SHRINKAGE OF MALAYSIAN PALM OIL CLINKER CONCRETE

Mohd Hilton Ahmad, Lee Yee Loon, Nurazuwa Mohd Noor, Suraya Hani Adnan
Department of Structurals and Materials Engineering,
Faculty of Civil and Environmental Engineering,
Universiti Tun Hussein Onn Malaysia (UTHM),
86400 Parit Raja, Batu Pahat, Johor. Tel: 07-4537320 Fax: 07-4536070
Email: hilton@uthm.edu.my, nurazuwa@uthm.edu.my

ABSTRACT : Palm oil industry becomes one of the main Malaysian commodities as indicated in Ninth Malaysian Plan (RMK9). As Malaysian focus on biotechnology industry, it is expected that million tones of waste produced annually and treated as disposal waste. By recycle the waste, it is not only can save the disposal area but also can sustain green environment. Four series of mixture were identified including series of using palm oil clinker as coarse aggregates only, series combination of using palm oil clinker as coarse and fine aggregates as well as series using replacement of fly ash. All the series was compared with control mixture. As palm oil clinker is a lightweight and porous material, it tends to adsorbs water and gave significant effects to the concrete properties especially to its durability. This paper will discuss the drying shrinkage as one of the most important parameter on long-term properties of palm oil clinker concrete. It shows that series with palm oil clinker concrete gave the lowest rate of shrinkage compared to other series. However, due to adsorption characteristic of palm oil clinker, observation on shrinkage gave higher value compared to control concrete.

Keyword: Waste material, palm oil clinker, shrinkage, fly ash, cement replacement

1. INTRODUCTION

Malaysia currently developing towards bio-technology industry as indicated in Ninth Malaysian Plan (RMK9). Under this plan, one of the main Government's agenda is focusing into generating huge amounts of agriculture product to be exported overseas. One the main commodities been listed is palm oil industry. It is expected that the growth of palm oil productions will be increased tremendously. As the production of palm oil increased, by-product from this industry which normally be treated as disposal waste will be increased as well. Palm oil clinker is the by-product from burning of fibers and husks inside the boiler under very high temperature in order to generate the steam engine for oil extracting process.

Shrinkage strain occurs due to volumetric change even when it is free from externally imposed stress and temperature changes which is caused by loss of water by evaporation, hydration of cement and also by carbonation. In addition to deformation caused by the applied stress, volume changes due to shrinkage and temperature variation are considerable important because in practice these movements are usually partly or wholly restrained, and therefore they induce stress. Drying shrinkage is not completely reversible process but alternate wetting and drying causes expansion and contraction of concrete. It is generally attributed due to the relative humidity of the air surrounding the concrete, the surface area from which moisture can be lost relative to the volume of concrete and on the mix proportions; it is increased slightly by carbonation and self-desiccation and reduced by prolonged curing.

The disadvantage associated with the use of neat Ordinary Portland Cement (OPC) concrete is cracking due to drying shrinkage. The drying shrinkage of concrete is directly influenced by the amount and the quality of the cement paste present. It increases with an increase in the cement paste-to-aggregate ratio in the concrete mixture, and also increases with the water content of the paste. Puzzolana finds its chief application where the reduction effected in the heat of hydration is of great importance and the slower gain in strength is not of much consequence, i.e. where mass concreting is to be done.

In this paper, palm oil clinker which is a by-product from palm oil industry be used as conventional aggregate replacement in concrete mixture. Besides for sustaining green environment due to using recyclable materials, it was chosen because it has light density with specific gravity of 2.17 compared to conventional aggregates 2.6. The study of shrinkage characteristic will shows the concrete performance for the long-tern durations which exhibits the overall performance of palm oil clinker lightweight concrete. This paper will discuss the performance of palm oil clinker aggregate size to the drying shrinkage. Since there many other factors that influence the study of shrinkage, the variable undertaken for series undertaken will focus upon the size of the aggregate used and using palm oil clinker aggregates as fine aggregates compared to conventional river sand while other parameters done assume constant.

By using recycle materials as aggregate and fly ash as pozzolans, the most beneficial potential for the use of industrial by-product is the environmental values. This efforts will not only benefits to the government in reduction of providing land for disposal, but also increase the economy growth in various sectors especially amongst construction industry. By replacing certain amounts of OPC will significantly reducing the dependent on its large amounts; thus emission of CO_2 or green house gases will be reduced as well.

2. PREDICTION ON SHRINKAGE

A method for determination for determination of short-term shrinkage is prescribed in BS 1881: Part5: 1970 which states that the specimens are dried for a specified period under prescribed conditions of temperature and humidity. The shrinkage occurring under these conditions is about the same as that after a long exposure to air with a relative humidity of approximately 65 percent. The American test method is prescribed by ASTM C 157-93; the air movement past the test specimens is carefully controlled and the relative humidity is maintained at 50 percent.

Many code of practices of which CEB is typical presents the effects of aggregates size used by showing the different rates of shrinkage occurs. An estimate of the shrinkage of symmetrically reinforced concrete sections may be obtained from equation:

$$\frac{\varepsilon_{sh}}{1+K\rho} \tag{1}$$

where ε_{sh} is the shrinkage of the plain concrete

ρ is the area of steel relative to that of the concrete

K is a coefficient, taken as 25 for internal exposure and as 15 for external exposure

According to ACI 209R-92, the development of shrinkage with time follows the equation:

$$S_t = (t/(35+t)*S_{ult}$$

(2)

where S_t =shrinkage after t days since the end of 7-days moist curing

S_{ult} =ultimate shrinkage

t = time in days since the end of moist curing

Prediction of the development of shrinkage by the above equation is subject to considerable variability, but the equation can be used to estimate ultimate shrinkage of a wide range of moist-cured concretes. It can be seen that one-half of the ultimate shrinkage is expected to occur after 35 days drying.

ACI 209-92 gives a general expression for the prediction of shrinkage by modifying a standard value by a number of coefficients which allow for various factors. The error involved in such an approach must be to be large. Various expressions for shrinkage are discussed by Neville et al. These expressions can be used to estimate long-term shrinkage from short-term tests on the actual concrete. Such tests are necessary for a reasonably accurate prediction of shrinkage.

3. SPECIMEN PREPARATION AND TESTING

3.1 Palm oil clinker as aggregates

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.


Figure 1: Lightweight Palm oil clinker obtained from palm oil mill (left)
Pile of crushed palm oil clinker aggregates (right)

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 POC and conventional aggregates

Physical properties	Palm oil clinker	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	1651.76
Fineness Modulus	2.84 (fine POC)	2.65 (river sand)
Aggregate Crushing Value (%)	18.88	-
Aggregate Impact Value (%)	38.6	-

3.2 Other concrete mix components

Some series using local and non-reactive river sand was used as fine aggregate. Its physical properties were as follows: compacted bulk density, 2680 kg/m^3, loose bulk density, 2550 kg/m^3, water adsorption, 1.5%; specific gravity, 2.65 moisture content 0.05% and fineness modulus of 2.6 which is in moderate particle sizes.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.

3.3 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 3.

Table 3: Series of palm oil clinker concrete mix

No.	Series	Description
1	S1	control mix (conventional mix OPC)
2	S2	10 mm POC as coarse aggregates and river sand as fine aggregates + 90% OPC + 10% fly ash as binders
3	S3	20 mm POC as coarse aggregates and river sand as fine aggregates + 90% OPC + 10% fly ash as binders
4	S4	10 mm POC as both coarse and fine aggregates + 90% OPC + 10% fly ash as binders
5	S5	20 mm POC as both coarse and fine aggregates + 90% OPC + 10% fly ash as binders

For this project the mix design to design the concrete mix is using the DOE (British) Mix Design Method. The method uses the relationship between water-cement ration and compressive strength of concrete depending on the type of cement and the type of aggregate used. This method gives the mix proportions in terms of quantities of materials per unit volume of concrete. For lightweight concrete design mixture, advanced DOE Method was used based on specific gravity obtained.. The water-binders 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%. All palm oil clinker series used mix proportion of 1:1.48:1.74 and control concrete of 1:1.75:2.85.

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.

The water-reducing property of fly ash can be advantageously used for achieving a considerable reduction in the drying shrinkage of concrete mixtures. Water-reducing admixture called superplasticizers (sulfonated, naphthalene-formaldehyde condensate type) was added in the mixture so that it might reduce the shrinkage besides to 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.

All the mixes are done after few series of trial mixes is conducted to establish the mix with optimum strength.

3.4 Testing

It is expressed as the reduction in volume, i.e. volumetric strain, is equal to 3 times the linear contraction, and in practice we measure shrinkage simply as a linear strain and the units are mm per mm usually expressed in 10^{-6}. The test is carried out by using 100 mm x 100 mm x 500 mm prisms specimens. Three identical test specimens were used for each series specified earlier. Beside shrinkage measurement, weight loss of the specimens was also recorded including temperature and relative humidity of the surrounding environment. The specimens were stored inside the lab (internal exposure) so that the changes in the humidity were insignificant. Drying shrinkage is discussed in BS8110: Part 2, section 7.4.

Twenty four hours after casting, the specimens were stripped and initial readings were taken; both sets of specimen were water cured at 27 ± 1˚C for 28 days respectively. After water cured for 28 day, subsequence reading was taken and the specimens were stored in a controlled environment of 25 ± 2˚C and 50 ± 5% room humidity. Stainless steel stud were fixed onto the faces of the specimen using Epoxy adhesive resin. There were two studs on each face which is the Demountable Mechanical Gauge (DEMEC) point separated at a distance of approximately 200 mm along the centre axis. The measurements were taken by using the demountable DEMEC Mechanical Strain gauges which is a simple dial gauge mechanism incorporating a standard gauges length of 200 mm. Six readings of shrinkage strains were taken from each specimen and were averaged to determine the shrinkage strain. Measurements were taken at the age of 1, 3, 7, 14, 28, 96, 270, and 365 days. Figure 1(a) and 1(b) shows the equipment of strain gauge and shrinkage specimens with DEMEC points on them.

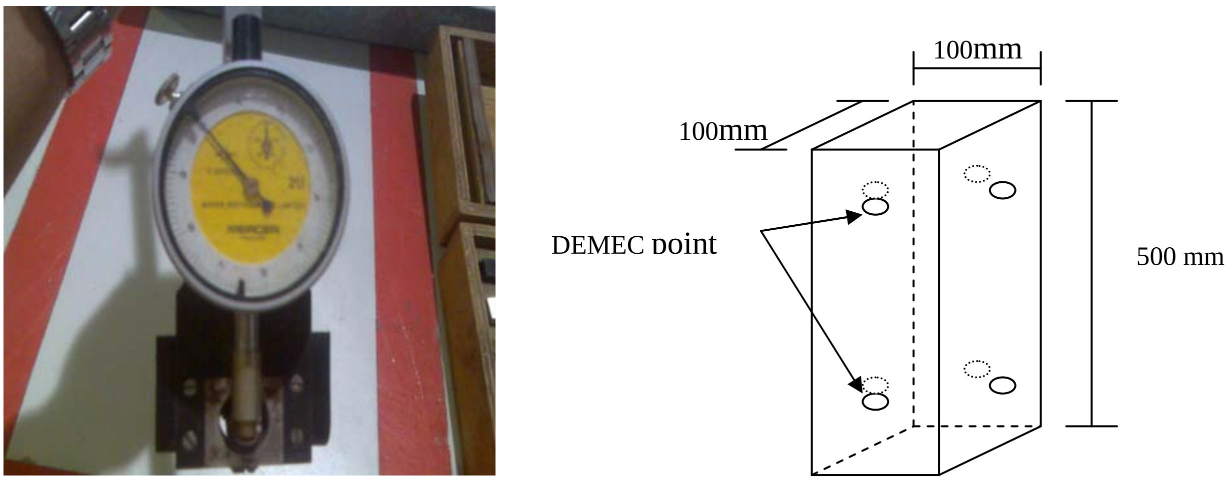

Figure 1: (a) DEMEC Mechanical Strain Gauge (b) Prism with DEMEC points at four sides

4. RESULTS AND DISCUSSIONS

There are many parameters that effects the drying shrinkage in hardened concrete; but however the most important factor for lightweight concrete is exerted by the aggregates itself which restrains the amount of shrinkage of the cement paste that can be actually realized in the concrete as reported by [8-9]. The development on the performance of all series conducted this study on shrinkage strain with drying period to 365 days under initial water curing condition of 28 days which is shown in Figure 2. Theoretically, for a prolonged moist cuing; 28 days for instance, the strength and elastic modulus of the binding matrix in hardened concrete increased gradually. McGovern [10] reported that concretes wet cured for longer durations would have less shrinkage due to drying and autogenously effects than had less water cured.

From all the series undertaken, Series 4 shows highest value shrinkage, followed by Series 5, Series 3 and Series 1. Aggregates with a low modulus may cause to higher shrinkage compared to normal concrete and this should taken seriously for estimating drying shrinkage for design purposes. From table 1, we can observe the higher value of crushing aggregate value which directly indicates that the low modulus, low stiffness and high compressibility of palm oil clinker aggregates gave low restrains upon to the shrinkage process. Compared with control concrete, we can see that all lightweight palm oil clinker concrete which represents by Series 2 until Series 5 shows less resistance to the shrinkage process especially at early ages. However, there is no significance difference in shrinkage rates between palm oil clinker concrete and control concrete at later ages.

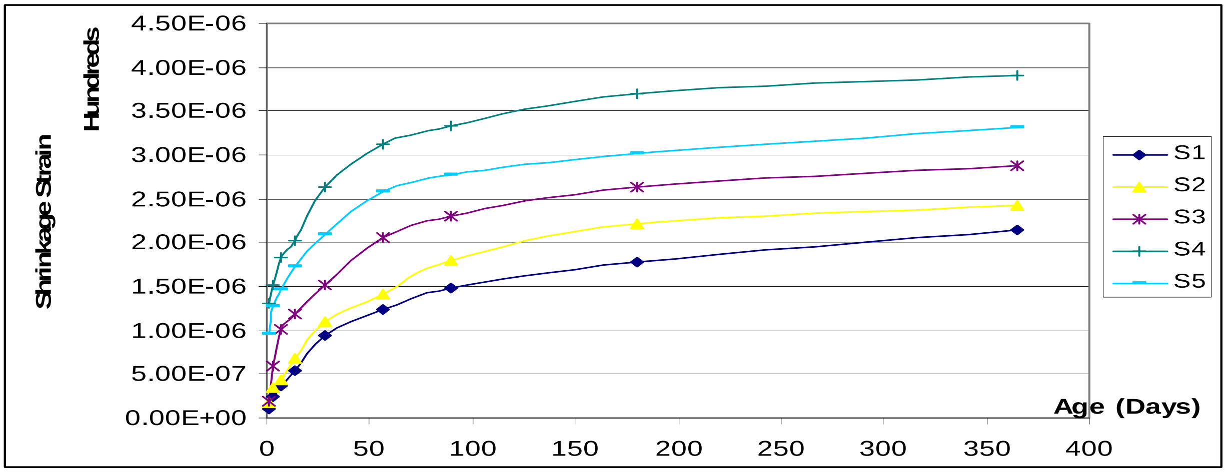

Figure 2: Drying shrinkage of lightweight palm oil clinker aggregate concrete and control concrete with time under 28-days of initial water curing conditions.

Another parameter that can be compared in this study is the size of the lightweight palm oil clinker aggregates that been employed. As seen in Table 4, the magnitude of drying shrinkage of palm oil clinker concrete increases with the increment size of the lightweight aggregates and is comparatively greater than control concrete by a range of 25-85%. Series 2 and Series 4 using 10 mm size of palm oil clinker compared to Series 3 and Series 5 using bigger size which is 20 mm. From the figure shown, it was significantly shown that Series using 10 mm exhibit higher value of shrinkage than series of using size 20 mm.

As the size of lightweight palm oil clinker aggregates used as coarse aggregates decreases, it will increase the surface area and the porous void of aggregates. This will promotes higher adsorption of water from the capillary action therefore the free water content increased in the air-trapped voids within the concrete matrixes will be increased as well. Therefore, the larger amount of free water molecular will be released when exposed. In concrete production, it is important to produce concrete that is denser which means that there is none or small existence of voids. The existence of voids or porous structures will enhance the water adsorption capacity.

On the other hand, series using palm oil clinker aggregates as both coarse and fine aggregate produces higher shrinkage than series using palm oil clinker as coarse aggregates only mixes with normal river sand. This due to the higher porosity of the lightweight aggregates; hence higher water adsorption capacity produced and tend to give higher shrinkage. Compared to the parameter studied earlier, the coarse aggregates might has less surface area compared to fine aggregates which has large surface area exposed for water adsorption. The fine aggregates has much porous in aggregates structures, therefore exhibits air-trapped voids that contains water which be released and shrinks the concrete members. However, factor for the size of palm oil clinker used is not so significance compared to using palm oil clinker as fine aggregates which produces higher value of shrinkage.

Table 4 Drying shrinkage of palm oil clinker concrete series and control concrete under 28 days initial water curing days.

Series	Drying shrinkage at 365 days (ε_{sh})
S1	214×10^{-6}
S2	390×10^{-6}
S3	332×10^{-6}
S4	243×10^{-6}
S5	287×10^{-6}

Besides above parameters, the length of drying period and the humidity of the surrounding air also are the factors that influence the shrinkage. The shrinkage rate is reduced gradually with elapsed time for all series. The shrinkage rates of lightweight palm oil clinker concrete and the control concrete are quite different at earlier ages. In this experiment, we find that the most critical shrinkage value is within the first 28 days. Here, we can see that the rate of shrinkage risen rapidly. Within these days, a linear line of the graph is shown. Based on the graph shown, after 28 days, the values of shrinkage have a smaller shrinkage rate and beyond 90 days, the shrinkage values tend to have a constant value. In this experiment, all samples are stored in a control room and therefore the relative humidity is assumed to be constant. However, theoretically, the rate of shrinkage is lower at higher values of relative humidity.

5. CONCLUSIONS

After the entire test been done to determine the shrinkage of palm oil clinker concrete, the following conclusions can be drawn from the investigation;

1. Due to low modulus of palm oil clinker concrete due to its porosity, generally palm oil clinker series produces high shrinkage than conventional concrete.
2. The shrinkage for bigger aggregates size used exhibits lower value of shrinkage compared to smaller size of aggregates.
3. The shrinkage rates of Palm oil clinker concrete are greater than control concrete at earlier ages and shrinkage strains of palm oil clinker series was lower than that of the control concrete.
4. Palm oil clinker concrete using palm oil clinker aggregates as both coarse and fine aggregates perform less resistance of shrinkage compared to palm oil clinker concrete using only palm oil clinker as coarse aggregate and conventional river sand as fine aggregates.

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REFERENCES

[1] A. M. Neville. 1995. *Properties of Concrete – Fourth Edition*. **Longman.**
[2] BS 1881: Part 5: 1970, *"Methods of testing hardened concrete for other than strength"*.
[3] BS 1881: Part 206: 1986, "*Recommendations for Determination of Strain in Concrete*".
[4] BS 812: Part 120: 1989, *"Method for Testing and Classifying Drying Shrinkage of Aggregates in Concrete"*.
[5] Design, New Concrete Materials, Vol. 1, Surrey University Press, 1983, pp. 41-69.
[6] CEB-FIP. Diagnosis and assessment of concrete structures – State of the art report, CEB Bulletin 1989; 192:83-5.
[7] FIP Manual of Lightweight of Lightweight Aggregate Concrete: Second Edition. Surrey University Press 1983
[8] Chen, Lianrong (Ian) and Ng, Hon Song. 997 High Performance Concrete and its Strength Development 5^{th} International Conference on Concrete Engineering and Technology pp. 47-56.
[9] Li Jianyong, Yao Yan. 2001 "A Study on creep and drying shrinkage of high performance concrete", Cement and Concrete Research Vol. 31 pp. 1203-1206.
[10] McGovern M. Design and control of concrete mixtures. 14^{th} ed. Berlin: Portland Cement Association; 2002. March