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Mechanical Properties Of Palm Oil Clinker Concrete

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Abstract— **Palm oil clinker is a by-product of palm oil industry which normally being dumped abundantly as waste which caused to the undesirable effects to our environment sustainability. This paper studied the mechanical properties of local palm oil clinker concrete including compressive strength, three point bending strength and tensile splitting test which is the most important parameters in engineering properties of concrete as the primary measurement to its suitability for the appliance for the structural use. Five series of palm oil clinker concrete with same mix proportioning were batched and tested. The series includes control mix, palm oil clinker as coarse aggregate, palm oil clinker as coarse and fine aggregate and addition of fly ash to the mix proportion. The mechanical properties of this study were conducted and measured accordance to the British Standard. The effects of another local waste material from coal combustion i.e., pulverized fly ash (pfa) which replace the cement content in mix proportion on mechanical properties of palm oil clinker concrete were compared and the mechanism were been analyzed. The results given by the palm oil clinker was found to be in good agreement with the structural use which been indicated by the structural concrete Code of Practice BS8110. Addition of pulverized fly ash as pozzolanic material produces more strong and durable concrete compared to palm oil clinker without fly ash.**

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I. INTRODUCTION

One of the major factor that affects the behavior and properties of a Lightweight Concrete is the aggregate itself. The strength, shape, size and gradation of the aggregate contribute directly to the strength of the lightweight concrete. Hence, many studies and research has been carried out to improve and refine on the aggregate itself. In many cases, natural aggregate has been substituted with artificial aggregate to provide that extra strength that natural aggregate are difficult to provide. Due the limitation and difficulties in finding strong natural aggregate in certain region, artificial aggregate has been used widely to replace the natural aggregates. Current technologies and discoveries has made it possible to create a strong artificial aggregate that out performs natural aggregates.

Malaysia, being one of the largest producer and manufacturer of palm oil products, generates large amount of palm oil by-products, which can be recycled into Palm Oil Clinker. If this palm oil clinker is put into good use, in this case as a main material in high performance concrete mix, then it will largely reduce the cost of high performance concrete. At the same time, it will also reduce the amount of waste generated by the palm oil industry thus achieving a global aim of sustainable development. Not only it reduces the waste, it also preserves the nature by eliminating the need to harvest natural aggregates from natural sources.

Pozzolans were commonly used in concrete technology to enhance the concrete properties. Silica dioxide, SiO_2 which the main constituents in pozzolans will react with calcium hydroxide, $Ca(OH)_2$ which is deleterious to concrete strength and product from process of hydration, $(C_3S + H_2O \xrightarrow[hydration]{} C-S-H + Ca(OH)_2)$ to produce more $C-S-H$ compound which contribute to its strength. The equilibrium equation of the pozzolanic reaction is given as $(Ca(OH)_2 + SiO_2 \rightarrow C-S-H$.

This paper reports the results of an investigation into the mechanical properties of palm oil clinker concrete. The influence of fly ash at 10% replacement upon the cement content on the concrete strength also been investigated. 10% replacement was selected as it gave the optimum reaction as reported by Neville. The target strength for palm oil clinker concrete was at least achieving compressive strength of 30 N/mm^2 so that it can be used as structural concrete members as prescribed in BS 8110.

II. MATERIALS AND EXPERIMENTAL PROCEDURES

Palm oil clinker as aggregate

The Palm Oil Clinker (POC) was taken from the palm oil mill factory from Dengkil. The factory is Sri Ulu Langat Palm Oil Mill. The by-product that is collected from inside the boiler is called clinker. The clinker looks like a porous stone which is gray in color. All the clinkers are prepared to be crushed into required size. Clinker with nominal size of 20mm is used as coarse aggregate and size below 4.75mm is used as fine aggregate. The clinkers were flaky and irregular shaped. The broken edges were rough and spiky.

The physical properties such as water adsorption, moisture content and bulk density are shown in Table 1. Palm oil clinker and conventional coarse aggregate, i.e., gravel used in saturated surface dry condition.

Table 1
Physical properties of fine POC and coarse POC

Physical properties	Fine	Crushed stone
Specific gravity (SSD condition)	2.17	2.60
Moisture content (%)	0.08	0.05
Water adsorption (%)	4.65	1.79
Bulk density (kg/m^3)	863.65	1815.23
Fineness Modulus	2.84	2.65

Other concrete mix components

River sand was used as fine aggregate which has a fineness modulus of 2.56. Fly ash and Malaysian Ordinary Portland Cement with specific gravity of 2.66 and 3.15 respectively was used as binders. Fly ash was taken from TNB Kapar in Selangor. Superplasticizers also been used as an admixtures for water-reducing agent.

Test samples

Basically, the test can be divided into 2 major part; one part by using palm oil clinker (POC) as both coarse and fine aggregate and latter only using POC as coarse aggregate while river sand as fine aggregate. There are five series of test been conducted, namely as shown in Table 2.

Table 2
Series of palm oil clinker concrete mix

No.	Series	Description
1	S1	control mix (conventional mix OPC)
2	S2	POC coarse aggregate and 100% OPC as binders
3	S3	POC coarse and fine aggregates –and 100% OPC as binders
4	S4	POC coarse aggregate and 90% OPC + 10% fly ash as binders
5	S5	POC coarse and fine aggregates and 90% OPC + 10% fly ash as binders

Control mix was designed using Department of Environmental (DOE Method) while lightweight series mixtures were design by using FIP Method which was designed as 35 N/mm^2. The water-cement ratio (w/c) was fixed at 0.55. As this mix falling under lightweight concrete, the cement content must be within 285 – 510 kg/m^3. Fly ash replaced the Ordinary Portland Cement (OPC) by 10%.

Table 3
Mix proportion of concrete samples

Series	Proportion by weight				
	Water	OPC	Fly ash	Fine aggregate	Coarse aggregate
S1	210	382	-	668	1090
S2	231	420	-	621 (sand)	729 (POC)
S3	231	420	-	621 (POC)	729 (POC)
S4	231	378	42	621 (sand)	729 (POC)
S5	231	378	42	621 (POC)	729 (POC)

The water content in this mix includes the water adsorption percentage by palm oil clinker. Because of it is porous in nature; palm oil clinker adsorbed a lot of water especially for series 3 and 5 which using palm oil clinker as fine aggregates. We know that higher water cement ratio will produce lower strength of concrete. However, low w/c ratio will reduce workability of the concrete and in worst case, hard in compaction and honeycombing will occur.

Hence, we must introduce water-reducing admixture called superplasticizers (sulfonated, naphthalene-formaldehyde condensate type) in the mixture so that it can compensate the water requirement to produce stronger and durable concrete. Its usage depends on water content in the mix design. For this samples, superplasticizers mix proportions was fixed at 1.60/100 kg of cement. As reported by Chen, the superplasticizer dosage went up to 1.75 litre per 100 kg binders, the one day strength of concrete decrease to a certain extent.

Table 4
Code of Practice for concrete testing

No	Type of testing	Code of Practice Used
1	Compressive strength	BS 1881: Part 115: 1986. *Specification for Compression Testing Machines for Concrete*
2	Flexural Test (3-point loading)	BS 1881: Part 118: 1983. *Method for Determination of Flexural Strength.*
3	Tensile Splitting Test	BS 1881: Part 117: 1983. Method for Determination of Tensile Splitting Strength.

All the mixes are done after series of trial mixes is conducted to establish the mix with optimum strength. For compressive test sample, it was cast into a 100mm x 100mm x 100mm cube. Flexural test sample were cast into a 100x100x500mm prism. Meanwhile, for tensile splitting test were cast into a 150mm diameter x 300mm length cylinder.

Testing

The physical properties of palm oil clinker, river sand, gravel, cement and fly ash were conducted for mix design data purposes. Properties of fresh concrete; i.e., workability were measured throughout all the series mixes. The fresh concrete properties are shown in Table 3.

Table 3
Fresh concrete properties

Series	Slump (mm)	Compaction factor
S1- Control mix	190	0.98
S2 – POC coarse + OPC	105	0.94
S3 – POC coarse & fine + OPC	85	0.92
S4 – POC coarse + FLY ASH	125	0.96
S5 – POC coarse & fine + FLY ASH	100	0.95

All the mechanical properties; compressive strength, flexural strength and tensile splitting were performed by using Universal Testing Machine located in Material Lab, Universiti Tun Hussein Onn Malaysia. All the samples were cured in water curing upon 24 hours casting.

Basically, there are 2 types of strength been conducted; first is strength due to compression load which is performed in compression concrete test and the latter case is tension test; which is performed by flexural test (direct tensile test) and tensile splitting test (indirect tensile stress). All the test procedures follow the code of practice as mentioned in Table 4. Compressive test, flexural test (modulus of rupture), and tensile Splitting Test is carried out on the 7th and 28th day upon casting.

III. Results and Discussion

Cube compressive strength

The compressive strength for palm oil clinker concrete series and control concrete are tabulated in the form of graphs as shown in Figure 1. Basically all series are showing almost the same patterns of development at 3rd, 7th and 28th days of testing. Control concrete gave the highest value of compressive strength. Compared with mixture of using 100% OPC, series with fly ash replacement gave better compressive strength. This is due to the help of pozzolanic reaction that produced more C-S-H which is a substantial compound that contributes to the strength of the concrete.

Series of using POC as coarse aggregate and natural sand gave better results than series using POC aggregates as coarse and fine aggregates. This is due to the fine aggregates which are higher specific surface of porous particles that contribute to the less strength. This, however can produced 33.76 N/mm^2 at 28 days which exceeding the concrete strength that can be used as structural concrete, 30 N/mm^2. Since this mixture using normal OPC, the concrete strength expected to increase after the 28th days due to the matrix strength.

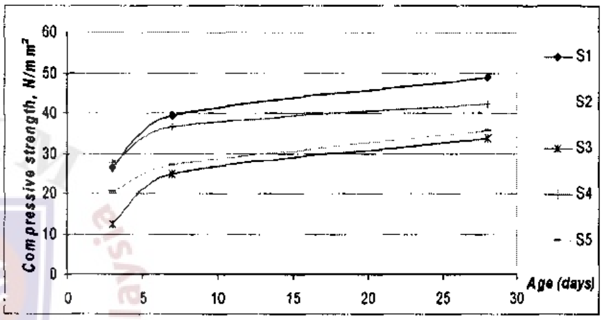

Figure 1: Development of compressive strength for all the series

The density of in saturated surface dry condition is shown in Table 4. Series using only coarse POC aggregates and natural sand (Series 2 and 4) gave around 2000 kg/m^3 and series using POC aggregates as coarse and fine aggregates (Series 3 and 5) gave around 1850 kg/m^3. As density of normal-weight concrete density is 2486 kg/m^3, there is a saving in the self-weight 19% and 26% respectively. This savings can produced lighter structures in design stage which will reduced the cost of construction as less dead load can be obtained.

The 7-day compressive strength for palm oil clinker series vary from 24 N/mm^2 (Series 3) to 37 N/mm^2 (series 4) and 28-days compressive strength ranging from 34 N/mm^2 (Series 3) to 42 N/mm^2 (series 4). Comparison with control concrete mix, palm oil clinker concrete series gave less strength from 13%-31% of compressive strength. The aggregates had in comparison with concrete, relatively high strength and their full potential strength was not used.

Table 4
Compressive strength development

Series	28^{th} days / 7^{th} days ratio	Relative less strength compared to control concrete	Density in SSD conditions (kg/m^3)
S1	1.24	-	2486
S2	1.22	16.67%	2018
S3	1.36	30.86%	1846
S4	1.15	13.43%	2026
S5	1.31	27.13%	1878

From the comparison above, it can be concluded that conventional mixes are still stronger than lightweight mixes series with POC. However, based on 30 N/mm^2 compressive strength criteria, the lightweight concrete using POC as an artificial lightweight aggregate has performed up to the par and has exceeded 30 N/mm^2 on the 28^{th} day test by achieving an average of 38 N/mm^2. This proves that the POC is satisfactory in its application as a substitute for coarse aggregate in the lightweight concrete. The cube compressive strength is satisfactory with respect to the 7^{th} and 28^{th} day strength.

Flexural Test

When concrete is subjected to bending, tensile and compressive stresses, and in many cases direct shearing stresses developed. The most common plain-concrete structure subjected to flexure is in highway pavement, and the strength of concrete for pavements is commonly evaluated by means of bending tests on beam specimens. The results of the flexural test are shown in Figure 2.

The tensile strength of palm oil clinker lightweight aggregates varies from 5.4 – 6.4 MPa as seen in Figure 2. The porosity characteristic of POC aggregates will reduce the flexural strength of POC concrete; this however will be offset by the geometry of the POC aggregates. The angular and sharp edges will increase the tensile strength of the aggregate. Although this effect cannot surpass the control concrete strength, this however will compensate the reduction of strength of the coarse aggregates.

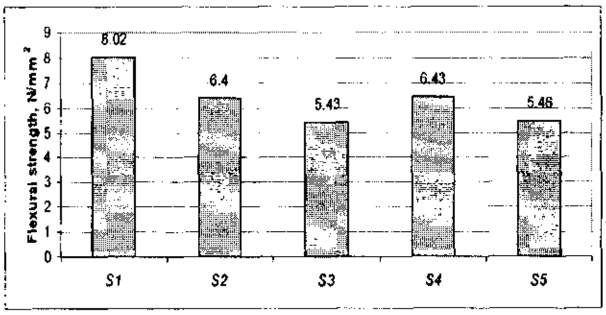

Figure 2: Flexural strength of the series taken.

From the results in Figure 2, series with POC lightweight produced lower flexural strength than concrete mix. The reduction of strength compared to control concrete ranging from 19.8% (series 4) to 32.3% (series 3). However, structurally the flexural strength can be enhanced by using reinforced bars commonly at the bottom zone of the concrete cross section that exposed to tensile cracks.

Tensile Splitting Test

All the series mixes were cast into cylinder mould for the tensile splitting test. Two specimens for each concrete were tested at 7 and 28 days. From the result obtained, control concrete has higher tensile splitting strengths than concrete with palm oil clinker aggregates. This is well understood that the POC aggregates having lower strength than natural aggregates. POC aggregates which are porous might get crushed through the process of mixing and compaction. As reported by Wu, the results of the splitting tensile tests show that the splitting tensile strength of concrete is influenced by the splitting tensile strength of aggregates to a small extent.

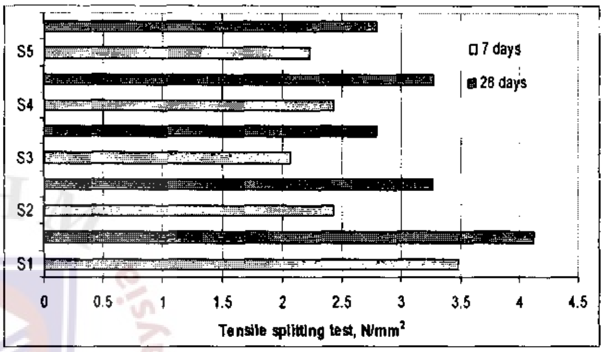

Figure 3: Development of tensile splitting tests all the series.

A range of 16% - 32% reduction in tensile splitting strength at 28-days was observed for concrete with POC aggregates compared with control concrete, as shown in Table 5. Findings by Zia who reports that at most 35% lower indirect tensile strength for lightweight concrete compared to control concrete.

Table 5
Tensile splitting test development

Series	28^{th} days / 7^{th} days ratio	Relative less strength compared to control concrete
S1	1.18	-
S2	1.34	21.07%
S3	1.28	32.45%
S4	1.34	20.82%
S5	1.25	16.36%

Compressive, flexural and tensile splitting strength of palm oil clinker series and control concrete are related to data in Figure 1 to Figure 3. From the graphs, flexural and tensile splitting strength can be estimated from known compressive strength. Therefore, it is important to determine the relationship between compressive, flexural and tensile splitting strength of concrete.

Table 6
Relationship of development of flexural and tensile strengths to compressive strength for all series

	Flexural strength to compressive strength		Tensile strength to compressive strength	
	7^{th} days	28^{th} days	7^{th} days	28^{th} days
S1	15%	17%	8%	9%
S2	14%	16%	7%	8%
S3	14%	16%	8%	8%
S4	14%	15%	7%	8%
S5	14%	15%	8%	8%

For palm oil clinker concrete, tensile splitting strength is only 7 -8% (7 days) and 8% (28 days) of the compressive strength. Meanwhile, the flexural strength is 14% (7 days) and between 15-16% (28 days) of its compressive strength. On the other hand, tensile splitting strength of control concrete is from 8% (7 days) to 9% (28 days) of its compressive strength.

From Gonnerman and Shuman, the flexural strength ranges from 11-23% of the compressive strength and the tensile strength ranges from 7-11% and average about 10% of the compressive strength. With proper design and research, palm oil clinker has great potential to be used in the construction industry in the future.

IV. Conclusions

The following conclusions can be drawn from this investigation:-

1. The compressive strength of palm oil clinker concrete series is lower than control concrete. This is attributed to the air content of palm oil clinker aggregates.
2. POC series with 10% fly ash replacement in cement content produce higher compressive and tensile strengths than POC series with 100% POC.
3. POC series with using as coarse aggregates only produces higher compressive and tensile strengths than POC series with using POC as both coarse and fine aggregates.
4. However, all the POC series can produce compressive strength more than 30 N/mm^2 to be used as structural members.

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