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Development of Lightweight Concrete Using Industrial Waste Palm Oil Clinker

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Abstract: Concrete is a major material used in the construction of buildings and structures in the world. Gravel and sand are the major ingredients of concrete but are non-renewable natural materials. Therefore, the utilisation of palm oil clinker (POC), a solid waste generated from palm oil industry is proposed to replace natural aggregate in this research to reduce the demand for natural aggregates. One mix of ordinary concrete as control concrete; while four mix proportions of oil palm clinker concrete were obtained by replacing 25%, 50%, 75%, and 100% of gravel and sand of control concrete with coarse and fine oil palm clinker respectively by volume, with same cement content and water cement ratio. Compressive strength test was carried out of concretes with different percentages of oil palm clinker; whereas water absorption tests according to respective standard, were carried out to determine the durability properties of various mixes. Based on the results obtained, the study on the effect of percentage of clinker on strength and durability properties was drawn. According to ACI classification of light weight concrete only the 100 percentage replacement can achieve the definition of light weight concrete since its density is less than 1,900 kg/m^3 and strength larger than 17 MPa. Eventually the 25% replacement of the normal aggregate by the OPC will improve the strength and durability of the concrete.

Key words: Lightweight concrete, palm oil clinker, industrial waste, Malaysia.

1. Introduction

In developing countries where abundant agricultural and industrial wastes are discharged, these wastes can be used as potential material or replacement material in the construction industry [1]. This will have the double advantage of reduction in the cost of construction material and also as a means of disposal of waste. It is at this time, the above approach is logical, worthy and attributable [2]. The recycling or utilisation of solid wastes generated from most agro-based industries and manufacturing industries is very rewarding. The anxiety about enormous waste production, resource preservation, and material cost has focused attention for the reuse of solid waste [3]. Material recovery from the conversion of agricultural wastes and industrial wastes into useful materials has not only environmental gains, but may also preserve natural resources. It is thus appropriate that research on the effective utilisation of various types of solid wastes has gained greater attention in the past several decades. The exponential growth rate of population, development of industry and technology, and the growth of social civilisation can be considered as the underlying factors that have caused the increased waste production in the recent years [4]. The basic strategies to decrease solid waste problems have been focused at the reduction of waste production and recovery of usable materials from waste as well as utilisation of waste as raw materials whenever feasible. Today, concrete is one of the most versatile construction materials in which it is the most usable materials right after water in this world. It is accounted that the demand for concrete is predicted to increase approximately 18 billion tonne a year by 2050 [3].

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Today, concrete is one of the most versatile construction materials. The oil palm industry in Malaysia is one of the largest producers of palm oil in the world [5]. Palm oil industry is set to grow further with the global increase in vegetable oil demand. However, it is also the main contributor to the nation’s pollution problem, which includes the annual production of 3.6 million tons of solid waste in the form of oil palm shells [6]. In recent years there has been renewed interest in lightweight aggregate concretes, in particular for production of high performance concrete that can be used for bridge construction and other special applications such as off shore structures [7]. Lightweight concrete is known for its advantage of reducing the self-weight of the structures, reducing the areas of sectional members as well as making the construction convenient [8, 9]. Thus, the construction cost can be saved when applied to structures such as long-span bridge and high rise buildings. The objective of the current study is to determine the effect of percent replacement of aggregate by palm oil clinker on physical and mechanical properties of fresh and hardened concrete. Furthermore, it is to determine the effect of water cement ratio and cement content on workability, strength properties and durability of palm oil lightweight concrete.

2. Materials and Methods

For this research, oil palm clinker is used to partially and fully replace the normal aggregate (crushed gravel and normal sand) in the control concrete (normal weight concrete) by volume. The first step involved in the preparation of materials is to isolate the oil palm clinker and cements which are going to be used in this research from the bulk mass. This is a critical step, yet often overlooked. In the plants, oil palm clinker is produced in batches. Even though there are standard procedures and process for the production of clinkers, the raw materials, the palm oil shells, might vary from batch to batch. This can be due to several reasons, such as the soil condition at different oil palm plantations, different environments and weathers at which the oil palm tree grown and cultivated, and so on. These factors can cause the chemical compositions in the palm oil shells to vary from one another, thus affecting the homogeneity of the product clinkers. Similarly, the raw materials used in cement production, which are limestone, sand iron ore, shale, and so on, might vary from batch to batch. Therefore, it would be preferable to use the clinkers and cements which are produced from the same batch to ensure the accuracy of the final results. Next the clinker will be crushed in to smaller sizes using jaw crusher. After being crushed into smaller sizes, the clinkers will then be separated into coarse and fine aggregates. This will be done by using the 5.0 mm sieve, as required by the British Standard, which stated that any aggregates passing the 5 mm sieve size are classified as fine aggregates. After sieving to separate the coarse and fine clinker, specific gravity test, absorption test, and sieve analysis of clinker and natural aggregate are done to determine their physical properties. While test on cement is neglected since both normal weight concrete and oil palm clinker concrete use the same type of cement. Two types of aggregate have been utilised, the natural aggregate and oil palm clinker. Each type has been defined based on its source, size, shape and the standard used.

2.1 Partial Replacement of Concrete

To investigate the effect of percent replacement of aggregate by palm oil clinker on physical and mechanical properties of fresh and hardened concrete, five (5) concrete mixture proportions were prepared. The cement content of theses mixtures was 450 kg/m^3, with water cement ratio of 0.5.

A mix proportion of normal weight concrete is chosen and acts as the control concrete. Since the control concrete contains no clinker, its mix designation is given as POCC_0. The other four mixes contain 25%, 50%, 75% and 100% replacement of both fine and coarse aggregates by the palm oil clinker. The mixes are named as POCC_25, POCC_50, POCC_75 and POCC_100 respectively. The mixture proportions are shown in Table 1.

2.2 Full Replacement Concrete

The selection of mix proportions is thus, simply, the process of choosing suitable ingredients of concrete and determining their relative quantities with the object of producing as economically as possible concrete of certain minimum properties, strength, durability and a required consistency. The ACI standard practice ACI 211.2-98 is referred for general applicable methods of selecting and adjusting mixture proportions for structural lightweight aggregate concrete using palm oil clinker. Modifications had been made to the mix selections of lightweight aggregate concrete using palm oil clinker to obtain concrete within required properties.

In this study, 5 mix proportions of POCC were selected based on ACI standard practice with modifications. The proportioning selection follows the volume method in the standard practice; fits the characteristics of the available materials into mixture suitable for the work. The selection covers specification requirements including choice of slump, choice of nominal maximum size of lightweight aggregate, estimating of mixing water. The most two factors affecting concrete properties were investigated. These factors are w/c ratio and cement content. Three levels of each factor were studied. All the mix proportions are detailed in Table 2.

2.3 Testing and Curing Test Specimens

Some tests are conducted to determine the effects of incinerated oil palm aggregates on the workability, durability and compressive strength of concrete as well as to determine the optimum mix proportions. The following paragraphs will describe the detailed steps for conducting each test.

2.3.1 Unit Weight

The unit weight of all concrete mixes was measured according to ASTM C138, Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete.

2.3.2 Slump Test

The slump test is prescribed by ASTM C 143-90a and BS 1881: Part 102: 1983. The mould for slump test is a frustum of a cone; 300 mm high. It is placed on a smooth surface with the smaller opening at the

Table 1 Mix proportion for partial replacement concrete.

Mix designation	Fine aggregate (kg/m^3)		Coarse aggregate (kg/m^3)	
	Sand	Clinker	Gravel	Clinker
POCC_0	620	0	1050	0
POCC_25	465	121.8	787.5	164.6
POCC_50	310	243.7	525	329.1
POCC_75	155	365.5	262.5	493.7
POCC_100	0	487.3	0	658.3

Cement content = 450 kg/m^3 and water-cement ratio = 0.5.

Table 2 Mix proportion of palm oil clinker concrete.

Mix_ID	w/c	Water	Add_water	Cement	POC_coarse	POC_fine
		kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3
PC1W3	0.44	154	131.9	350	556	794.7
PC3W5	0.50	225	108.2	450	572	567.2
PC3W3	0.44	198	113.9	450	576	616.7
PC3W1	0.38	171	119.7	450	580	666.3
PC5W3	0.44	242	95.9	550	596	438.7

top, and filled with concrete in three layers. Each layer is tamped 25 times with a standard 16 mm diameter steel rod, rounded at the end, and the top surface is struck off by means of sawing and rolling motion of the tamping rod. The mould must be firmly held against its base during the entire operation; this is facilitated by handles or foot-rests brazed to the mold. Immediately after filling, the cone is slowly lifted, and the unsupported concrete will now slump—hence the name of the test. The decrease in the height of the slumped concrete is called slump, and is measured to the nearest 5 mm. The decrease is measured to the highest point according to BS 1881: Part 102: 1983, but to the “displaced original centre” according to ASTM C 143-90a. In order to reduce the influence on slump of the variation in the surface friction, the inside of the mold and its base should be moistened at the beginning of every test, and prior to lifting of the mould the area immediately around the base of the cone should be cleaned of concrete which may have dropped accidentally.

2.3.3 Compressive Strength Test

The most common of all tests on hardened concrete is the compressive strength test, partly because it is an easy test to perform, and partly because many, though not all, of the desirable characteristic of concrete are qualitatively related to its strength; but mainly because of the intrinsic importance of the compressive strength of the concrete in structural design. The strength test results may be affected by variation in: type of test specimen; specimen size; type of mold; curing; preparation of the end surface; right of the testing machine and rate of application of stress. For this reason, testing should follow a single standard, with no departure from prescribed procedure. Compressive strength tests on specimens treated in a standard manner which includes full compaction and wet curing for a specified period give results representing the potential quality of the concrete. Of course, the concrete in the structure may actually be inferior, for example, due to inadequate compaction, segregation, or poor curing. These effects are of importance if we want to know when the formwork may be removed, or when further construction may continue, or the structure be put into service. For this purpose, the test specimens are cured under conditions as nearly as possible to those existing in the actual structure. Even then, the effects of temperature and moisture would not be the same in a test specimen as in a relatively large mass of concrete. The age at which service specimens are tested is governed by the information required. On the other hand, standard specimens are tested at prescribed ages, generally 28 days, with additional tests often made at 3 and 7 days. Two types of compression test specimens are used: cubes. Cubes are used in Great Britain, Germany, and many other countries in Europe. Cylinders are the standard specimens in the United States, France, Canada, Australia, and Newzealand.

For this research, cube specimens are used. The specimens are cast in steel or cast-iron moulds of robust construction, generally 150 mm cubes, which should conform within narrow tolerances to the cubical shape, prescribed dimensions and planeness. However, for this study, 100 mm cubes are used for compression strength test since many specimens are required. The mould and its base must be clamped together during casting in order to prevent leakage of mortar. Before assembling the mould, its mating surfaces should be covered with mineral oil, and a thin layer of similar oil must be applied to the inside surfaces of the mould in order to prevent the development of bond between the mold and the concrete. The standard practice is to fill the mould in three layers. Each layer of concrete is compacted by a vibrating hammer, or using a vibrating table, or by not fewer than 35 strokes of a 25 mm square steel punner. Ramming should continue until full compaction without segregation has been achieved because it is essential that the concrete in the cube be fully compacted if the test result is to be representative of the properties of fully-compacted concrete. If, on the other hand, a check on the properties of the concrete as placed is required, then the degree of compaction of the concrete in the cube should simulate that of the concrete in the structure. Thus, in the case of precast members compacted on a vibrating table, the test cube and the member may be vibrated simultaneously, but the disparity of the two masses makes the achievement of the same degree of compaction extremely difficult, and this method is not recommended.

After the top surface of the cube has been finished by means of a float, the cube is stored undisturbed for 24 ± 4 hours. In the compression test, the cube, while still wet, is placed with the cast faces in contact with the platens of the testing machine, i.e. the position of the cube when tested is at right angles to that as-cast. The compressive strength, known also as the crushing strength, is reported to the nearest 0.5 MPa; a greater precision is usually only apparent.

2.3.4 Flexural Strength Test

The flexural strength of the concrete specimens was determined according to ASTM C293, Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading). The 100 × 100 × 500 mm (4 × 4 × 20 inch) beams were tested at the ages of 7 and 28 days. Beam specimens were loaded to failure at a rate of 0.02 MPa/s.

2.3.5 Splitting Tensile Strength

The determination of splitting tensile strength was done according to ASTM C496, Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. Tests were performed on 150 × 300 mm (6 × 12 inch) specimens at the ages of 7, 28 days, which were loaded to failure at a rate of 0.02 MPa/s.

2.3.6 Concrete Absorption Test

The volume of pore space in concrete, as distinct from the ease with which a fluid can penetrate it, is measured by absorption; the two quantities are not necessarily related. Absorption is usually measured by drying a specimen to a constant mass, immersing it in water, and measuring the increase in mass as a percentage of dry mass. Various procedures can be used, and widely different results are obtained. According to BS 1881: Part 122: 1983, three separated specimens are used. The specimens are put into an oven to dry at 100 °C for 72 hours. After 72 hours, the specimens are weighed and the weight is recorded. Immediately after weigh, the specimens are put into water tank and immerse for 30 minutes. The distance from water surface to the top surface of immersed concrete cube must be more than 25 mm.

After 30 minutes, the specimen is taken out and by using a specified cloth to remove the water on the concrete surface quickly, without absorbing the water within concrete cube. Then weight the specimen. The difference in mass of the specimens is the mass of the water absorbed. Water absorption can be shown through the mass, or more accurately by dividing it with the total surface area giving the mass per unit area.

3. Results and Discussions

3.1 Partial Replacement of Aggregate

Partial replacement of aggregate was fulfilled based on 0, 25, 50, 75 and 100 percent replacement with the oil palm clinker. The density of concrete, measured slump, compressive strength and water absorption results and its discussion are presented in the following paragraphs.

Table 3 shows the density of various mixes of concrete and its reduced percentages of normal aggregate. The results indicate that the density of palm oil clinker concrete is decreased with increasing percentage of replacement of normal aggregate with oil palm clinker. This is because normal sand and crushed gravel have higher density or specific gravity than the fine and coarse oil palm clinker respectively. According to (ACI 211), the density of normal weight concrete lies within the range of 2,200 to 2,600 kg/m^3, while the density of structural lightweight concrete is between 1,350 to 1,900 kg/m^3. Table 4 shows the description of concretes based on the density.

Table 3 Density of concretes and its reduced percentage.

Mix ID	POCC_0	POCC_25	POCC_50	POCC_75	POCC_100
Total = density	2,345	2,213.90	2,082.80	1,951.69	1,820.59
% reduced in density		5.6	11.2	16.8	22.4

Table 4 Description of concretes based on density.

Mix designation	Density, kg/m^3	Description
POCC_0 POCC_25	2,345 2,214	Normal weight concrete.
POCC_50 POCC_75	2,083 1,952	Between normal weight concrete and structural lightweight concrete.
POCC_100	1,821	Structural lightweight concrete.

Table 5 Description of concretes based on measured slump.

Mix designation	Measured slump, mm	Description
POCC_0	70	Medium workability
POCC_25	50	Medium workability
POCC_50	45	Medium
POCC_75	5	Low workability
POCC_100	0	No slump

The workability of oil palm clinker is reduced as the volume of oil palm clinker increased. This is because palm oil clinker has higher water absorption than normal aggregate, therefore when the volume of palm oil clinker is increased; more water is absorbed by oil palm clinker, and consequently reducing in fluidity and lubrication of the fresh concrete. Moreover, the honeycombed and rough surfaces texture with visible pores and cavities of the clinker need more paste to fill the pores and cavities, hence low workability. POCC_75 and POCC_100 are having very low workability, hence very difficult to compact, resulting in a honeycombed structure at the base and surfaces of the concrete cubes when hardened. Description of the concretes based on the measured slump is indicated in Table 5.

3.1.1 Compressive Strength

The relationship between the compressive strength and the percent replacement of normal aggregate with oil palm clinker for different percentages is illustrated in Fig. 1. The figure indicates that the 25% replacement shows higher strength when compared to normal concrete. Increasing replacement more than 25% replacement will decrease the compressive strength significantly. This can be attributing to the following:

- Small replacement of 25% of the normal aggregate by the oil palm clinker will absorb some water from the mix thus, will reduce the amount of free water in the mix and the water cement ratio of the mix will decrease also therefore; the compressive strength will be increased.
- Higher replacements above 25% the effect of the weak light weight aggregate reduce the strength.
- Higher replacements above 25% high amount of water absorbed by light weight aggregate which does not leave enough water in the mix for hydration.

The compressive strengths as a function of percent replacement of normal aggregate with oil palm clinker for the ages 1, 3, 7, 14 and 28 days are shown in Fig. 2. This figure indicates when the number of days in which the concrete specimens present in water increased the compressive strength will increase as well.

3.1.2 Durability

The results of the water absorption test for partially replaced oil palm clinker are shown in Table 6. From the results obtained, POCC_0 and POCC_50 resulted in an approximately the same water absorption,

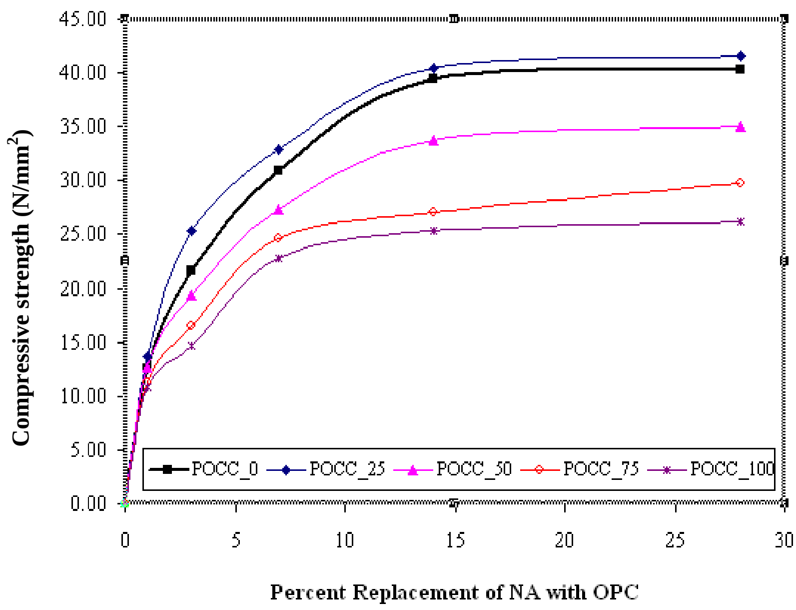

Fig. 1 Compressive strength versus % replacements within 28 days.

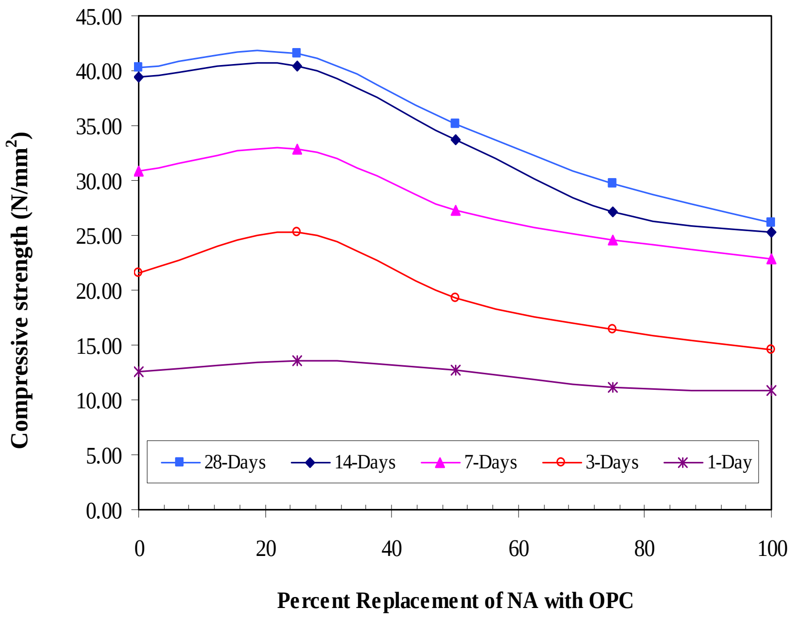

Fig. 2 Compressive strength versus % replacement for different ages.

POCC_25 has the lowest water absorption, hence the most durable among the mixes; POCC_100 has the highest water absorption among the mixes. Results are also shown in the bar chart in Fig. 3.

Fig. 4 indicates the following:

- Small replacement of 25% of normal aggregate with by the oil palm clinker absorbed less water and hence well improved the durability.
- For large replacement above 25% of normal aggregate by the oil palm clinker, large amount of porous aggregate will be present in the mix, and this will lead to higher and more porous concrete, hence the porosity of lightweight aggregate will absorbed more water and this will decrease the hydration process.

Table 6 Results for water absorption test of OPC_LWC.

Mix ID	Mass of concrete after immersed in water for 30 minutes (kg)	Mass of concrete after oven-dried for 72 hours (kg)	Mass of water (kg)	Total surface area of concrete (m^2)	Water absorption (kg/m^2)
POCC_0	7.870	7.780	0.090	0.135	0.667
POCC_25	7.585	7.500	0.085	0.135	0.630
POCC_50	7.157	7.060	0.097	0.135	0.719
POCC_75	6.812	6.700	0.112	0.135	0.830
POCC_100	6.286	6.144	0.142	0.135	1.052

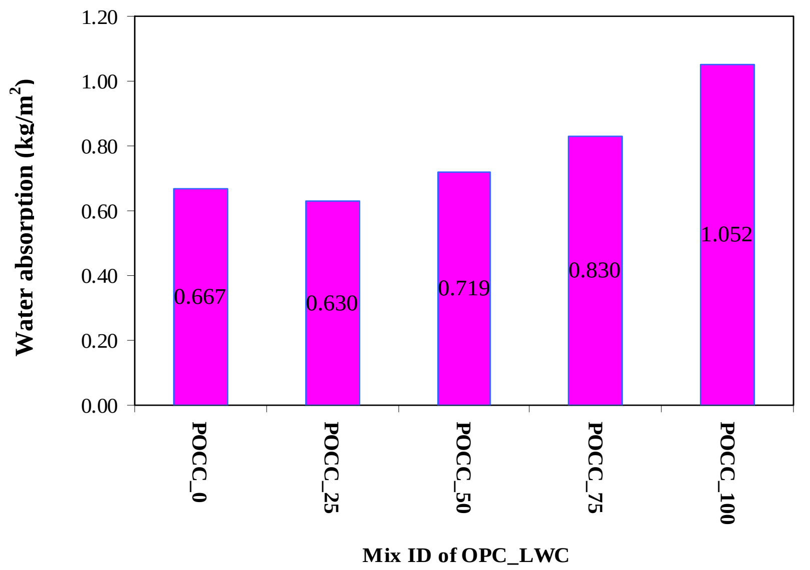

Fig. 3 Results for water absorption test of OPC_LWC.

Table 7 Density of fully replacement concretes.

Mix ID	PC1W3	PC3W5	PC3W3	PC3W1	PC5W3
Total = density	1,843	1,820	1,860	1,884	1,858

3.2 Full Replacement or Aggregate

The density of concrete, the effect of water cement ratio, the effect of cement content on compressive strength, flexural and splitting strength results for the fully replacement of normal aggregate by oil palm clinker lightweight aggregate are indicated and presented as below.

3.2.1 Density and Workability

The density of fully replacement of normal aggregate by the palm oil clinker results is indicated in Table 7.

3.2.2 Effect of Water Cement Ratio on Strength

The effect of water cement ratio on compressive strength, flexural strength and splitting strength is illustrated in details as below.

(1) Compressive Strength Relation to the Water Cement Ratio

Results of the effect of w/c ratio on compressive strength of oil palm lightweight concrete at all ages are illustrated in Fig. 4. This figure indicates when the water cement ratio at all ages increases the compressive strength will be decreased.

Fig. 5 illustrates the effect of water cement ratio on 28 days compressive strength of oil palm lightweight concrete. This figure indicates when the water cement ratio increases, the compressive strength will decrease.

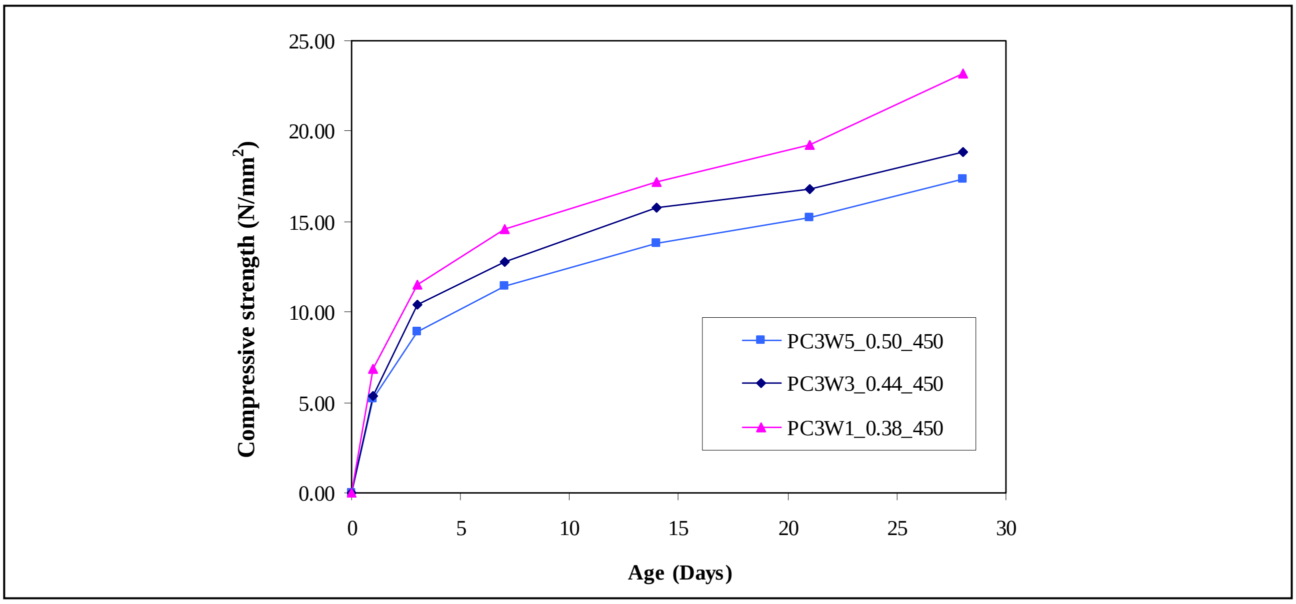

Fig. 4 Effect of water cement ratio on compressive strength of POLWC.

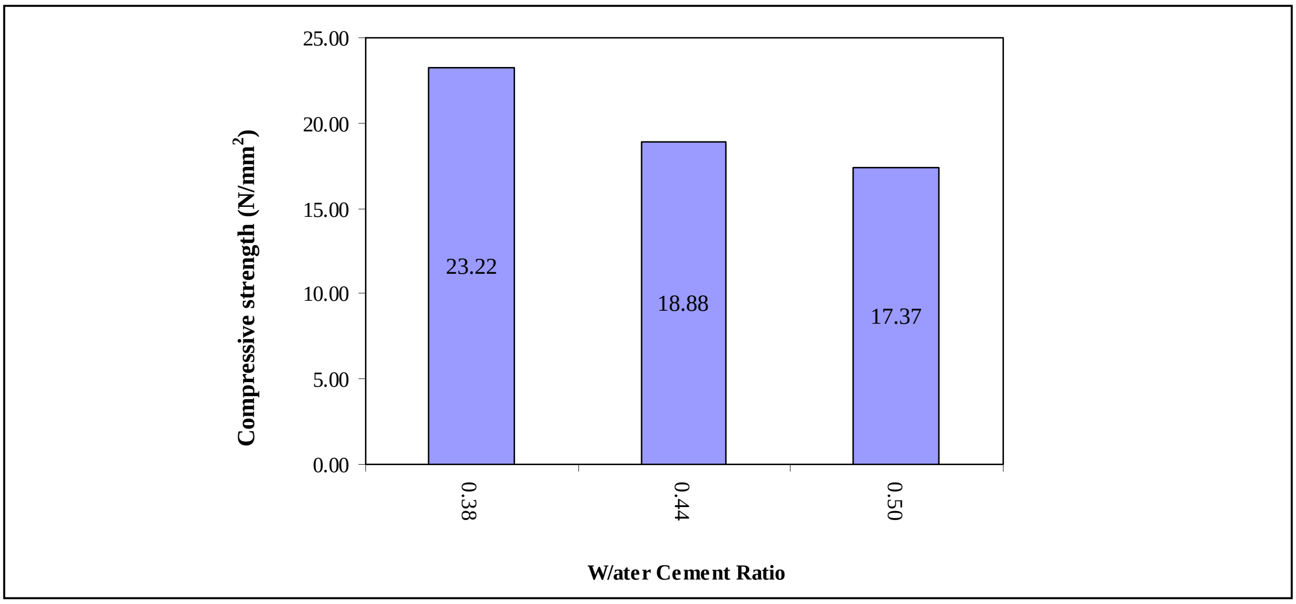

Fig. 5 Effect of water cement ratio on 28 days compressive strength of POLWC.

Fig. 6 illustrates the relationship between water cement ratio and 28 days compressive strength of oil palm lightweight concrete. The compressive strength is correlated to the water cement ratio by the equation $y = 8.140x^{-1.067}$. Substituting each value of water cement ratio will get a value for compressive strength, and the line that is shown in the figure is represented the best fit straight line, and this line indicates that when the water cement ratio increases the compressive strength will be decreased. The correlation coefficient, R^2 of the equation indicates a very high value equal to 0.96.

(2) Flexural Strength

The results of the effect of the water cement ratio on the 28 days flexural strength of oil palm lightweight concrete is shown in Fig. 7, and this figure indicates when the water cement ratio increases, the flexural strength will decrease.

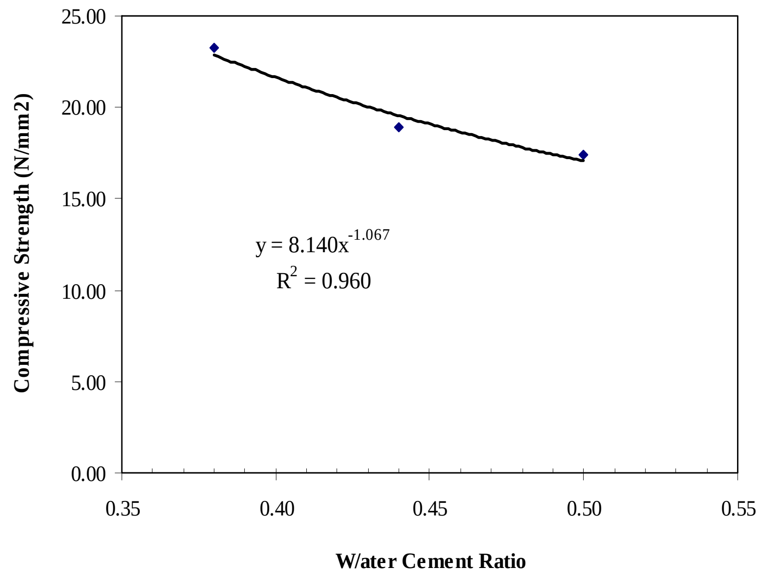

Fig. 6 Relationships between water cement ratio and 28 days compressive strength of POLWC.

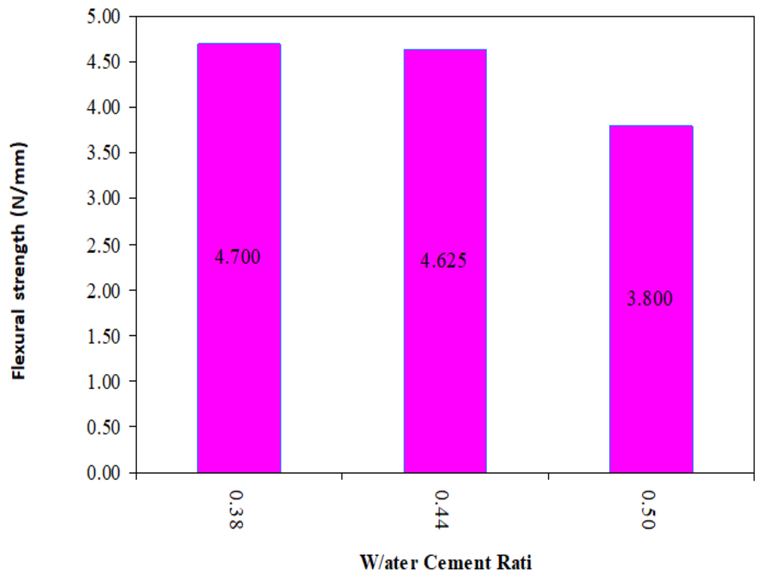

Fig. 7 Effect of water cement ratio on 28 days flexural strength of POLWC.

(3) Splitting Strength

The effect of water cement ratio on 28 days splitting strength of the oil palm lightweight concrete results is illustrated in Fig. 8. The figure indicates when the water cement ratio increases the splitting strength will be decreased.

3.2.3 Effect of Cement Content on Strength

The effect of cement content on compressive strength, flexural strength and splitting strength is illustrated in details as below.

(1) Compressive Strength

The effect of the cement content on compressive strength of oil palm lightweight concrete at different curing ages is illustrated in Fig. 9. This figure indicates that when the cement content is increased for all ages; the compressive strength will increase as well.

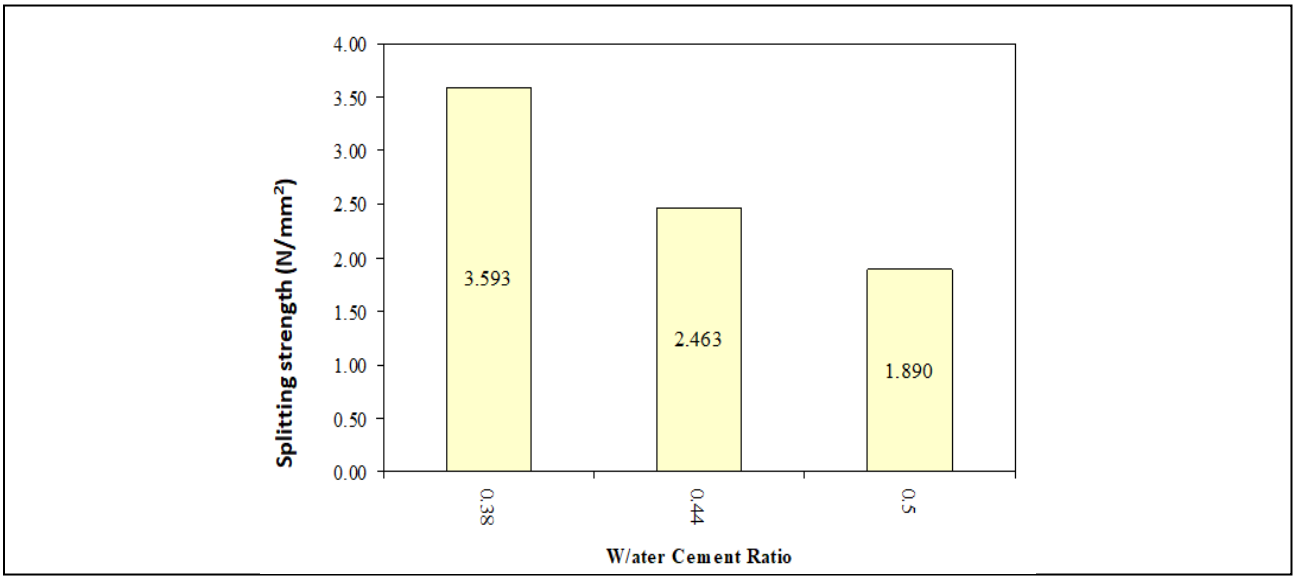

Fig. 8 Effect of water cement ratio on 28 days splitting strength of POLWC.

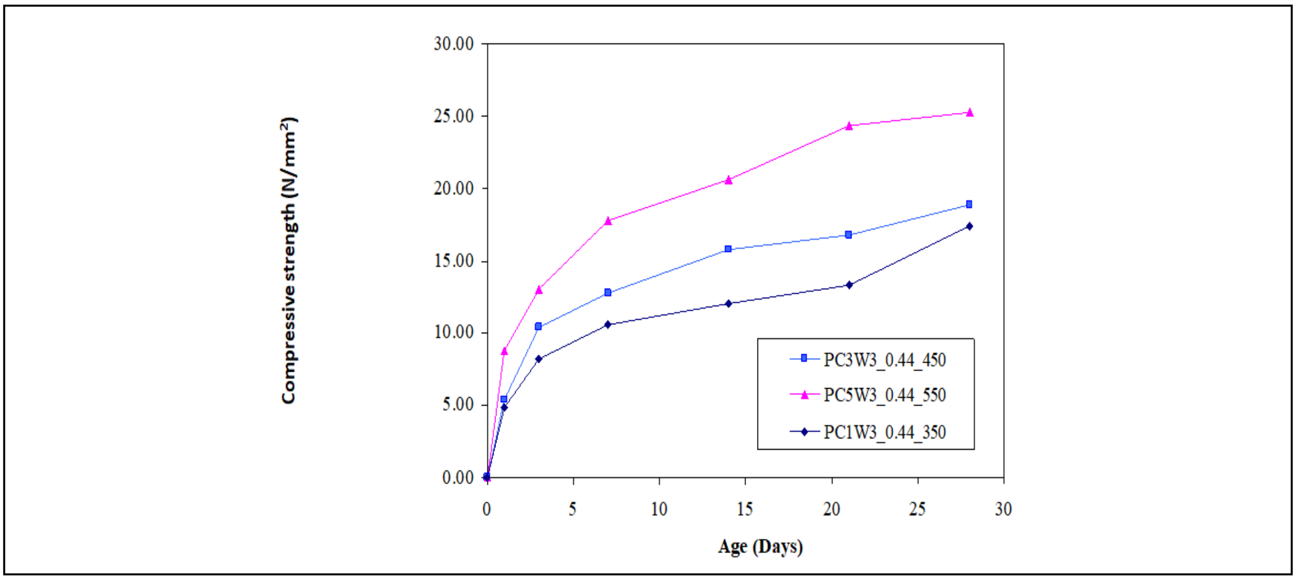

Fig. 9 Effect of cement content on compressive strength of POLWC at different curing age.

Fig. 10 illustrates the effect of cement content on the 28 days compressive strength of palm oil light weight concrete. This figure indicates when the cement content increases the compressive strength will be increased as well.

The relationship between cement content and the 28 days compressive strength of oil palm lightweight concrete is illustrated in Fig. 11, in which the compressive strength is correlated to the cement content by the equation $y = 8.795\ e^{0.002x}$. Substituting each value of the cement content will obtain a value of the compressive strength. The line shown in the figure is represented by the best fit straight line and it is indicated that when the cement content increases, the compressive strength will be increased as well and it shows very high correlation coefficient that is equal to 0.903.

(2) Flexural & Splitting Strength Relation to the Cement Content

Fig. 12 illustrates the effect of the cement content on the 28 day flexural strength of oil palm lightweight concrete, in which when the cement content increases,

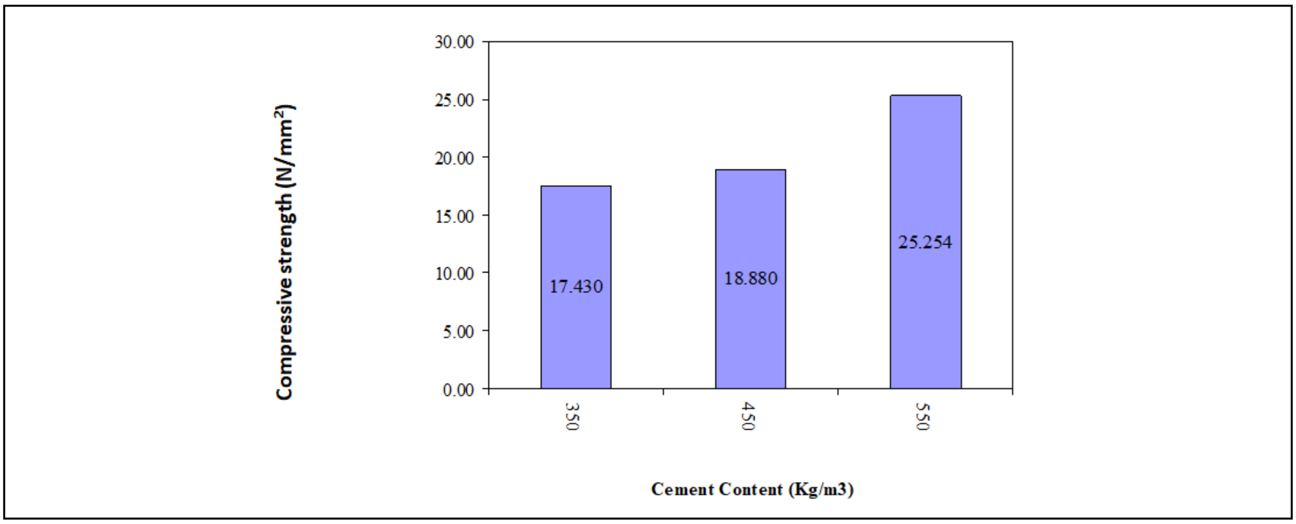

Fig. 10 Effect of cement content on 28 days compressive strength of POLWC.

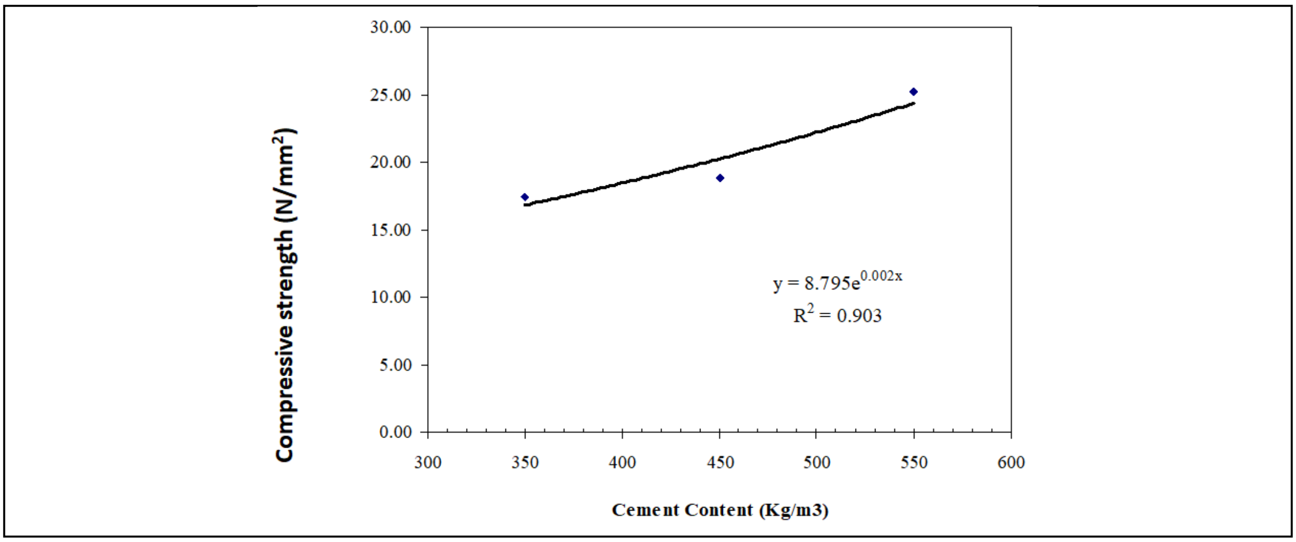

Fig. 11 Relationships between cement content and 28 days compressive strength of POLWC.

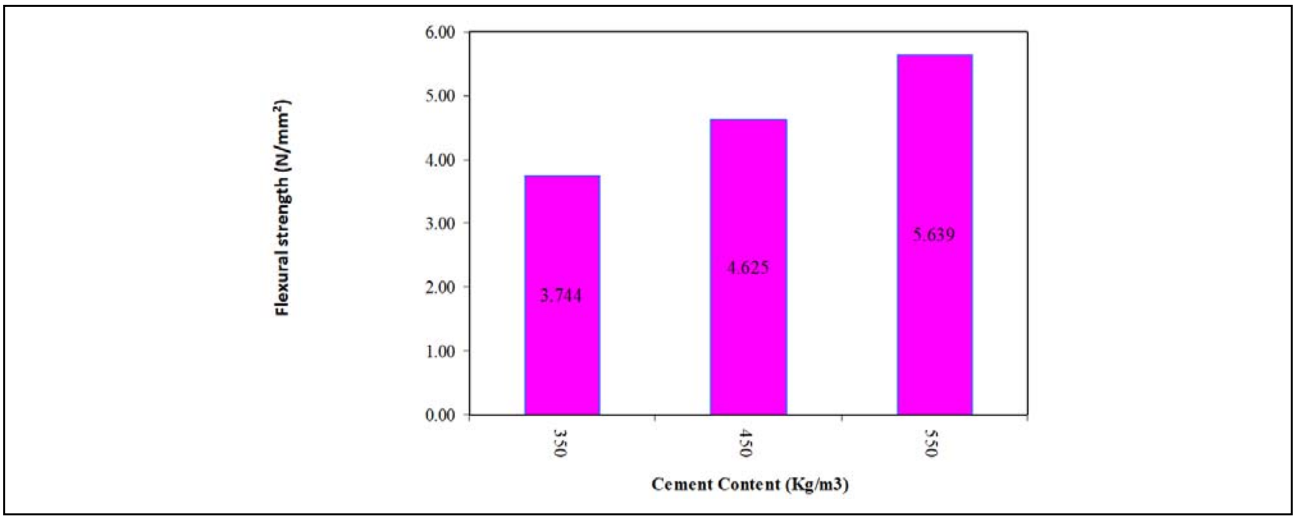

Fig. 12 Effect of cement content on 28 days flexural strength of POLWC.

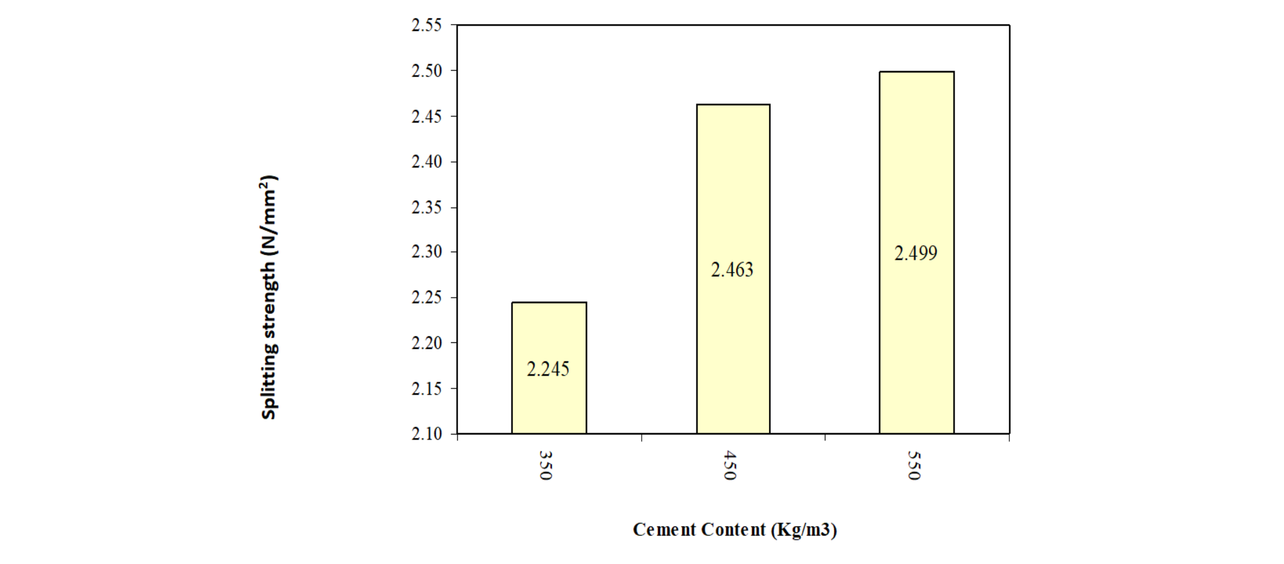

Fig. 13 Effect of cement content on 28 days splitting strength of POLWC.

the flexural strength will be increased as well. Fig. 13 illustrates the effect of the cement content on the 28 days splitting strength of oil palm lightweight concrete, in which when the cement content increases, the splitting strength will be increased as well.

3.2.4 Relationship between Compressive and Flexural Strength

The relationship between the 28 days compressive and the flexural strengths of the oil palm lightweight concrete is illustrated in Fig. 14. The flexural strength is correlated to the compressive strength by the equation $y = 0.1981x + 0.4535$. The line in this figure is demonstrated by the best fit straight line and it indicates that when the compressive strength increases, the flexural strength also increases. The correlation coefficient indicated is high and is equal to 0.8427.

3.2.5 Relationship between Compressive and Splitting Strength

The relationship between the 28 days compressive strength and the splitting strength of the oil palm lightweight concrete is illustrated in Fig. 15. The splitting strength is a function of the compressive

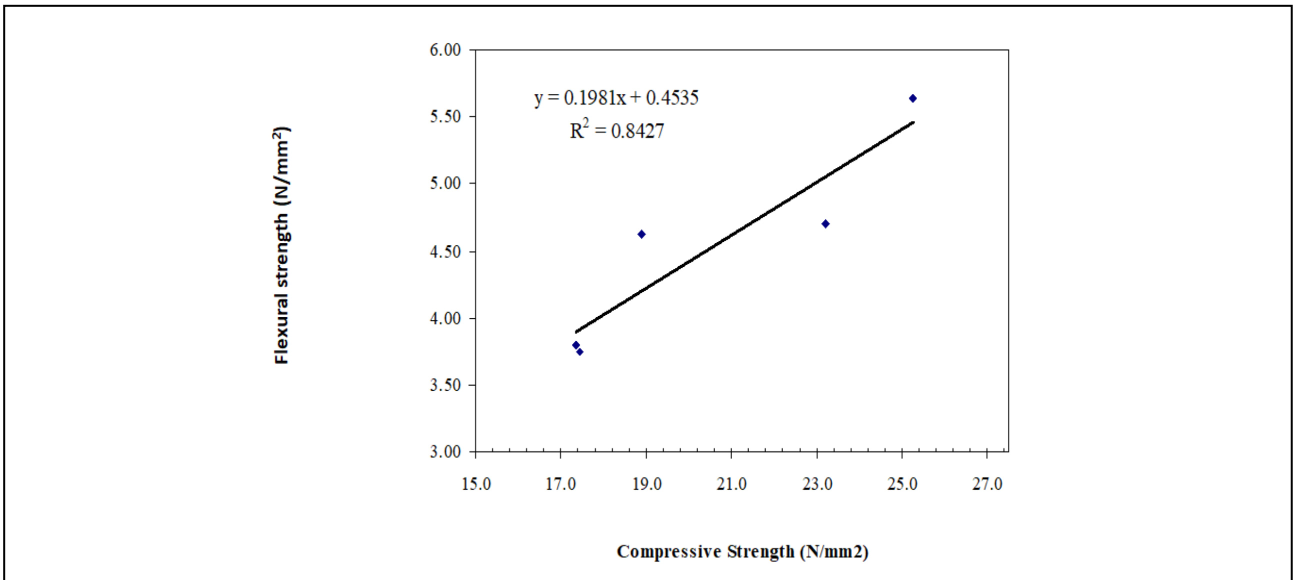

Fig. 14 Relationships between 28 days compressive strength and flexural strength of POLWC.

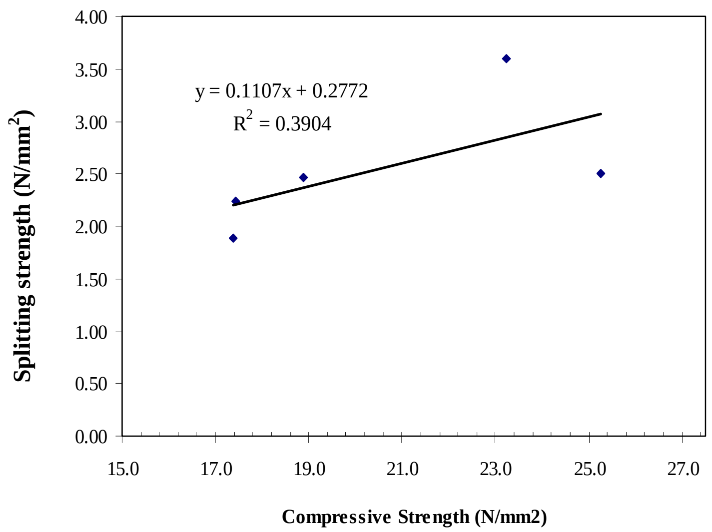

Fig. 15 Relationships between 28 days compressive strength and splitting strength of POLWC.

strength by the equation y = 0.1107x + 0.2772. Substituting each value of the compressive strength will give a value for the splitting strength. The line in the figure is demonstrated by the best fit straight line, and it indicates that when the compressive strength increases the splitting strength is increased as well.

4. Conclusions

From the results of partially replacement of normal aggregate with the oil palm clinker, it is indicated that the 25% replacement of normal aggregate with the palm oil clinker has improved the strength and durability. Furthermore, the replacement of normal aggregate with the palm oil aggregate of more than 25% results in a strength reduction.

Regarding the full replacement of normal aggregate with the palm oil aggregate it is noticed that when the water cement ratio increases, the strength (including the compressive strength, flexural and splitting strength) will be increased. According to ACI classification of lightweight concrete only the 100% replacement can achieve the definition of lightweight concrete since its density is less than 1,900 kg/m^3 and the strength is larger than 17 MPa. Eventually, the relationship between the water cement ratio and the 28 days compressive strength has been established.

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