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Mercerization Effect on Mechanical Properties of Empty Fruit Bunch Fibre in Reinforcing Low Densities Lightweight Foamed Concrete

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Abstract: Due to the minimum cost, availability and renewable character, natural fibre had managed to grab the attention of researchers to utilize this industrial waste as industrial and structural material to restore the structures. This is due to the renewable nature of the fibre, minimal cost, low density and the amenability towards the chemical modification. The purpose of this paper is to oversee the reaction of empty fruit bunches fibre in the low densities of lightweight foamed concrete after been modified with the different percentages of alkali treatment using sodium hydroxide (NaOH). The effect of this fibre chemical treatment (2%-10% sodium hydroxide chemical treatment) on the mechanical properties of lightweight foamed concrete was investigated expansively. There were three different densities of lightweight foamed concrete (500kg/m^3, 700kg/m^3 and 900kg/m^3) used in this study. There were three different experimental test conducted to determine the lightweight foamed concrete strengths which were axial compressive strength test, flexural test and splitting tensile strength. The test result shows that 6% of sodium hydroxide chemical treatment of empty fruit bunches fibre offered the best results. The result showed that the highest strength result is obtained from 900kg/m^3 density of lightweight foamed concrete with 6% sodium hydroxide treatment on the empty fruit bunches fibre while the lowest strength was obtained by 500kg/m^3 lightweight foamed concrete with 0% of sodium hydroxide treatment on the fibre. Out of 257% of intensification in axial compressive strength test, 88% were showed in flexural strength test and 61% increase in splitting tensile strength test.

Keywords: Lightweight foamed concrete, natural fibre, mechanical properties

I. INTRODUCTION

In industrial countries, the usage of lightweight aggregate has reduced the production of natural resources. This natural resources are being replaced by the industrial waste materials as it is more sustainable. The continuous extraction of natural resources such as coarse aggregates and fine aggregates resulted on the irregular ecological deterioration of the sources itself [1]. Malaysia is heading towards the biotechnology hub area and thus there will be billion tons of palm oil by-products produced and these by-products were treated as waste disposal [2].

Oil palm industry in Malaysia had created millions tones of industrial waste and this has resulted to various environment problem. There are approximately 22% of those waste that consists of empty fruit bunches (EFB) fibre. In order to reduce the number of industrial waste that has been created, this EFB fibre can be utilized as natural fibre based composites. From the previous research conducted, this empty fruit bunches fibre has the potential of being developed as the alternative fibre in the fibre reinforcing concrete (Corinadelsi, 2011). Due to the fibre advantages such as low density, lower cost, reduced health hazard, the availability and amenability to chemical modification, the fibre catches great attention of using it inside the plastic composites [3].

Lightweight foamed concrete is the combination of cement, fine aggregates, water and stable foam. This lightweight foamed concrete consists of entrapped bubbles that act as the aggregate in order to make it better in the terms of workability, flowability, and thermal properties and lighter in weight [4]. The entrapped bubbles or pore system does not influence the strength of foamed concrete but directly related to creep and shrinkage of the lightweight foamed concrete [5].

According to British Cement Association, in order to produce sustainable building all over the world, lightweight foamed concrete have become a popular construction material. Despite of the advantages, lightweight foamed concrete is considerably brittle, low in flexural strength, poor fracture toughness, poor resistance to crack propagation and low impact on strength [6]. Lightweight foamed concrete is low in tensile and flexural strength as it comprises of many micro cracks on the internal [7].

Lightweight foamed concrete has a long history and was first used in 1923 as insulating materials. It is a versatile material that consists of cement mortar mixture with at least 20% by volume of air. This reduced the density of the concrete inside the lightweight foamed concrete. With the usage of lightweight foamed concrete, the production of cement can be reduced as it can be replaced with other additives [6]. Due to the rapid development of the construction industry in Malaysia, it has led to the innovation of the lightweight foamed concrete [7].

The chemical treatments of the empty fruit bunches fibre is necessary in order to achieve good interface properties. The chemical treatment has the ability to react on the fibre and alter the fibre composition [8]. In order to develop composites with good chemical properties, chemical treatments are carried out to reduce the hydrophilic

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behaviors of the fibre and the absorption of moisture as it will result in weak interfacial bonding between the fibre and the matrixes [9, 10]. The chemical treatment of sodium hydroxide towards the empty fruit bunches fibre reduces the rate of moisture absorption, clean the fibre surfaces, promotes the interfacial bonding and improve the mechanical properties of the lightweight foamed concrete [11, 12].

The introduction of empty fruit bunches fibre in to the cementitious matrices is to increase the impact resistance and the fracture strength of the lightweight foamed concrete. As the empty fruit bunches fibre possess the quality of becoming the reinforcement of the lightweight foamed concrete, it helps to increase the tensile and flexural strength of the foamed concrete.

Therefore, this research investigate the effect of mercerization (2%-10% sodium hydroxide chemical treatment) on the mechanical properties of empty fruit bunch (EFB) fibre in reinforced low densities lightweight foamed concrete. There were three different densities of lightweight foamed concrete (500kg/m^3, 700kg/m^3 and 900kg/m^3) were cast and tested for this study.

II. EXPERIMENTAL SETUP

Materials

Cement

In this research, Ordinary Portland Cement (OPC) produced by YTL Cement Sdn Bhd is used throughout the process of mixing. This Type 1 Ordinary Portland Cement complies with the BS 12:1196 were the main binder in this process.

Fine Sand

Locally sourced sand was utilized as the fine aggregate in order to produce lightweight foamed concrete. In this study, the locally sourced sand was dried under the sun in order to eliminate the water content. Then the sand is filtered through a sieve of 2.00 mm after the drying process. The sieving method of the sand is either by hand or mechanically as described in ASTM C136 (2004).

Water

The water used throughout the entire research must be free from the impurities and maintain the natural pH as it might affect the hydration of the cement mortar and the durability. The water to cement ratio that is being used in this research is 0.45. This water to cement ration value has achieved the reasonable workability for the foamed concrete (Othuman Mydin and Wang, 2012). Water is used in two important parts of preparing the specimen in this research which are the mixing concrete for the production of foamed concrete and the curing process of the specimen.

Surfactant (foaming agent)

Foam is an air entraining agent which consists of the stable bubbles that been produced by the mixing foamed agent which is protein based surfactant (Noraite PA-1) and water in the foam generator. This foam agent is used due to its stable and smaller bubbles and its stronger bonding structure of bubbles in comparison to the synthetic based surfactant. The ration of foaming agent to water is 1:30 by volume. In order to produce the targeted density of foamed concrete, the foam density must remain between 60-75 g/L. Clean water is needed in order to produce foam agent as the density of foamed concrete is determined by the volume of the foam added into the cement mortar.

Empty Fruit Bunch Fibre

Table 1 displays its physical properties and Table 2 shows the chemical compositions of EFB fibre used for this research.

Table. 1 Physical properties of Empty Fruit Bunch (EFB) fibre

Component	Value
Average Length (mm)	19
Density of fibre (g/cc)	1.38
Elongation at break (%)	10.21%
Tensile strength (N/mm^2)	251
Tensile modulus (GPa)	8.13
Diameter of fibre (μm)	13.21
Diameter of lumen (μm)	7.86

Table. 2 Chemical composition of Empty Fruit Bunch (EFB)

Component	Percentage
Lignin	23.80%
Cellulose	48.90%
Hemi-Cellulose	17.50%
Extractives	2.20%
Ash Content	5.10%
Water Soluble	2.50%

Mix Design

There are a total of 18 mixes prepared in this study. Table 3 shows the mix design proportions for 500kg/m^3, 700kg/m^3 and 900 kg/m^3. The ratio value for the fibre used in this study is 0.3% from the total volume of the mix. For this study, fixed cement, sand and water ratio is used. This ratio of 1:1.15:0.45 is fixed throughout the mixing process.

Table. 3 Mix design

Mix Density (kg/m^3)	Sample	Mix Ratio (S:C:W)	Cement (kg)	Fine Aggregates (kg)	Water (kg)
500	0% NaOH	1:1:5:0.45	9.71	14.56	4.37
	2% NaOH	1:1:5:0.45	9.71	14.56	4.37
	4% NaOH	1:1:5:0.45	9.71	14.56	4.37
	6% NaOH	1:1:5:0.45	9.71	14.56	4.37
	8% NaOH	1:1:5:0.45	9.71	14.56	4.37
	10% NaOH	1:1:5:0.45	9.71	14.56	4.37
700	0% NaOH	1:1:5:0.45	13.32	19.98	5.99
	2% NaOH	1:1:5:0.45	13.32	19.98	5.99
	4% NaOH	1:1:5:0.45	13.32	19.98	5.99
	6% NaOH	1:1:5:0.45	13.32	19.98	5.99
	8% NaOH	1:1:5:0.45	13.32	19.98	5.99
	10% NaOH	1:1:5:0.45	13.32	19.98	5.99
900	0% NaOH	1:1:5:0.45	16.93	25.39	7.62
	2% NaOH	1:1:5:0.45	16.93	25.39	7.62
	4% NaOH	1:1:5:0.45	16.93	25.39	7.62
	6% NaOH	1:1:5:0.45	16.93	25.39	7.62
	8% NaOH	1:1:5:0.45	16.93	25.39	7.62
	10% NaOH	1:1:5:0.45	16.93	25.39	7.62

Compressive Strength Test

In order to comply with BS EN12390-Part 3[13], the compressive test for foamed concrete was tested by using 100 mm x 100mm x 100mm size cube. There were 3 specimen tested for each curing age at the duration of 7-days, 28-days and 60-days. These average values obtained from each test were recorded. This test was conducted by using universal testing machine (GTECH GT-7001-BS300).

Fig. 3 Compressive strength test

Flexural Strength Test

According to ASTM C348 [14], flexural strength test was conducted by using three-point bending method. The specimen is prism shaped with the size of 40x40x160mm. This test was conducted by using universal testing machine at the aged of 7 days, 28 days and 60 days of curing.

Fig. 4 Flexural strength test (3-point bending)

Splitting Tensile Strength Test

Three specimens of cylindrical specimens with the diameter of 100 mm and the height of 200 mm were test for the splitting tensile strength test for each 7 days, 28 days and 60 days of curing. The obtained results were recorded as the splitting tensile strength result. This test was conducted using universal testing machine (GTECH GT-7001-BS300). This test complied with the ASTM C496.

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Fig. 5 Splitting tensile strength test

Performance Index

The axial compressive strength and dry density of foamed concrete has correlated relationship. In theory, higher density of foamed concrete will lead to higher compressive strength. The density of foamed concrete for this research was control to within 600 kg/m^3 to900kg/m^3.

As the density for each sample was varying, the performance index of foamed concrete was considered to enhance the precision of the results attained from the experimental work. The equation for performance index is presented in Equation (1):

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

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

III. EXPERIMENTAL RESULTS

This section present the mechanical properties results obtained through laboratory investigation. Table 3, Table 4 and Table 5 summarized the compressive strength, three-point bending strength and tensile of all three densities (800, 1100 and 1400 kg/m^3 cast and tested for this study) correspondingly. Table 6 shows the Performance index results. The specimen is tested at the curing aged of 7 days, 28 days and 60 days.

Table. 4 Result of compressive strength at different densities and mercerization percentages

Density (kg/m^3)	Sample	Compressive Strength (MPa)		
		7-day	28-day	60-day
500	0% treatment	0.81	0.97	1.09
	2% treatment	0.85	1.04	1.11
	4% treatment	1.14	1.29	1.43
	6% treatment	1.22	1.39	1.48
	8% treatment	0.99	1.11	1.23
	10% treatment	0.78	0.92	1.12
700	0% treatment	1.56	1.81	2.03
	2% treatment	1.64	1.92	2.09
	4% treatment	1.90	2.07	2.25
	6% treatment	1.93	2.17	2.36
	8% treatment	1.68	2.03	2.22
	10% treatment	1.53	1.79	1.89
900	0% treatment	2.27	2.62	2.91
	2% treatment	2.38	2.85	3.12
	4% treatment	2.69	3.12	3.52
	6% treatment	2.89	3.29	3.66
	8% treatment	2.32	2.75	3.21
	10% treatment	2.12	2.62	2.89

Table. 5 Results of bending strength at different densities and mercerization percentages

Density (kg/m^3)	Sample	Three-point bending Strength (MPa)		
		7-day	28-day	60-day
500	0% treatment	0.21	0.24	0.27
	2% treatment	0.23	0.28	0.30
	4% treatment	0.32	0.36	0.41
	6% treatment	0.36	0.42	0.46
	8% treatment	0.26	0.30	0.33
	10% treatment	0.21	0.24	0.28
700	0% treatment	0.39	0.45	0.51
	2% treatment	0.44	0.52	0.56

	4% treatment	0.53	0.63	0.68
	6% treatment	0.60	0.67	0.73
	8% treatment	0.45	0.55	0.60
	10% treatment	0.38	0.44	0.49
900	0% treatment	0.57	0.66	0.73
	2% treatment	0.64	0.77	0.84
	4% treatment	0.75	0.91	1.04
	6% treatment	0.90	1.02	1.15
	8% treatment	0.63	0.77	0.91
	10% treatment	0.59	0.78	0.88

Table. 6 Results of tensile strength at different densities and mercerization percentages

Density (kg/m^3)	Sample	Tensile Strength (MPa)		
		7-day	28-day	60-day
500	0% treatment	0.12	0.15	0.17
	2% treatment	0.14	0.17	0.19
	4% treatment	0.22	0.28	0.31
	6% treatment	0.24	0.31	0.34
	8% treatment	0.15	0.22	0.25
	10% treatment	0.13	0.16	0.19
700	0% treatment	0.24	0.28	0.31
	2% treatment	0.28	0.33	0.36
	4% treatment	0.35	0.43	0.48
	6% treatment	0.41	0.46	0.52
	8% treatment	0.25	0.30	0.38
	10% treatment	0.24	0.29	0.33
900	0% treatment	0.35	0.41	0.45
	2% treatment	0.40	0.48	0.53
	4% treatment	0.49	0.65	0.74
	6% treatment	0.61	0.69	0.78
	8% treatment	0.40	0.52	0.61
	10% treatment	0.35	0.47	0.53

Table. 7 Performance index (PI) of different densities and mercerization percentages

Density (kg/m^3)	Sample	Performance Index (MPa per 1000kg/m^3)		
		7-day	28-day	60-day
500	0% treatment	1.62	1.94	2.18
	2% treatment	1.70	2.08	2.22
	4% treatment	2.28	2.58	2.86
	6% treatment	2.44	2.78	2.96
	8% treatment	1.98	2.22	2.46
	10% treatment	1.56	1.84	2.24
700	0% treatment	2.23	2.59	2.90
	2% treatment	2.35	2.74	2.98
	4% treatment	2.72	2.96	3.21
	6% treatment	2.76	3.11	3.37
	8% treatment	2.41	2.90	3.17
	10% treatment	2.18	2.55	2.69
900	0% treatment	2.52	2.91	3.23
	2% treatment	2.64	3.17	3.47
	4% treatment	2.99	3.47	3.91
	6% treatment	3.21	3.66	4.07
	8% treatment	2.58	3.06	3.57
	10% treatment	2.36	2.91	3.21

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Compressive Strength

Figures 1, 2 and 3 demonstrate the axial compressive strength with three different densities at the age of 7 days, 28 days and 60 days. All the figures showed the increase of compressive strength of the specimen until 6% of NaOH treatment to the fibre. In these figures it exhibited that, 6% of NaOH treatment with the density of 900kg/m^3 show the better result with the reading of 3.66 MPa at the age of 60 day while 1.48 MPa and 2.36 MPa for 500 kg/m^3 and 700 kg/m^3 density of lightweight foamed concrete respectively.

The compressive strength of the lightweight foamed concrete decrease gradually on the 8% and 10% of NaOH treatment to the fibre. According to Coker et. al [16] the longer the time of curing the lightweight foamed concrete specimen, the higher the strength gained.

Based on the research that had been conducted by Othuman Mydin et. al [17] the untreated fibre show poor matrix interfacial bonding while the 5% alkali treated fibre shows better interfacial bonding as it has a large amount of visible residues such as epoxy resin which implies a much more better interfacial bonding between the fibre and the matrix.

The alkali treatment towards the fibre have caused rougher surface of the fibre and eliminates the surface impurities such as hemicellulose, lignin, pectin and waxes of the fibre. This would increase the aspect ratio, mechanical interlocking and provide more interfacial bonding of the fibre to the cement.

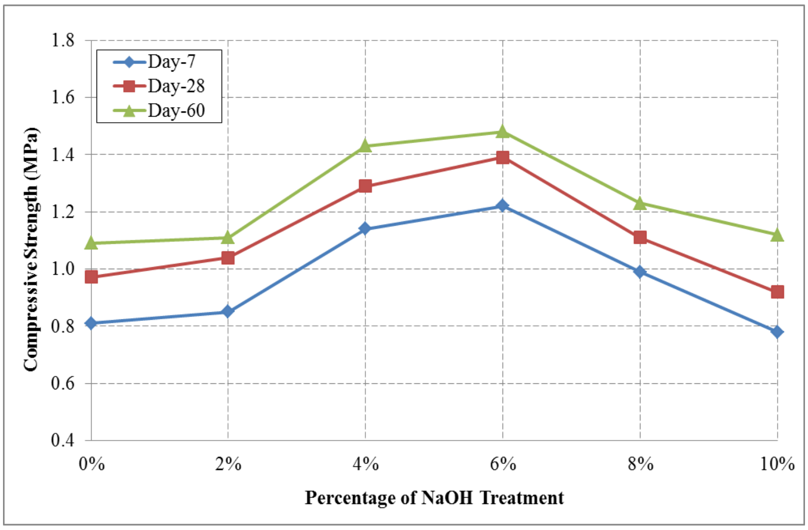

Fig. 1 Axial compressive strength of 500 kg/m^3 density foamed concrete of different mercerization percentages

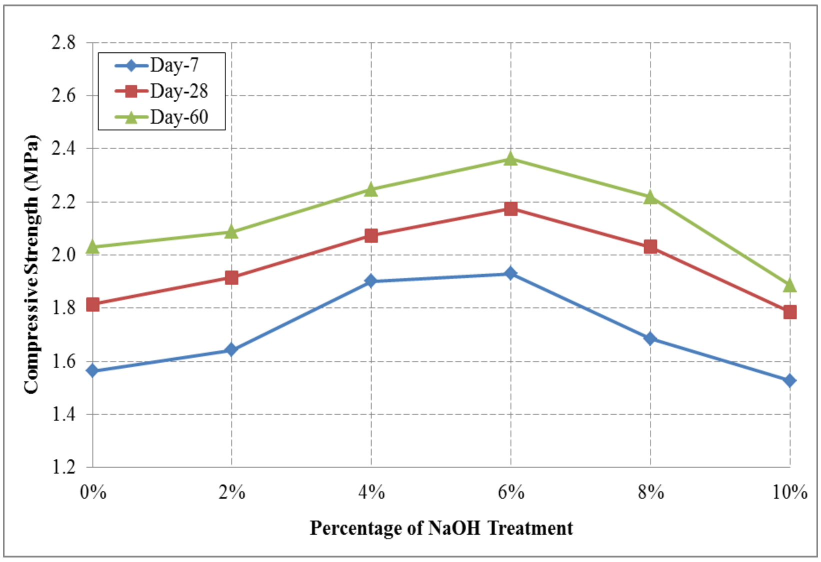

Fig. 2 Axial compressive strength of 700 kg/m^3 density foamed concrete of different mercerization percentages

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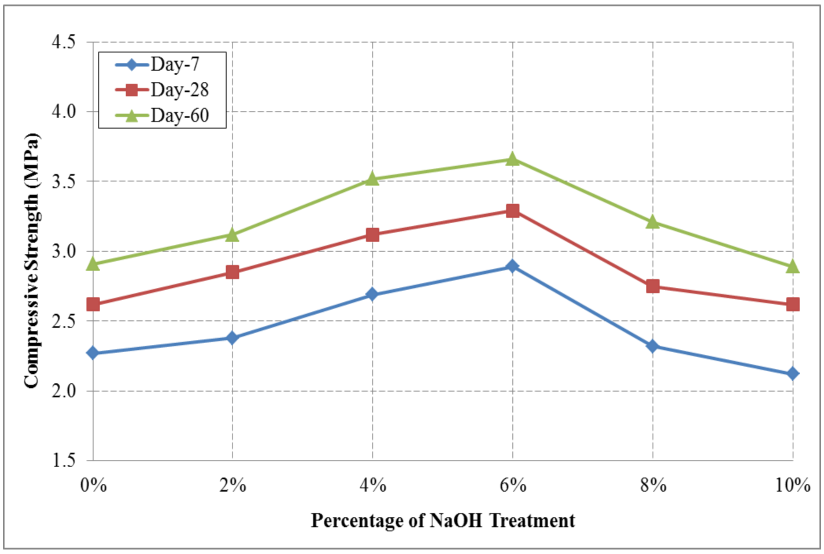

Fig. 3 Axial compressive strength of 900 kg/m^3 density foamed concrete of different mercerization percentages

Flexural Strength

The results of the flexural strength test of the lightweight foamed concrete with three different densities were displayed on figures 4, 5 and 6. The increase of strength can be seen up to 6% of sodium hydroxide treatment towards the fibre and decrease gradually on the 8% and 10% sodium hydroxide treatment. It shows the flexural strength of the lightweight foamed concrete with the density of 900kg/m^3 is the highest amongst the three densities. It achieved 1.15MPa compared to 0.73 MPa for 700kg/m^3 and 0.46 MPa for 500kg/m^3. This improvement on the flexural strength is credited to the enhancement of the empty fruit bunches fibre and the interfacial adhesion after the alkali treatment.

The importance of the sodium hydroxide treatment is the commotion of the hydrogen attachment in the fibre surface and it removes the high percentages of oils, wax and lignin that covered the outer surface of the fibre. According to a research conducted by Othuman Mydin et. al [17] the alkali treatment increases the fracture energy that attributed on the cement matrix interfacial bonding and fibre. The empty fruit bunches fibre act as the fibre bridging as the effective secondary reinforcement of the lightweight foamed concrete. The fibre reinforced concrete was tested and broken into halves in order to observe the fibre failure. Fibre breaking and pull out and fibre debonding between the cement matrixes were observed [18, 19].

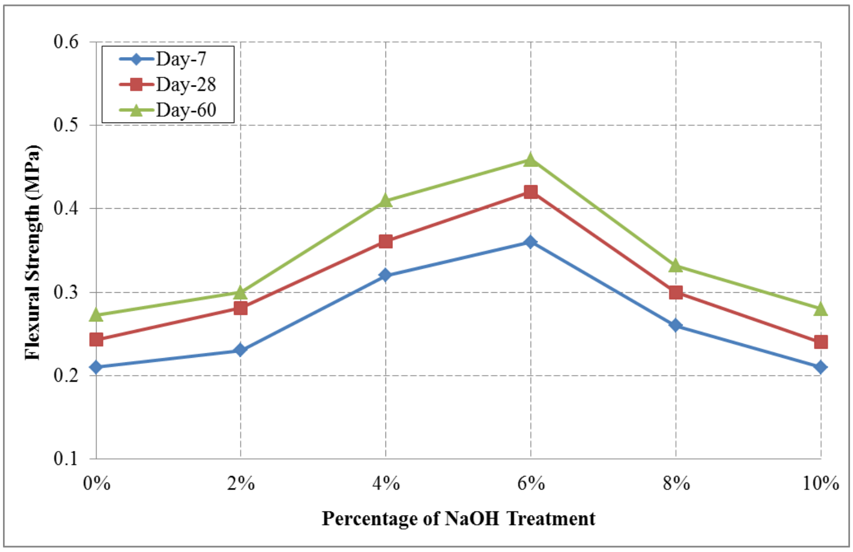

Fig. 4 Three-point bending strength of 500 kg/m^3 density foamed concrete of different mercerization percentages

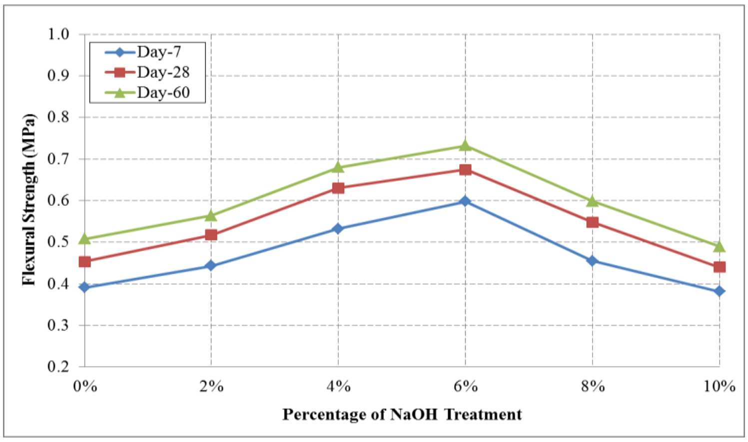

Fig. 5 Three-point bending strength of 700 kg/m^3 density foamed concrete of different mercerization percentages

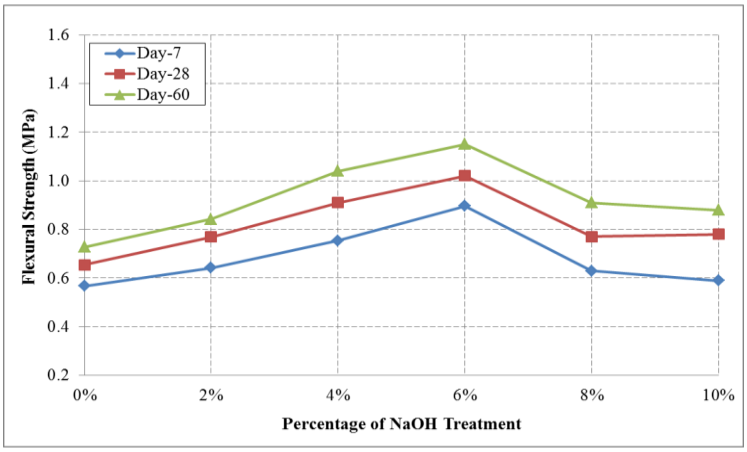

Fig. 6 Three-point bending strength of 900 kg/m^3 density foamed concrete of different mercerization percentages

Tensile Strength

Figures 7, 8 and 9 exhibit the results of splitting tensile for the lightweight foamed concrete with the density of 500 kg/m^3, 700 kg/m^3 and 900 kg/m^3. From the figures below, it shows an increase of tensile strength from 0% to 6% of NaOH treatment of the fibre. The highest result strength increase from 0.24 MPa to 0.34 MPa for 500 kg/m^3 on day-60. For density 700 kg/m^3 and 900 kg/m^3 a better result were obtained at the 6% of NaOH treatment with 0.52 MPa and 0.78 MPa respectively.

Based on the result, the percentage of NaOH treatment on the fibre influenced the strength of the lightweight foamed concrete. An inclusion of fibres can influence the increasing or decreasing of splitting tensile strength up to 11% [18]. The relationship between tensile strength and compressive strength depends on few factors which were the aggregate type, particle size distribution, the age of the concrete, the curing process and air content [20].

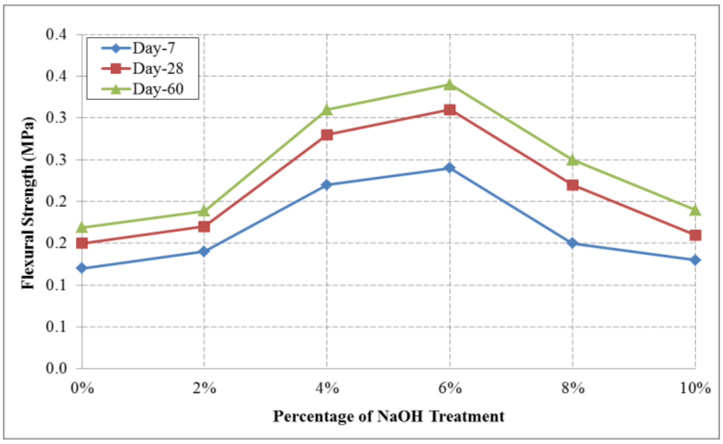

Fig. 7 Tensile strength of 500 kg/m^3 density foamed concrete of different mercerization percentages

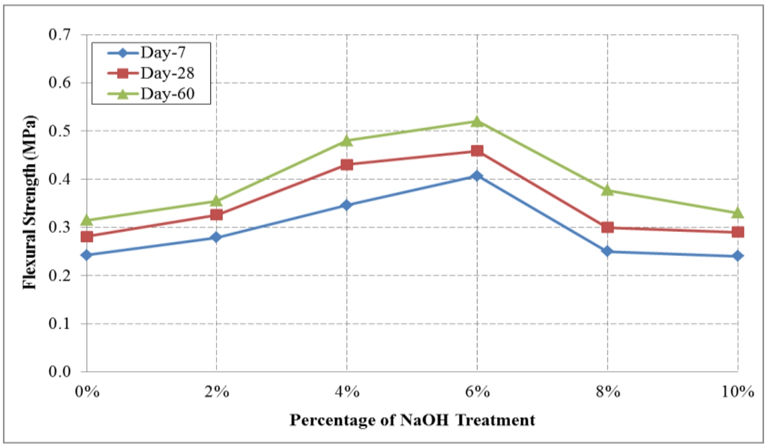

Fig. 8 Tensile strength of 700 kg/m^3 density foamed concrete of different mercerization percentages

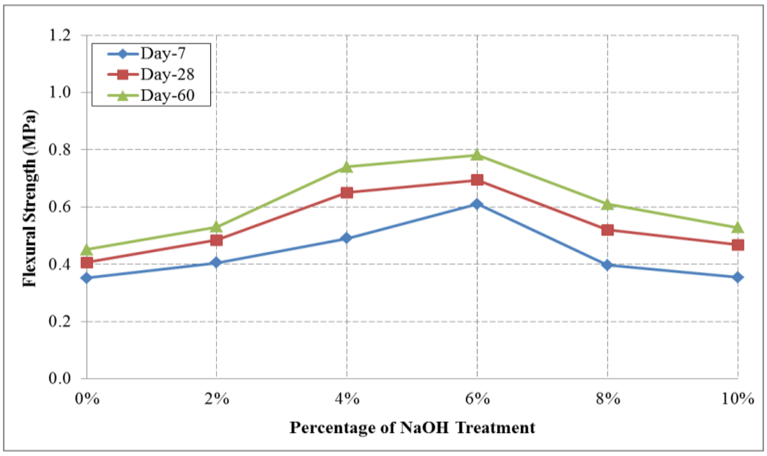

Fig. 9 Tensile strength of 900 kg/m^3 density foamed concrete of different mercerization percentages

Performance Index

Figures 10, 11 and 12 display the performance index (PI) of 500 kg/m^3, 700 kg/m^3 and 900 kg/m^3 densities respectively. It can be seen that parallel tendency was reached by performance index, in which the performance index is unswervingly proportionate to the specimen's age of curing. For 500kg/m^3 density, the 60-day PI was attained by lightweight foamed concrete mix with 6% mercerization, which is 2.96N/mm^3 per 1000 kg/m^3. Subsequently, for 700kg/m^3 density, the 60-day PI was accomplished by foamed concrete mix with 6% mercerization, which is 3.37N/mm^3 per 1000 kg/m^3. Conversely, 60-day PI achieved by 900kg/m^3 density is similar (foamed concrete mix with 6% mercerization) which is 4.07N/mm^3 per 1000 kg/m^3.

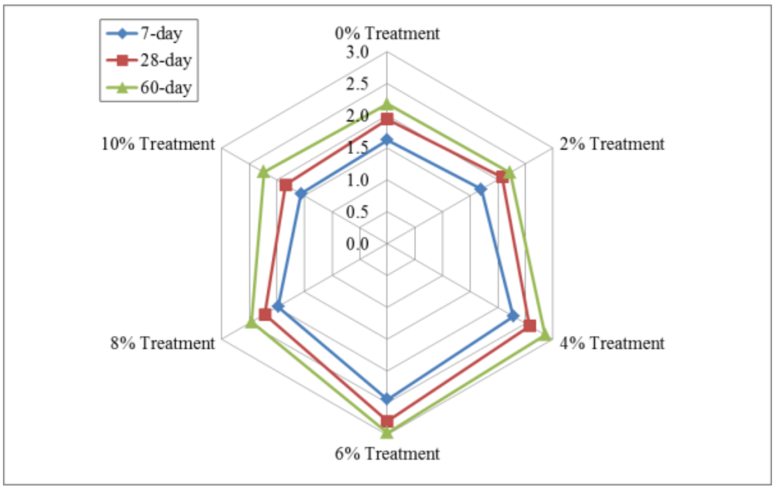

Fig. 10 Performance index of 500 kg/m^3 density foamed concrete of different mercerization percentages

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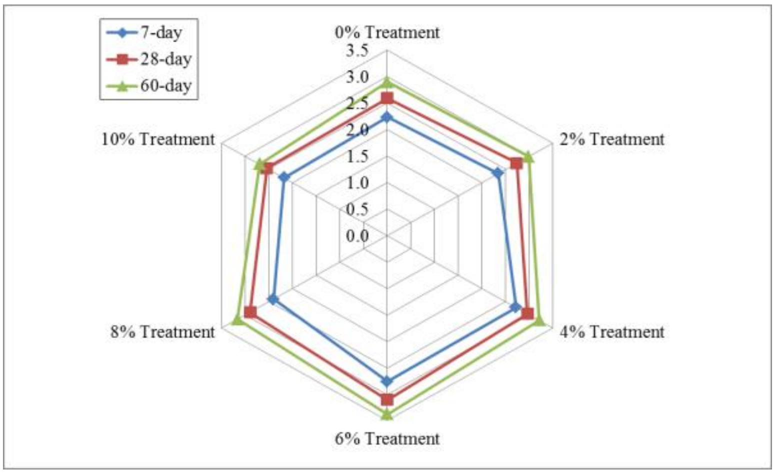

Fig. 11 Performance index of 700 kg/m^3 density foamed concrete of different mercerization percentages

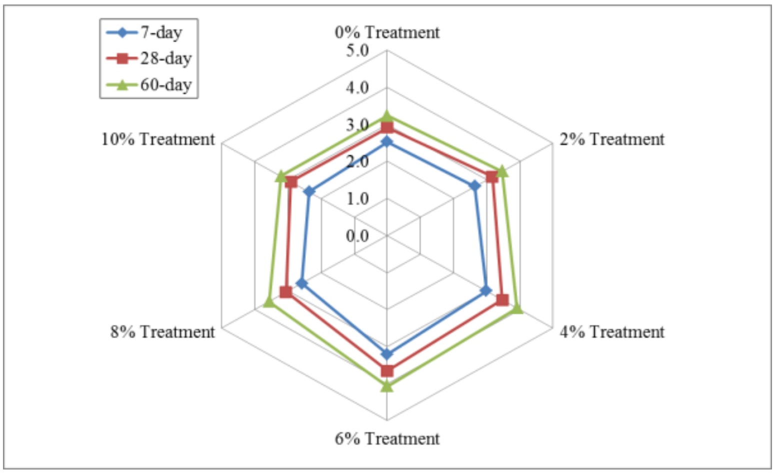

Fig. 12 Performance index of 900 kg/m^3 density foamed concrete of different mercerization percentages

IV. CONCLUSION

Based on the result obtained from the experimental test, it shows that the treatment of sodium hydroxide on the empty fruit bunches fibre reinforced lightweight foamed concrete and enhance the mechanical properties. The treatment has improved and enhanced the strength of the concrete. The 6% sodium hydroxide treatment on the empty fruit bunches fibre improve the interfacial bonding between the fibre and the cement matrixes. The result decrease after the 6% treatment of sodium hydroxide due to the excessive treatment that remove part of the boundary layers of the empty fruit bunches fibre and caused deterioration to the fibre particles. The failure modes that have been observed in this experiment were fibre breakage, fibre pull out and fibre debonding between the cement matrixes and the fibre.

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