Influence of caustic soda treatment on mechanical performance of ‘cocos nucifera linn’ fiber reinforced lightweight foam mortar

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Abstract. With regards to environmental concerns and in line with Malaysia government environmental strategy on utilizing sustainable waste materials such as those from natural resources in turn to diminish the harmful effect of synthetic materials on the environment, it has brought a challenge to reconnoiter how it can be attained by promoting the agricultural wastes into useful products. Natural fibers are renewable, cost-effective, low in density, eco-friendly, non-abrasive and readily obtainable anywhere. Hence this research attempts to investigate the potential use of cocos nucifera linn fiber as reinforcement material in foam mortar. The effect of fiber treatment via caustic soda on mechanical properties of cocos nucifera fiber reinforced foam mortar was examined. The test results indicate that cocos nucifera linn fiber had a much cleaner and rougher fiber surface after the treatment through caustic soda. Compared with the untreated cocos nucifera linn fiber, treatment improved the compressive, flexural and splitting tensile properties of the foam mortar. However, the treatment also reduced the damping ratio of the foam concrete. The increase in compressive, flexural and splitting tensile properties and reduction in damping ratio are attributed to the improvement of fiber and matrix interfacial adhesion due to the caustic soda treatment. As a whole, 4.5% wt. caustic soda solution treatment of cocos nucifera linn fibers contributed to excellent compressive strength, bending strength and splitting tensile strength results compared to other chemical solution percentages.

1. Introduction
In the last few years, there are emerging attentions by using lightweight foam mortar as a non-structural and semi structural component in building in turn to take its advantages of the exceptional insulation properties. The difference between normal strength concrete and foam mortar is foam mortar has no coarse aggregates [1]. Foam mortar is a combination of cement, fine sand, clean water and stable foam [2]. It contains of trapped bubbles stand-in as an aggregate hence making it a superior product in terms of flow ability, thermal properties, workability and lesser self-weight [3]. However, foam mortar has been perceived to have some drawbacks which are extensive breakability; low bending strength, poor resistance to crack spread and low impact strength [4,5]. Hence, for the past few decades, attempts have been made to include natural fibers in cementitious matrix to improve and enhance the bending strength, surface toughness, impact resistance, and fracture energy [6,7].
Cocos nucifera linn fiber is discontinuous and generally distributed randomly throughout the matrix [8,9]. Randomly dispersed cocos nucifera linn fiber will provide three dimensional reinforcement compared to the traditional rebar which provides two dimension reinforcement [10,11].

Cocos nucifera linn fiber reinforced lightweight foam mortar can be a cost effective and useful construction material because of the flexibility in method of fabrication [12]. The treatment of natural fibers with alkali solution such as caustic soda could improve fiber to matrix interaction, enhanced bonding characteristic and composite strength which are typically perceived for treatments with caustic soda concentrations of between 2.2% to 6.8% [13]. Chemical treatment of fibers using caustic soda cleans the fiber planes hence stimulates interfacial bonding and increases the mechanical performance of concrete based materials [14]. Therefore this research attempts to examine the potential use of cocos nucifera linn fiber as reinforcement material in foam mortar. The effect of fiber treatment via caustic soda on mechanical properties of cocos nucifera fiber reinforced foam mortar was examined.

2. Experimental Works

This section presents the constituent material to produce foam mortar and the experimental setup to perform entire laboratory assessment in order to acquire the engineering properties.

2.1. Materials Preparation & Mix Proportions

Cocos nucifera linn fibres prepared for special purposes like brushes and mats was used for the study because of its availability. These fibres were pre-cut in a length of 200 mm as received. These fibres were then cut into an average length of 30 mm for study. These fibers were properly cleaned with distilled water to remove dusts and debris. The caustic solution of 1.5%, 3.0%, 4.5%, 6.0% and 7.5% wt. concentration were prepared. For the 1.5% wt. concentration, 1.5 grams of caustic soda was dissolved in 100ml of distilled water. For the 3.0%, 4.5%, 6.0% and 7.5% wt. concentration, 3.0 grams, 4.5 grams, 6.0 grams and 7.5 grams of caustic soda were dissolved in 100ml of distilled water respectively. For producing the foam mortar, the cement used was Ordinary Portland cement (OPC) supplied by YTL Cement Bhd in accordance to BS 12:1989 Standard. Locally sourced river sand was used which was dried and sieved passing a sieve of 2.36mm. Table 1 shows the characteristics of fine sand used in this research. Protein based surfactant was utilized in this research as it is more stable compared to the others available in the market. Protein based surfactant shaped tiny bubble size, which offers sturdier closed bubble structure in the foam mortar mix. The foam density ranged between 60 to 65 kg/m³ was utilized for the production of foam mortar.

Table 1. Characteristics of fine sand.

| Component                        | Value      |
|----------------------------------|------------|
| True density (γ₀)                | 2650–2710 kg/m³ |
| Bulk density (γbulk)             | 1535–1590 kg/m³ |
| Silt and clay particles          | 2.5%       |
| Fineness modulus                 | 0.9–1.2    |
| Organic inclusions               | nil        |
| Water absorption                 | 1.23%      |

For this particular study, there were total of 12 mixes were prepared which focuses on low densities foam mortar which were 600 kg/m³ and 900 kg/m³. The proportion of mortar was cement, sand and water in the ratio of 1:1.5:0.45. Alkali solution of 1.5%, 3.0%, 4.5%, 6.0% and 7.5% wt. concentration were prepared using tap water and alkali pellets. For all mixes, 0.2% cocos nucifera linn fiber out of the total volume of the mix was added. The sample code used for this research is shown in Table 2.
Table 2: Sample coding for foam mortar.

| Mix Design | Sample Code |
|------------|-------------|
| Control Mix 600 kg/m³ | C6 |
| 600 kg/m³ density with untreated fiber | C6-X |
| 600 kg/m³ density with 1.5% caustic soda alkali treatment fiber | C6-1.5% |
| 600 kg/m³ density with 3.0% caustic soda alkali treatment fiber | C6-3.0% |
| 600 kg/m³ density with 4.5% caustic soda alkali treatment fiber | C6-4.5% |
| 600 kg/m³ density with 6.0% caustic soda alkali treatment fiber | C6-6.0% |
| 600 kg/m³ density with 7.5% caustic soda alkali treatment fiber | C6-7.5% |
| Control Mix 900 kg/m³ | C9 |
| 600 kg/m³ density with untreated fiber | C9-X |
| 900 kg/m³ density with 1.5% caustic soda alkali treatment fiber | C9-1.5% |
| 900 kg/m³ density with 3.0% caustic soda alkali treatment fiber | C9-3.0% |
| 900 kg/m³ density with 4.5% caustic soda alkali treatment fiber | C9-4.5% |
| 900 kg/m³ density with 6.0% caustic soda alkali treatment fiber | C9-6.0% |
| 900 kg/m³ density with 7.5% caustic soda alkali treatment fiber | C9-7.5% |

2.2. Laboratory Tests

To determine the mechanical properties of cocos nucifera linn fiber reinforced foam mortar, 3 tests have been performed which were compression test, bending test and splitting tensile test. Compressive strength (Figure 1) test was conducted in accordance with BS EN 12390 on 100mm x 100mm x 100mm cube and bending test (Figure 2) was conducted in accordance to BS EN 1521:1997 on 100mm x 100mm x 500m prism. In addition, tensile splitting test (Figure 3) was done by referring to the ASTM C496 standard. The specimen size used was 100mm in diameter and 200mm in height cylinder.

Figure 1. Setup for compression test according to BS-EN 12390.
3. Results and Discussion
This section presents the results obtained from experimental works which will cover 5 main findings which are axial compressive strength, flexural strength, splitting tensile strength and performance index.

3.1. Axial Compressive Strength
Figures 4 and 5 display the axial compressive strength results for 600 kg/m$^3$ and 900 kg/m$^3$ densities correspondingly. From both figures, it can be clearly seen that 4.5% wt. caustic soda treatment of cocos nucifera linn fibers contributed to remarkable axial compressive strength results compared to other caustic soda solution percentages which were 1.43 N/mm$^2$ for 600 kg/m$^3$ density and 3.36 N/mm$^2$ for 1400 kg/m$^3$ at 60-day. Caustic soda treatment of 4.5% wt. strengthens the bonding between the cocos nucifera linn fiber and the cement matrix. Meantime, control and untreated cocos nucifera fiber samples reinforced foam mortar shows lower compressive strength since there are natural and
artificial impurities in the cocos nucifera linn fiber that lead some effect to the bonding between the cement matrixes [15].

Figure 4. Compressive strength results for 600\(\text{kg/m}^3\) density.

Figure 5. Compressive strength results for 900\(\text{kg/m}^3\) density.

3.2. Bending Strength
On the other hand, Figure 6 and Figure 7 show the bending strength results for 600 kg/m\(^3\) and 900 kg/m\(^3\) densities correspondingly. Same results were obtained as per axial compressive strength. From both figures, it can be noticeably seen that 4.5\% wt. caustic soda treatment of cocos nucifera linn fibers contributed to significant bending strength results compared to other caustic soda solution percentages which were 0.31 N/mm\(^2\) for 1100 kg/m\(^3\) density and 0.86 N/mm\(^2\) for 900 kg/m\(^3\) at 60-day. The improvement in bending strength is attributed to the enhancement in cocos nucifera linn fibers quality and interfacial adhesion after the treatment process via caustic soda [7].
3.3. Splitting Tensile Strength

Figures 8 and 9 demonstrate the splitting tensile strength of 600 kg/m$^3$ and 900 kg/m$^3$ densities correspondingly. Identical results were attained as per axial compressive strength. From Figure 8 and Figure 9, it can be seen that 4.5% wt. caustic soda treatment of cocos nucifera linn fibers contributed to highest splitting tensile strength results in comparison with other alkali treatment solution percentages which were 0.18 N/mm$^2$ for 600 kg/m$^3$ density and 0.46 N/mm$^2$ for 900 kg/m$^3$ at 60-day. The improvement in splitting tensile strength is attributed to the improvement in of cocos nucifera linn fibers and interfacial adhesion after treatment. The importance of caustic soda treatment is the commotion of hydrogen attachment in the fiber surface, thus amassed the surface irregularity. As been shown in Figure 10, a rougher cocos nucifera linn fiber surface is attained after the caustic soda treatment process in which it is beneficial for the interfacial adhesion between the fiber and cement.
matrix since a rougher surface facilitates in excellent mechanical interlocking [14]. The caustic soda treatment process at the same time removes high percentages of oils, wax and lignin, which covered the outside surface of the fiber cell wall [15].

Figure 8. Splitting tensile strength results for 600kg/m³ density.

Figure 9. Splitting tensile strength results for 900kg/m³ density.
4. Conclusion
In this study, the influence of caustic soda treatment of cocos nucifera linn fibers as reinforcement in foam mortar on its mechanical performance was investigated. As a whole, 4.5% wt. caustic soda solution treatment of cocos nucifera linn fibers contributed to excellent compressive strength, bending strength and splitting tensile strength results compared to other chemical solution percentages. Enhancement in mechanical properties is accredited to the improvement in cocos nucifera linn fibers and interfacial adhesion after the caustic soda treatment process. The importance of caustic soda treatment is the commotion of hydrogen attachment in the fiber surface, thus amassed the surface irregularity. The cross section of cocos nucifera linn fiber was extremely transformed through the caustic treatment process in comparison with untreated fiber. The cross sectional area that undergoes caustic soda treatment was lesser compared to untreated fiber. Moreover, the individual cell in the cocos nucifera linn fiber cross section was transformed from a polygon shape to an oval shape, complemented a lot of gaps between the cells which at the same time improved the overall mechanical performance of foam mortar. A rougher cocos nucifera linn fiber surface is attained after the caustic soda treatment process in which it is beneficial for the interfacial adhesion between the fiber and cement matrix since a rougher surface facilitates in excellent mechanical interlocking. Caustic soda treatment also removes high percentages of oils, wax and lignin, which covered the outside surface of the fiber cell wall.

5. References
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Acknowledgement
The authors are grateful for the financial assistance of this research granted by Ministry of Higher Education Malaysia under FRGS Grant (Ref. No. 203/PPBGN/6711514).