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PROPORTIONING OF CRUSHED BRICK CONCRETE REINFORCED BY PALM FIBER

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Abstract

In this study, structural lightweight concrete derived from coarse lightweight crushed brick and fine lightweight crushed brick (CLWA and FLWA) were investigated. Compressive strength and density of the concrete were determined to establish the appropriate design mix of lightweight concrete. The suitable designs of concrete mixture were selected to determine their using different percentages of palm fiber; 0, 0.2, 0.4, 0.6, 0.8, and 1.0% based on volumetric fractions. The results show that the voids between fine aggregate particles (sand + FLWA) had significant effect on the compressive strength of the crushed brick concrete. By using 0.6% of palm fiber, the compressive strength and flexural strength of the concrete mix increased by about 11.2% and 16.6%, respectively.

1. Introduction

Research has been conducted worldwide on a large number of natural or artificial lightweight aggregates. The mix design of lightweight

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concrete used for structural purposes is more complicated because it depends on the type of lightweight aggregate. The use of a local product depends on its specific properties and the requirements for a particular job. Structural lightweight concrete has its obvious advantages of higher strength/weight ratio, lower co-efficient of thermal expansion, and superior heat and sound insulation characteristic due to air voids in the lightweight aggregate. Furthermore, the reduction in dead weight of a construction could result in a decrease in size of structural members and steel reinforcement (Hossain [12] and [13]). Structural lightweight concrete has an in-place density (unit weight) on the order of 1440 to 1840kg/m^3 compared to the normal weight concrete with a density in the range of 2240 to 2400kg/m^3. For structural applications, the concrete strength should be greater than 17.0MPa (ACI 213R) for the concrete mix from lightweight coarse aggregate. The mix may be made of a portion or the entire fine aggregate of a lightweight material (Neville [19]).

The primary use of structural lightweight concrete is to reduce the dead load of a concrete structure, which then allows the structural designer to reduce the size of columns, footings, and other load bearing elements. Structural lightweight concrete mixtures can be designed to achieve similar strengths as normal weight concrete. The same is true for other mechanical and durability performances. Structural lightweight concrete provides a more efficient strength-to-weight ratio in structural elements (Holm and Valsangkar [11]).

In most cases, the marginally higher cost of the lightweight concrete is offset by the reduction of the size of structural elements, amount of reinforcing steel, and the volume of concrete used, resulting in lower overall cost.

Lightweight concrete can be manufactured with a combination of fine and coarse lightweight aggregate or coarse lightweight aggregate and normal weight fine aggregate. Complete replacement of normal weight fine aggregate with a lightweight aggregate will decrease the concrete density by approximately (160kg/m^3). The structural design generally relies on an equilibrium density (sometimes referred to as air-dry density), the condition in which some moisture is retained within the lightweight concrete. Equilibrium density is a standardized value intended to represent the approximate density of the in-place concrete, when it is in service. Project specifications should indicate the required equilibrium density of the lightweight concrete. Equilibrium density is defined in ASTM C567 [2], and can be calculated from the concrete mixture proportions. Field acceptance is based on measured density of fresh concrete in accordance with ASTM C138 [2]. Equilibrium density will be approximately (50 to 130kg/m^3) less than the fresh density and a correlation should be agreed upon prior to delivery of concrete. The tolerance for acceptance on fresh density is typically (± 50kg/m^3) from the target value (ASTM [3]).

On the other hand, there has been a growing interest in utilizing natural fibers for making low cost construction materials in recent years. Knowledge of natural fibers use in cement composites, mechanisms of mechanical behavior, insulating behavior, etc. has increased substantially. Many research papers (Do and Lien [10]) indicated various advantages in the use of natural fibers in cement composites, such as, increased flexural strength, post-crack load bearing capacity, increased impact toughness, and improved bending strength (Semple and Evans [20]). Natural fibers also enhance mechanical and behave live reinforcement for the composites (Bilba et al. [6], Toledo et al. [23]). The major advantage of using natural fibers is that, they offer significant cost reduction and benefits associated with processing as compared to synthetic fibers. Hence, the material receives a lot of attention for replacing synthetic fibers (Thielemans and Wool [22]). However, due to increasing awareness on the environment and energy, special attention should be paid to natural fibers with a view to conserve energy and protect the environment. The addition of natural fiber also reduces the thermal conductivity of the composite specimens and yielded a lightweight product (Khedari et al. [16] and Asasutjarit et al. [4]). Some investigations have already been carried out on various mechanical and physical properties of concrete materials using natural fibers from coconut husk, sisal, sugarcane begasse, bamboo, jute, wood, akwara, elephant grass, water-reed, plantain and musamba, and cellulose fibers. These investigations (Aziz et al. [5], Bilba et al. [6], Toledo et al. [23]) have shown encouraging results. A wide variety of natural fibers have been used for numerous applications, but whilst many of these show considerable promise, the use of natural fibers to reinforce cement pastes, mortar, and concrete stilt remains to be a subject of further research and investigation.

2. Research Significance

The aim of this study is to determine the factors affecting the structural lightweight mix design using lightweight coarse aggregate crushed brick at different percentages of lightweight fine aggregate crushed brick. The most important properties of lightweight structural concrete to be studied are, the density and their compressive strength. The inclusion of different percentages of palm fiber in lightweight crushed brick concrete may enhance their mechanical properties, strength, and durability performance of such concrete.

3. Materials and Mix Proportions

3.1. Materials

The cement used in mixtures was ordinary Portland cement type I, a product of task corporation Berhad. The chemical composition of cement is given in Table 1. The superplasticizer (SP) of type Conplast SP1000 was supplied by Fosroc Sdn. Bhd using with a maximum dosage of 1.5% to produce the desired workability of the mixes. The fine aggregate is natural sand, with fineness modulus of 2.86 and the maximum size of less than 5mm as shown in Figure 1. The grading of the lightweight crushed brick fine aggregate (FLWA) is shown in Figure 2. The lightweight coarse aggregate (CLWA) is also from crushed brick with a maximum aggregate size of 20mm. Figure 3 illustrates the grading curve of coarse aggregate and Table 2 shows the properties of aggregate used in the study. The palm fiber is produced by Fiber-X(M) Sdn. Bhd, and its characteristics are shown in Table 3.

Table 1. Chemical composition of ordinary Portland cement

Constituent	**Ordinary Portland Cement**
	% by weight
Lime (CaO)	64.64
Silica (SiO_2)	21.28
Alumina (Al_2O_3)	5.60
Iron oxide (Fe_2O_3)	3.36
Magnesia (MgO)	2.06
Sulphur trioxide (SO_3)	2.14
N_2O	0.05
Loss of ignition	0.64
Lime saturation factor	0.92
C_3S	52.82
C_2S	21.45
C_3A	9.16
C_4AF	10.2

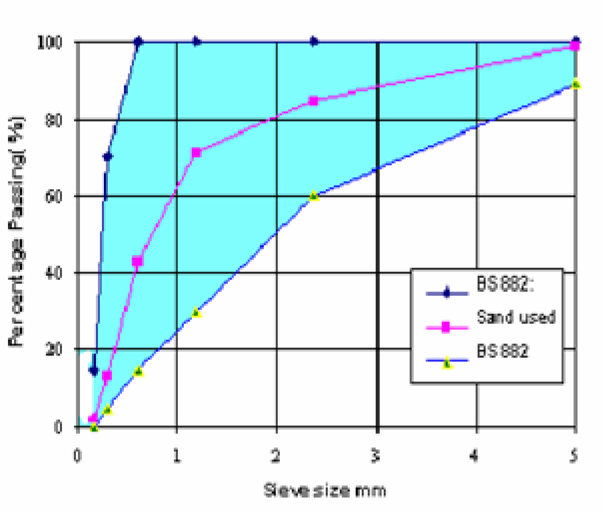

Figure 1. Grading curve of sand.

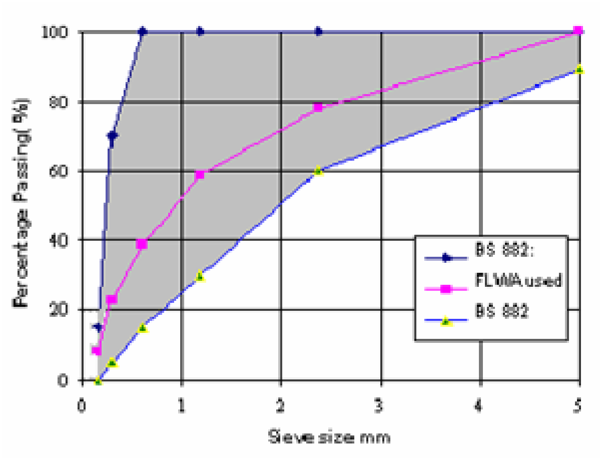

Figure 2. Grading curve of fine lightweight aggregate (FLWA).

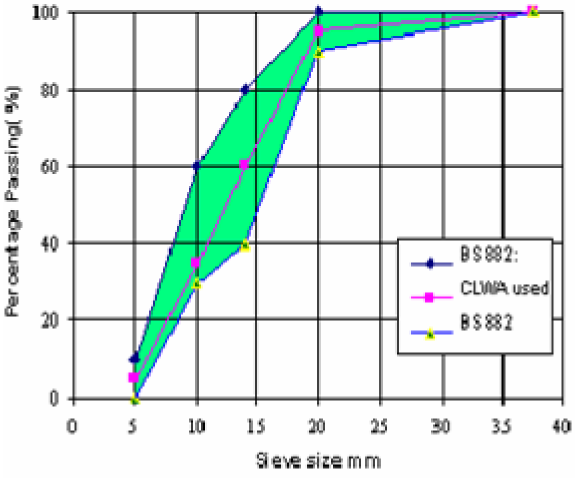

Figure 3. Grading curve of coarse lightweight aggregate (CLWA).

Table 2. Physical properties of aggregate

Aggregate type	**Water absorption** % (by weight)	**Specific gravity**
Sand	2.1	2.62
Fine lightweight crushed brick	18.2	2.0
Coarse lightweight crushed brick	15.4	1.8

Table 3. Characteristics of palm fiber

Fiber properties	**Quantity**
Average fiber length (mm)	30
Average fiber width (micron)	21.13
Tensile strength (MPa)	21.2
Elongation at break (%)	0.04
Specific gravity	1.24
Water absorption%, 24/48hrs	0.6

3.2. Mix proportions

First stage. Concrete mixes designed are given in Table 4. The concrete mixtures were designed according to the absolute volume method given by ACI [1]. Concrete of cement content 360kg/m^3 and water-cement ratio of 0.45 were chosen for the mix (C1). A partial replacement to a full replacement of sand by weight with lightweight fine crushed aggregate were achieved at mixes (C2-C7), then the weight and the volume of the ingredients for each mix was determined assuming that 3% air is trapped in fresh concrete. The voids between aggregate particles were determined according to ASTM C29, C127, and C128 [2]. This factor assumed as significant factor to study in this stage.

Table 4. Crushed brick lightweight concrete mixes*

Index	Cement Kg/m^3	Water Kg/m^3	SP %	W+ SP/C	Sand Kg/m^3	FLWA Kg/m^3	CLWA Kg/m^3	Slump mm	Fresh density Kg/m^3
C1	360	160	1.0	0.45	900	------	700	80	2050
C2	345	155	1.0	0.45	605	260	675	95	1980
C3	340	155	1.0	0.45	510	340	665	100	1960
C4	335	150	1.0	0.45	420	420	655	100	1940
C5	330	150	1.0	0.45	330	495	645	105	1860
C6	325	145	1.0	0.45	245	570	635	110	1835
C7	310	140	1.0	0.45	-----	775	605	120	1820

*All mixes, C1 to C7, have the same total aggregate to cement ratio by weight.

Second stage. The selected mix (C3) from the first stage, has been used here for all further tests. The mix was selected depending on two concepts. First, the mix with highest strength with acceptable range of density. Second, the mix of the least voids between aggregate particles. And thus, to study the mechanical properties of the concrete, the inclusion of the palm fiber with different volume fractions of 0, 0.2, 0.4, 0.6, 0.8, and 1.0% was used for the mixes CF0, CF1, CF2, CF3, CF4, and CF5, respectively, as shown in Table 6.

4. Test Methods

First stage. Three cubes of size 100mm × 100mm × 100mm were used for each mix to test the density and the compressive strength of the samples undergoing continuous water curing until the age of test. The density of fresh concrete was determined in accordance to ASTM C567 [2]. The cube specimens were left in the molds for 24h at room temperature of 20°C. After demolding, the specimens were kept in water curing till the age of test. Saturated surface dry of specimens were used in the test following the BS 1881: Part 114 [7]. The compressive strength was determined according to BS 1881: Part 116 [8].

Second stage. The same procedures as the first stage were applied for the mixes to determine the density and their compressive strength. Test samples of 100 × 100 × 500mm were used for the determination of flexural strength and according to BS 1881: Part 118 [9]. Continuously, the specimens reinforced by steel bar of the same prism's dimensions were used to determine the flexural strength of the reinforced samples as shown in Figure 4. The cylindrical mould (D = 15cm, H = 30cm) were used for determining the static modulus of elasticity according to ASTM C469.

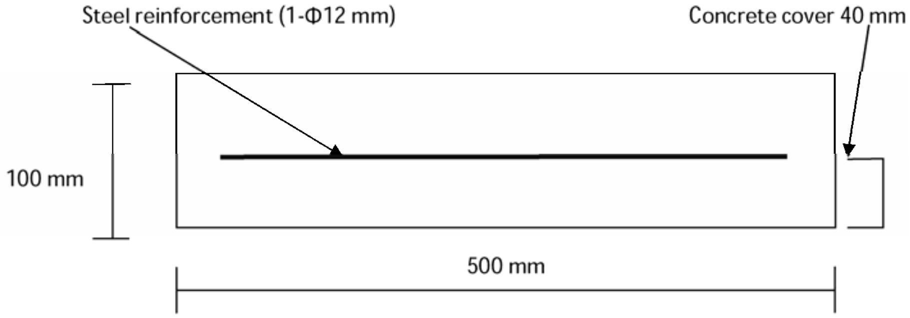

Figure 4. Reinforced specimens used for flexural strength.

5. Results and Discussion

First stage

5.1. Fresh status

Table 4 shows the results of the fresh density for all mixes. The comparison between mix C1 with mix C7 shows that the full replacement of sand by the FLWA reduces the fresh density by 200kg/m^3. This is attributed to the specific gravity of FLWA, which is less than that of sand. In general, the inclusion of FLWA in the mixes reduces the fresh density. The slump test results show that, the volume of mortar in the mix affect the slump values, where the increase in the amount of mortar would lead to the decrease in the coarse aggregate and hence, while promote higher values of slump (Neville [19]).

5.2. Compressive strength and saturated surface dry density

From Table 5, it can be concluded that the volume of FLWA and CLWA affect on the density. The inclusion of FLWA, in crushed brick concrete mixes reduces the density as it is shown in Figure 5. This is attributed to the specific gravity of FLWA, which reduces the whole density for the mix. On the other hand, the increase of CLWA volume in the mix, leads to higher density for the same cause listed above as shown in same Figure 5 too. The results of compressive strength show that the voids between aggregate particles in the mix determine the compressive strength of the mix, in another word, the mix with minimum voids gives the higher compressive strength, therefore, mix (C3), gives the higher compressive strength as the voids between aggregate particles were the least. Table 5 and Figure 6 illustrate the results of compressive strength at 28 days for different mix proportions.

Table 5. Mechanical properties of crushed brick lightweight concrete mixes

Index	Voids between aggregate particles %	Mortar volume %	FLWA volume %	CLWA volume %	Density Kg/m^3 7 days	Compressive strength, MPa 7day	Density Kg/m^3 28 days	Compressive strength, MPa 28 days
C1	13.31%	62.0	-----	35.0	2060	17.1	2080	21.5
C2	13.4%	63.9	14.1	33.8	2035	14.8	2055	21.0
C3	12.2%	64.1	18.4	33.2	2025	22.3	2040	30.4
C4	13.50%	64.3	22.6	32.7	2000	19.5	2020	21.1
C5	12.72%	65.0	26.8	32.2	1900	18.3	1930	24.5
C6	12.61%	65.2	30.8	31.7	1890	15.4	1910	27.4
C7	13.4%	66.0	42.0	30.3	1860	15.4	1880	21.8

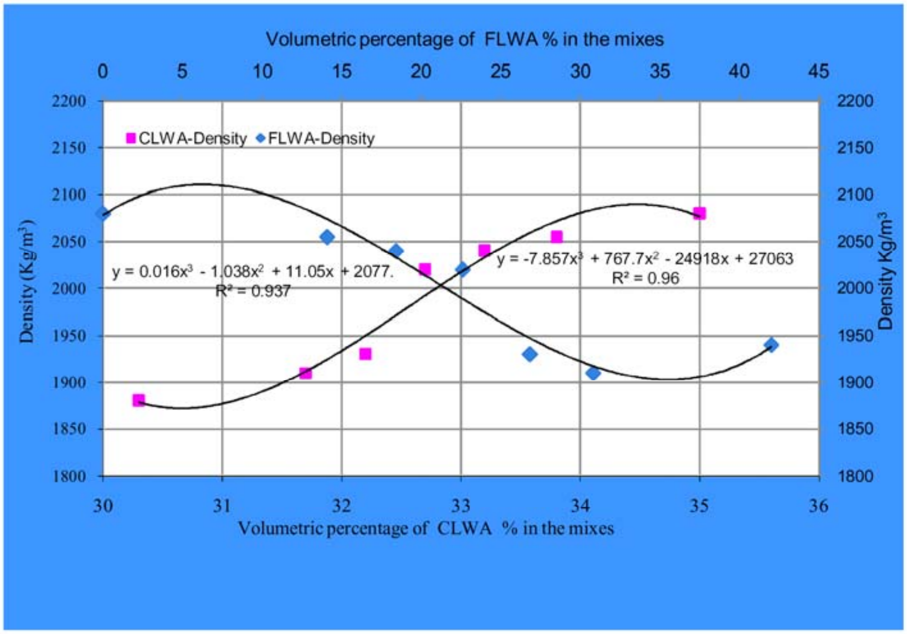

Figure 5. Relationship between CLWA-FLWA with density of crushed brick lightweight concrete mixes at 28 days.

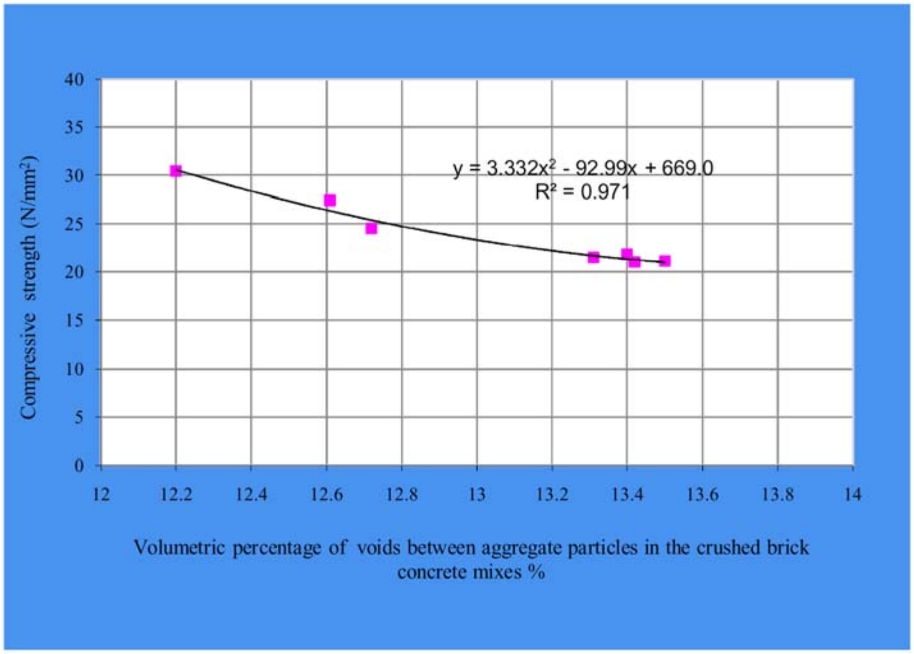

Figure 6. Relationship between voids between aggregate particles in the lightweight crushed brick concrete mixes with compressive strength at 28 days.

Second stage

5.3. Fresh status

Table 6 shows the results of the fresh density for all mixes. The results indicate that, the inclusion of palm fiber in the crushed brick lightweight concrete mixes reduces the fresh density as also represented in Figure 7. The slump test results also indicate that the inclusion of the fibers in the mix reduces slightly the slump.

Table 6. Palm fiber crushed brick concrete mixes

Index	Cement Kg/m³	Water Kg/m³	SP %	W/C	PF %*	Sand Kg/m³	FLWA Kg/m³	CLWA Kg/m³	Slump mm	Fresh density Kg/m³
CF0	360	160	1.0	0.45	0	510	340	665	100	1960
CF1	360	160	1.0	0.45	0.2	510	340	665	100	1960
CF2	360	160	1.0	0.45	0.4	510	340	665	90	1950
CF3	360	160	1.0	0.45	0.6	510	340	665	85	1940
CF4	360	160	1.0	0.45	0.8	510	340	665	80	1930
CF5	360	160	1.0	0.45	1.0	510	340	665	80	1920

*Volumetric fractions of palm fiber in concrete mixes.

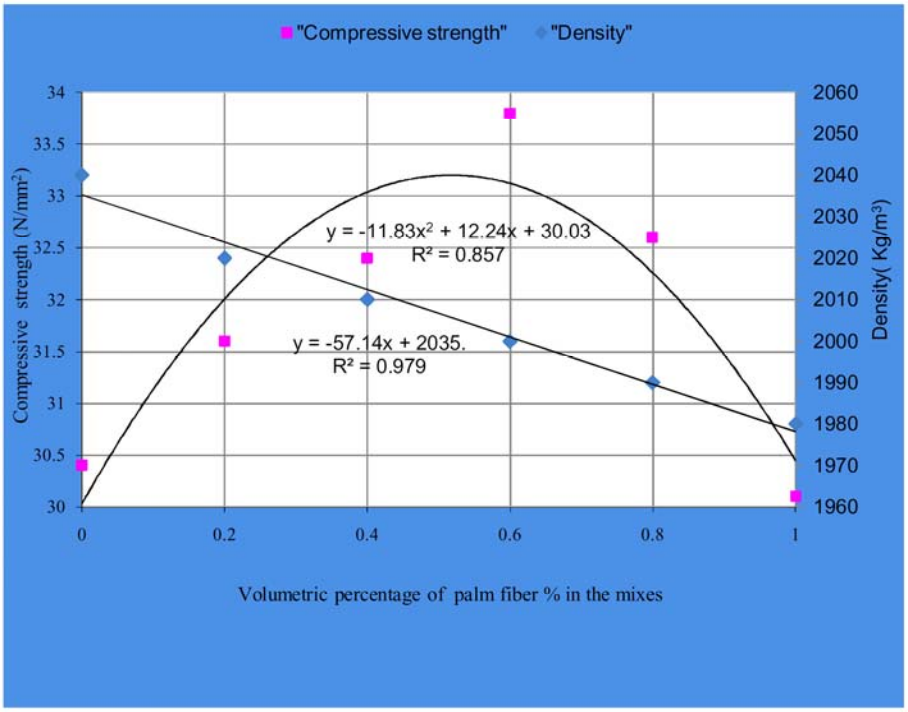

Figure 7. Relationship between volumetric percentage of palm fiber in lightweight crushed brick concrete mixes with each of compressive strength and density at 28 days.

5.4. Compressive strength and saturated surface dry density

From Table 7, it can be concluded that the increase of palm fiber had increased the compressive strength of the mix due to the reduction in porosity. The inclusion of more than 0.6% of the palm fiber reduces the compressive strength and this is attributed to the voids introduction in the mix due to excessive fiber content that may lead to reduction in bonding and disintegration (Mohammadi et al. [17]). From Figure 7, it can be observed that the increase of fiber from 0% to 0.6%, had increased the compressive strength by about 11.2%. On the other hand, there is a slightly decrease in density, which is considered a beneficial effect of using fiber in the mix as shown in Figure 7.

Table 7. Mechanical properties of lightweight concrete mixes

Index	Density Kg/m^3 7 days	Density Kg/m^3 28 days	Compressive strength (MPa) 7 days	Compressive strength (MPa) 28 days	Flexural strength (MPa) 28 days	Reinforced-flexural strength (MPa) 28 days	Static modulus of elasticity Ec (GPa) 28 days
CF0	2025	2040	22.3	30.4	4.15	6.9	17.59
CF1	2000	2020	22.9	31.6	4.41	7.2	18.62
CF2	1980	2010	22.9	31.9	4.60	7.6	19.35
CF3	1975	2000	23.3	33.8	4.84	8.1	22.35
CF4	1960	1990	22.3	32.6	4.62	8.0	21.44
CF5	1950	1980	21.8	30.1	4.46	7.9	20.84

5.5. Flexural strength

The flexural strength of the lightweight concrete mixes is shown in Table 7. The increase of the flexural strength is comparable with the compressive strength as shown in Figure 8. The results showed that the increase of the flexural strength is obtained up to 0.6% volumetric fraction of palm fiber used in the mix, and beyond this percentage, the decrease in flexural strength is significant. This is due to formation of voids in the matrix, which causes the flexural strength to reduce. The comparison between no-palm fiber mix with 0.6% of palm fiber mix, leads to a conclusion that the flexural strength has increased by about 16.6%, when the palm fiber is included in the mix. The relation between compressive strength and flexural strength is shown in Figure 9. On the other hand, the results of flexural strength of specimens reinforced by steel bars indicate the same concept of using 0.6% of palm fiber as the optimum percentage of palm fiber, where the crushed brick lightweight concrete matrix can be enhanced using the low volume fraction of palm fiber (Thanon and Ramli [21]) . This advantage may be obtained because of the improvement that the fibers impart to the tensile strength (Kayali et al. [14]).

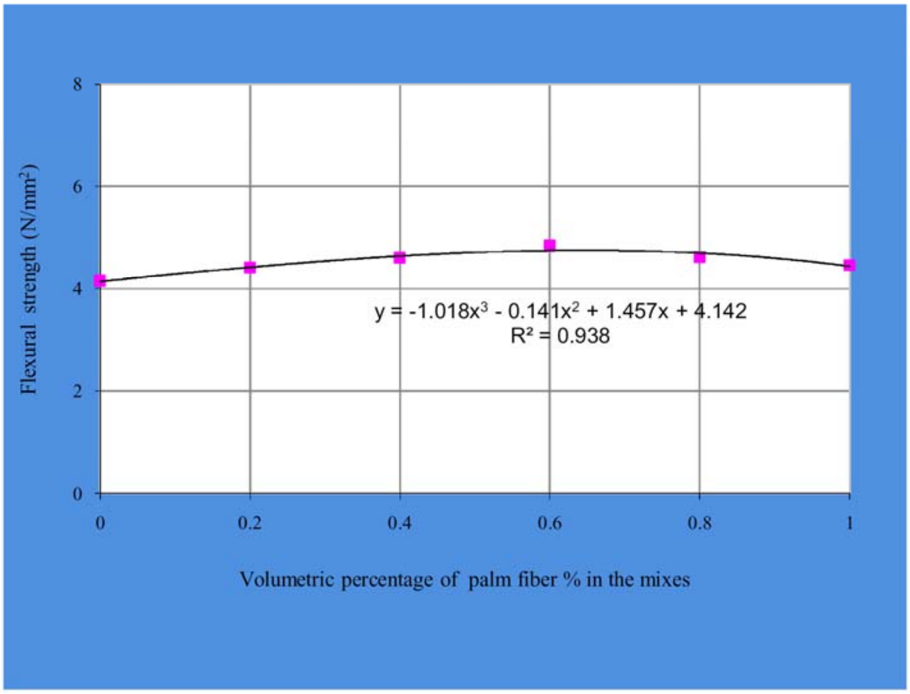

Figure 8. Relationship between volumetric percentage of palm fiber in lightweight crushed brick concrete mixes with flexural strength at 28 days.

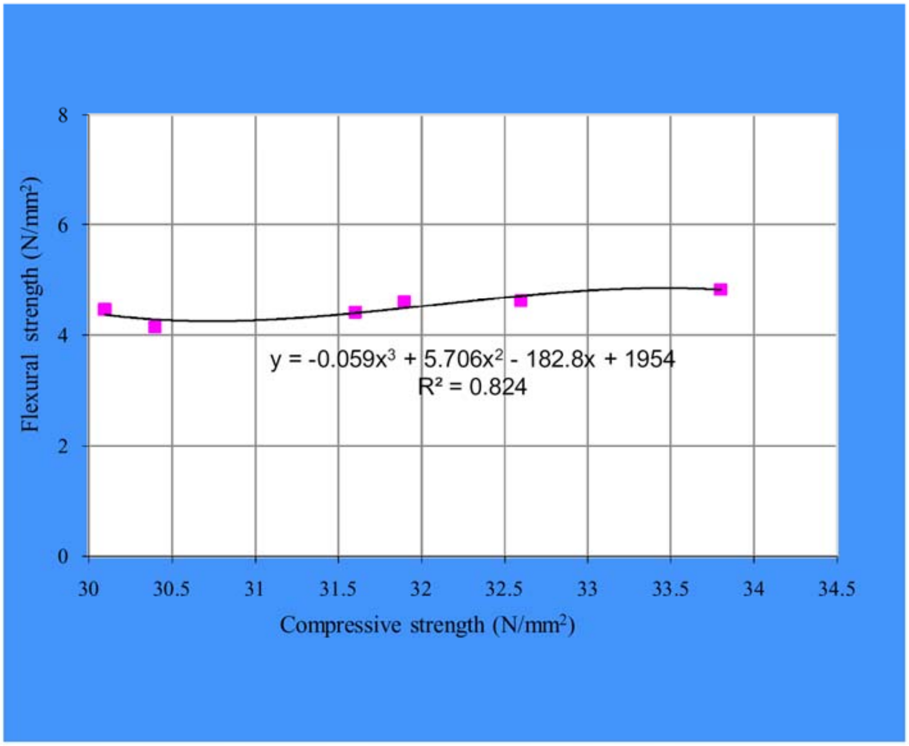

Figure 9. Relationship between compressive strength and flexural strength of lightweight crushed brick concrete mixes reinforced by palm fiber at 28 days.

5.6. Static modulus of elasticity (Ec)

The moduli of elasticity results for all mixes are presented in Table 7. The comparison between (CF0) with (CF3) indicates that the use of 0.6% of palm fiber leads to an increase in static modulus of elasticity. This is probably due to the optimization of this percentage of palm fiber to produce the higher bond strength behavior and thus a higher modulus of elasticity (Kayali et al. [15]).

6. Conclusion

This study was conducted to assess the proportioning of CLWA and FLWA on the properties of lightweight crushed brick concrete, and the effect of different percentages of palm fiber on the selected mix. The following conclusions were derived as follows.

1. The replacement of sand by FLWA for the production of structural lightweight concrete reduces the density of lightweight concrete without reduction of compressive strength. This is regarded as a significant economic contribution in the production of this type of concrete.

2. The incorporation of FLWA with sand improves the compressive strength as the voids between fine aggregate particles reduce, which leads to increase the compressive strength of the lightweight concrete mixes.

3. The inclusion of palm fiber reduces slightly the density and this is considered as promising results in the production of lightweight crushed brick concrete.

4. The use of 0.6% of palm fiber increases the compressive strength and flexural strength by about 11.2% and 16.6%, respectively.

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References

[1] ACI 211.2-92, American Concrete Institute, Farmington Hills, MI,(1994), Standard practice for selecting proportions for structural lightweight concrete, ACI Manual of Concrete Practice, Part 1: Materials and General Properties of Concrete, 1994. http://www.concrete.org

[2] ASTM C29, C94, C127, C128, C138, C143, C173, C330, and C567, Annual book of ASTM standard, Volume 04.02, ASTM International, West Conshohocken, PA. www.astm.org

[3] American Society of Testing Materials, Internal Curing Using Expanded Shale, Clay and Slate Lightweight Aggregate, Chapter 46-Lightweight Concrete and Aggregate, West Conshohocken, PA, 2006.

[4] C. Asasutjarit, J. J. Hirunlabh, J. Khedari, S. Charoenvai, B. Zeghmati and U. C. Shin, Development of coconut coir-based lightweight cement board, Construction and Building Materials 21 (2007), 277-288.

[5] M. A. Aziz, P. Paramasivam and S. L. Lee, Prospects for natural fiber reinforced concrete in construction, The International Journal of Cement Composite and Lightweight Concrete 2 (1981), 123-132.

[6] K. Bilba, M. A. Arsene and A. Ouensanga, Sugarcane bagasse fiber reinforced cement composites, Part I, Influence of the botanical components of bagasse on the setting of bagasse, Cement Concrete Compos. 25 (2003), 91-96.

[7] BS 1881, methods for determination of density of hardened concrete, British Standard, Part 114 (1983).

[8] BS 1881, methods for determination of compressive strength of concrete cubes, British Standard, Part 116 (1983).

[9] BS 1881, methods for determination of flexural strength, British Standard, Part 118 (1983).

[10] L. H. Do and N. T. Lien, Natural fiber concrete products, J. Ferrocement 25(25) (1995), 17-24.

[11] T. A. Holm and A. J. Valsangkar, Lightweight Soil Mechanics: Properties and Applications, Expanded Shale, Clay and Slate Institute, USA, 2001. http://www.escsi.org

[12] K. M. A. Hossain, Development of volcanic pumice based lightweight concrete, Magazine of Concrete Research 56(2) (2004), 99-109.

[13] K. M. A. Hossain, Blended cement and lightweight concrete using scoria: mix design, strength, durability and heat insulation characteristics, International Journal of Physical Sciences (IJPS) 1(1) (2006), 5-16.

[14] O. Kayali, M. N. Haque and B. Zhu, Drying shrinkage of fiber reinforced lightweight aggregate concrete containing fly ash, Cement & Concrete Research 29 (1999), 1835-1840.

[15] O. Kayali, M. N. Haque and B. Zhu, Some characteristics of high strength fiber reinforced lightweight aggregate concrete, Cement & Concrete Composites 25 (2003), 207-213.

[16] J. Khedari, S. Charoenvai and J. Hirunlabh, New insulating particleboards from durian peel and coconut coir, Building & Environment 38 (2003), 245-249.

[17] Y. Mohammadi, S. P. Singh and S. K. Kaushik, Properties of steel fibrous concrete containing mixed fibers in fresh and hardened state, Construction & Building Materials 22 (2008), 956-965.

[18] NAMCA, Concrete in Practice, CIP36-Structural Lightweight Concrete. http://www.nrmca.org/aboutconcrete/cips/36p.pdf

[19] A. M. Neville, Properties of Concrete, Fourth and Final Edition, 1995.

[20] K. Semple and D. Evans, Adverse effects of heartwood on the mechanical properties of wood-wool cement boards manufactured from radiate pinewood, Wood Fiber Sci. 32 (1999), 37-43.

[21] E. D. Thanon and M. Ramli, Study the effect of using palm fiber on the properties of high strength flowable mortar, CI Premier: 34th OWICs papers, Singapore 16-18 August (2009), 93-101.

[22] W. Thielemans and R. P. Wool, Butyrated kraft lignin as compatibilizing agent for natural fiber reinforced thermoset composites, Composites Part A: Applied Science and Manufacturing 35 (2004), 327-338.

[23] R. F. Toledo, K. Ghavami, G. L. England and K. Scrivener, Development of vegetable fiber-mortar composites of improved durability, Cement & Concrete Research 25(2) (2003), 169-279.

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