes from the fruit bunch of the oil palm. And last the oil palm trunk fibers come from the oil palm trunk [6]. Empty fruit bunches fibers are used for the fuel combustion for the generation of the steam boiler. However not all the fibers will be used, some of the amounts will be discarded and thrown away. This empty fruit bunches is about 3cm in length and 0.01mm in diameter after being crushed and dark brown in colour. Empty fruit bunches can be easily found in Malaysia as Malaysia is the largest oil palm producer in Asian. Empty fruit bunches known as it has excellent tensile strength, good elongation at break and has large fracture toughness [7].

Hence this research attempt to examine the effect of fiber treatment on mechanical properties of EFB fiber reinforced foamed concrete. EFB fibers were washed three times with tap water to eliminate unwanted debris, dusts and impurities and dried at room temperature for 48 hours prior to treatment process. Lye percentage of 2%, 4%, 6%, 8% and 10% wt. concentration were prepared using distilled water and lye chemical pellets. For the 2% wt. application, 2 grams of lye substance was liquefied in 100ml of distilled water which is equal to 100 grams. For 4, 6, 8 and 10% wt. applications, 4 grams, 6 grams, 8 grams and 10 grams of lye were liquefied in 100ml of distilled water correspondingly.

2. Materials & Mix Proportions
There are 5 main constituent materials used to produce foamed concrete for this research which are ordinary Portland cement, fine aggregate (sand), water, stable foam and oil palm empty fruit (EFB) fibers.

2.1. Ordinary Portland cement
The Ordinary Portland cement (OPC) used in this research was supplied by YTL Cement Bhd. This cement utilized conformed to Type I Portland Cement in accordance to BS 12 Standard. The cement was prepared before mixing and covered with plastic to avoid hydration process.

2.2. Fine Aggregate
For this research, fine river sand was utilized. The sand was dried and sieved passing a sieve of 2.36mm and treated in compliance to BS 882: 1992 to enhance the cellular mortar flow features and reliability as in BS12620: 2013.

2.3. Water
The water used for this study was potable tap water, free from any dissolved metal or ions that might oblige the setting and hydration process of the cellular foamed concrete mixes. The water was also used to insipid the foaming agent for aeration progression.
2.4. Stable foam
Protein-based foaming agent was used in this research as it is more stable compared to the others obtainable in the market. This protein-based foaming agent shaped tiny bubble size, which can offer more stable and sturdier closed bubble structure in the foamed concrete mix. The bubbles were formed by the foam making machine with the support of air compressor by using a surfactant and water at a ratio of 1 to 32. The foam density ranged between 58 to 63 kg/m$^3$ was utilized for the production of foamed concrete.

2.5 Treated Oil Palm Empty Fruit Bunches (EFB) Fiber
For lye-treated oil palm empty fruit bunches (EFB) fibers, a lye chemical solution of 2%, 4%, 6%, 8% and 10% wt. concentration were prepared using distilled water and lye pellets. For the 2% wt. concentration, 2 grams of lye chemical was dissolved in 100ml of distilled water which is equivalent to 100 grams. For the 4, 6, 8 and 10% wt. concentrations, 4 grams, 6 grams, 8 grams and 10 grams of lye were dissolved in 100ml of distilled water respectively. The physical and chemical properties of lye are summarized in Table 1.

| Properties                      | Value          |
|--------------------------------|----------------|
| Molecular weight               | 40.01          |
| Melting point                  | 318.4°C        |
| Boiling point                  | 1390°C         |
| Specific gravity               | 2.13           |
| Appearance                     | Pellets/white  |
| Vapour Pressure                | 1 mm at 739°C  |
| Density in Natural State       | 2.13 g/cm$^3$  |
| Percentage composition by mass | Sodium: 57.48% , Oxygen: 40.00% , Hydrogen: 2.52% |

2.6. Mix Proportions
For this particular study, there were total of 21 mixes were prepared. The proportion of mortar was cement, sand and water in the ratio of 1:1.5:0.45. The mix design proportions are shown in Table 2.

| Target Density (kg/m$^3$) | Sample      | Cement (kg) | Fine Sand (kg) | Water (kg) | Foam mass (kg) |
|---------------------------|-------------|-------------|----------------|------------|----------------|
| 750                       | Control     | 18.15       | 27.22          | 8.17       | 2.215          |
|                           | Non-treated | 18.15       | 27.22          | 8.17       | 2.215          |
|                           | 2% treatment| 18.15       | 27.22          | 8.17       | 2.215          |
|                           | 4% treatment| 18.15       | 27.22          | 8.17       | 2.215          |
|                           | 6% treatment| 18.15       | 27.22          | 8.17       | 2.215          |
|                           | 8% treatment| 18.15       | 27.22          | 8.17       | 2.215          |
|                           | 10% treatment| 18.15  | 27.22          | 8.17       | 2.215          |
| 1150                      | Control     | 24.65       | 36.97          | 11.09      | 1.652          |
|                           | Non-treated | 24.65       | 36.97          | 11.09      | 1.652          |
|                           | 2% treatment| 24.65       | 36.97          | 11.09      | 1.652          |
|                           | 4% treatment| 24.65       | 36.97          | 11.09      | 1.652          |
|                           | 6% treatment| 24.65       | 36.97          | 11.09      | 1.652          |
|                           | 8% treatment| 24.65       | 36.97          | 11.09      | 1.652          |
|                           | 10% treatment| 24.65| 36.97          | 11.09      | 1.652          |
| 1450                      | Control     | 31.15       | 46.72          | 14.02      | 1.089          |
3. Laboratory Tests

In order to obtain the engineering properties of foamed concrete, 2 tests will be conducted which are compression test and flexural test which will be explained in the next section thoroughly.

3.1 Compression Test

The compressive strength test was conducted by using compressive strength machine. The test was performed in accordance with BS EN 12390-3:2009 (2002) using a cube specimen size of 100mm x 100mm x 100mm. An axial compressive load with a loading rate of 0.2N/sec was applied to 100mm cube until failure occurred. GoTech GT-7001-BS300 universal testing machine with capacity of 3000kN was used to perform this compression test on the specimens. The result was taken at 7th and 28th day of age. Mean value accomplished from 3 specimens was then taken as cube compressive strength for each foamed concrete mix. Figure 1 shows the GoTech GT-7001-BS300 universal testing machine.

![GoTech GT-7001-BS300 universal testing machine](a)
![GoTech GT-7001-BS300 loaded with cube specimen](b)

Figure 1. (a) GoTech GT-7001-BS300 universal testing machine for compressive strength test. (b) GoTech GT-7001-BS300 loaded with cube specimen.

3.2. Flexural Strength Test

Flexural strength test was performed to scrutinize the flexural strength of the foamed concrete. It is a measurement to determine the bending properties of foamed concrete samples. Flexural strength of foamed concrete was established using GoTech GT-7001-C10 Universal Testing Machine as been shown in Figure 2. The test was carried out according to procedure in it was conducted according to BS EN 1521:1997. The specimen size is 100mm x 100mm x 500mm with the result taken at 7th and 28th day of age.
3.3. Performance Index
The compressive strength and dry density of foamed concrete has allied connection. Hypothetically, higher density of foamed concrete will lead to higher compressive strength. The density of foamed concrete for this research was control to within 750 kg/m$^3$, 1150 kg/m$^3$ and 1340 kg/m$^3$. As the density for each specimen was varying, performance index of foamed concrete was calculated to increase the accuracy of the results attained. The equation for performance index is shown in Equation (1):

$$PI = \frac{Sc}{\text{hardened density}}/1000$$  \hspace{1cm} (1)

Where $PI$ is the performance index (N/mm$^2$ per 1000 kg/m$^3$) and $Sc$ is the compressive strength (N/mm$^2$).

4. Results and Discussion
This section presents the results obtained from experimental works which will cover 3 main findings which are axial compressive strength, flexural strength, and performance index.

4.1. Compressive Strength
Figure 3, Figure 4 and Figure 5 show the axial compressive strength results for 750 kg/m$^3$, 1150 kg/m$^3$ and 1450 kg/m$^3$ densities respectively. From these figures, it can be clearly seen that 6% wt. lye treatment of EFB fibers contributed to exceptional axial compressive strength results compared to other chemical solution percentages which were 1.51 N/mm$^2$ for 750 kg/m$^3$, 3.81 N/mm$^2$ for 1150 kg/m$^3$ density and 7.39 N/mm$^2$ for 1450 kg/m$^3$ at 60-day. The prominence of lye treatment on EFB fiber is the fuss of hydrogen connection in the fiber external surface, consequently accumulated the surface indiscretion [8, 9]. A coarser EFB fiber surface was achieved after the lye treatment was done in which it is advantageous for the interfacial bonding amongst the EFB fiber and cementitious matrix subsequently a rougher surface enables in outstanding mechanical joining [10, 11].
Figure 3. Compressive strength results for 750kg/m$^3$ density.

Figure 4. Compressive strength results for 1150kg/m$^3$ density.

Figure 5. Compressive strength results for 1450kg/m$^3$ density.

4.2 Flexural Strength
Figures 6, 7 and 8 exhibit the flexural strength of 750 kg/m$^3$, 1150 kg/m$^3$ and 1450 kg/m$^3$ densities correspondingly. Equal results were accomplished as per axial compressive strength. From these three figures, it can be seen that 6% wt. lye chemical treatment of EFB fibers gave highest flexural strength
results in comparison with other lye treatment solution percentages which 0.42 N/mm² for 750 kg/m³, 0.84 N/mm² for 1150 kg/m³ density and 1.52 N/mm² for 1450 kg/m³ at 60-day. It should be pointed out that the control and untreated EFB specimens reinforced lightweight foamed concrete displays poorer flexural strength since there are existences of non-natural contaminations in the EFB fiber that contributed to inferior effect on the attachment between in the cementitious material [12,13].

Figure 6. Flexural strength results for 750kg/m³ density.

Figure 7. Flexural strength results for 1150kg/m³ density.

Figure 8. Flexural strength results for 1450kg/m³ density.
4.3. Performance Index

Figures 9, 10 and 11 show the performance index (PI) of 750 kg/m$^3$, 1150 kg/m$^3$ and 1450 kg/m$^3$ densities correspondingly. Similar trend obtained by performance index, where the performance index is directly proportional to the specimen’s curing age. For 750kg/m$^3$ density, the highest 60-day performance index was achieved by lightweight foamed concrete mix with 6% lye treatment, which is 1.88N/mm$^3$ per 1000 kg/m$^3$. Next, for 1150kg/m$^3$ density, the highest 60-day performance index was achieved by foamed concrete mix with 6% lye treatment, which is 3.48N/mm$^3$ per 1000 kg/m$^3$. On the other hand, highest 60-day performance index achieved by 1450kg/m$^3$ density is similar (foamed concrete mix with 6% lye treatment) which is 5.28N/mm$^3$ per 1000 kg/m$^3$.

![Figure 9](image1.png) Performance index of 750kg/m$^3$ density.  
![Figure 10](image2.png) Performance index of 1150kg/m$^3$ density.  
![Figure 11](image3.png) Performance index of 1450kg/m$^3$ density.

5. Conclusion

This paper has discussed the effectiveness of lye treatment of oil palm empty fruit bunch fiber as reinforcement in lightweight foamed concrete on its engineering properties. From this study, it can be concluded that 6% wt. lye treatment of EFB fibers offered outstanding compressive strength and flexural strength results compared to other lye solution percentages. The improvement in engineering properties is attributed to the improvement in EFB fibers and interfacial adhesion after the treatment process. The failure modes of the foamed concrete specimen under axial compression and flexural were fiber retreat, fiber rupture and fiber debonding from the cement matrix. Although encouraging
results have been reported in this study, more future researches are needed to thoroughly understand the EFB fibers performance as reinforcement in concrete based material.

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