FLEXURAL BEHAVIOR OF LIGHTWEIGHT OIL PALM SHELLS CONCRETE SLAB REINFORCED WITH GEOGRID

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ABSTRACT

This paper aims to study the flexural strength and deflection behavior of concrete slab casted with oil palm shells (OPS) as aggregates and reinforced with geogrid. Effects of oil palm shells content and amount of geogrid layers in concrete slab towards the enhancement of flexural strength and deflection were monitored. Data from test results shows that increment in oil palm shells content will reduce the flexural strength of slab while increment in amount of geogrid can increase the flexural strength. Both materials portray their potential as replacement for granite aggregates and steel reinforcement. Slab samples casted manage to fulfill criteria of lightweight concrete but fail to achieve high strength. Slab casted portrays similar properties and behavior as conventional steel-reinforced concrete with ductility and strain hardening. By comparing to design requirement for residential floor based on British Standard, the slab samples show adequate capacity to cater for both ultimate limit state and serviceability limit, hence can be adopted in construction of residential building.

Keywords: Flexural Behavior, Lightweight Oil Palm Shells, Geogrid Reinforcement.

1- Introduction

Oil palm shell (OPS) as one of the main agriculture wastes has been researched on to replace aggregate in lightweight concrete (LWC). Oil palm shell which has a density much lower than the normal aggregate contributes to the lightweight characteristic of the lightweight concrete. Nevertheless, characteristics of oil palm shell vary a lot from normal aggregate which lead to varying degrees to the lightweight concrete produced. Hence, many aspects regarding the properties of oil palm shell have to be taken into consideration and studied to bring out its potential as a substitute of aggregate in lightweight concrete. In the past researches, oil palm shell has been used to replace aggregate to produce lightweight concrete, however, most products were low in strength and hence are not implemented in structural purposes which require high strength concrete. These low strength lightweight concrete are dominantly used for non-structural purposes only.

In a lot of construction cases nowadays, the density of the concrete plays an important parameter and is sometimes more important than the strength, especially in the case of super high rise building, larger sized and larger span concrete structures. There are obvious considerable advantages in reducing the density of concrete by using lightweight concrete. Self weight of concrete takes up a very huge proportion of total dead load on the structures; hence, by using lightweight concrete to cast structure components such as slabs, there will be a great reduction in total dead load imposed. A reduction in density of concrete for the same strength level can allow a saving in dead load for structural design and foundation. This can lower the budget of construction.

When researches had been resumed to increase the strength of OPS lightweight concrete to create mix design with high strength, it became an ideal alternative as the major construction material. However, due to the problems surfaced such as low flexural strength, it was prevented to be used in concreting purposes, especially in structures concreting such as slab or beam. Thus, further researches and investigations are required to study the behavior of flexural or deflection of structures using OPS lightweight concrete so that it can be properly modified to replace normal concreting in structural components. Traditionally, steel or BRC have been the most common choice as reinforcement in slabs. Researches had been carried out to find other options to serve as replacements as slab reinforcement. Materials such as steel fiber or fiber reinforced polymer (FRP) reinforcing bars had been investigated as potential replacement for slab reinforcement.

In this research work, geogrids which are typically used as reinforcement in soil slopes or foundations will be analyze as reinforcement in OPS lightweight concrete slab. Prior to this work, the optimum mix design of lightweight concrete using OPS as aggregate was developed to obtain high strength properties of as minimum as 30MPa with saturated surface dry density lower than 2000kg/m3. By using the selected mix design to produce high strength lightweight concrete, a slab sample will be constructed with geogrid as the slab reinforcement. The flexural capacity and deflection behavior of the oil palm shell concrete slab reinforced with geogrid will be determined and monitored through laboratory testing. Structural behavior is tested for future implementation in construction industry which creates another option in purposes of structural construction, using lightweight concrete.

One of the main reasons of this study is to provide an option of cost saving construction for structural components. Structures such as slabs and beams require higher strength concrete than normal concreting. High strength lightweight concrete that fulfils the requirements of structural behavior will be the ideal alternative in the future of a cost saving concreting. In this modern era, due to high demand in development, costs of raw materials have been increasing continuously. Increasing cost of raw materials leads to escalating price of construction products. Therefore, by utilizing agriculture wastes such as oil palm shell as raw material is considered the best solution for this matter. Agriculture wastes that have no value in replacement of the original construction raw materials will cut down the budget and cost of construction by a great deal. Rather than disposing oil palm shell as wastes, utilize it as part of the construction materials can convert its zero-value-status into beneficial rank to cut down the cost of construction.

The main objective of this study is to investigate the flexural behavior including deflection of high strength lightweight oil palm shell (OPS) concrete slab with geogrid as reinforcement.

2- Background

2.1- *Oil Palm Shell (OPS) as Aggregates*

Being the world's main producer of oil palm, Malaysia is well noted for her oil palm agricultural industry. Due to the large amount of oil palm shells produced, researches were conducted on the utilization of the waste materials in construction industry. Since the development of lightweight concrete, the demand over lightweight concrete has been high in replacing normal concrete, especially in structural components. Lightweight concrete which is generally light in weight and density can contribute to the reduction in dead load of a building. In many ways to produce lightweight concrete, using lightweight aggregates is one of them.

Oil palm shell (OPS) is the hard endocarp that surrounds the palm kernel [1]. Oil palm shells are naturally sized, hard and light in weight than conventional coarse aggregates. Due to the stiff surfaces of oil palm shell organic origin, they will not contaminate or leach to produce toxic substances once they bound in the concrete matrix [2]. *Hence oil palm shells are the perfect substitution as aggregates in lightweight concrete casting*. The light characteristic of oil palm shells as aggregates contributes to the lightness of OPS lightweight concrete. From the product of integration of oil palm shells as aggregates in lightweight concrete, a model low-cost house of 58.68m2 areas was built in 2003 using OPS hollow blocks for walls and OPS concrete for footings, lintels and beams, which is performing well and has no structural problems at all [3]. OPS concrete can replace concrete in all its normal usage especially when the oil palm shells are available in plenty as solid waste materials, it can be used as road pavement, kerb-stones, concrete drains and flooring slabs [4]. However, for OPS concrete to be accepted in structural application, further investigations need to be conducted so that OPS lightweight concrete can be implemented in a wider range including condominiums, shop lots, high rise buildings and many more.

2.2- *Geogrids as Concrete Reinforcement*

Geogrids are made of high-modulus polymer material such as polypropylene and polyethylene. The main function of geogrids is to serve as reinforcement. As reinforcing elements, geogrids have been mainly used in earthen structures such as pavements, embankments, slopes and retaining walls. Geogrids are made of relatively netlike materials with openings called apertures which are large enough to allow for soil strike-through from one side of the geogrid to the other, as well as allowing interlocking with the surrounding soil or rock to perform the function as reinforcement or segregation, or both. Geogrids are manufactured in a way that the grids are greater than 50 percent of the total area. They develop reinforcing strength at low strain levels, such as 2 percent [5].

2.3- *Flexural Behavior*

Flexural behavior is the characteristic of a slender structural element subjected to an external load applied perpendicularly to a longitudinal axis of the element. Flexural strength is the mechanical parameter to define a material's ability to resist deformation under load. Flexural behavior of a structural component can be monitored through three point flexural test where load is applied to the element until it bends and fractures. The test gives results in terms of flexural modulus of elasticity, also known as flexural strength. Apart from that, during three point flexural test, deflection of the test element can also be determined to monitor how much the element can bend and deflect before failure. It is necessary to determine the flexural strength as part of the design of concrete mixtures to check compliance with established specifications or to provide information necessary to the design of an engineering structure [7].

Based on the previous researches, some investigations have been carried out to monitor the flexural behavior of oil palm shell lightweight concrete. As an on-going research project to investigate the structural performance of OPS lightweight concrete, a footbridge of 125 mm thick and 2.0 m span was constructed in May 2001 has been performing well, even when subjected to two-wheeler traffic [3]. However, most laboratory tests were done to determine behaviors in flexure on beams rather than slabs of OPS lightweight concrete. Besides, there has been no flexural test carried out on OPS lightweight concrete slab with geogrids as reinforcement, although geogrid is expected to enhance extra flexural strength in slab.

2.4- *Deflection*

Deflection is the degree to which the structural element is displaced under a load. The deflection of a member under a load can be calculated by integrating the function that mathematically describes the slope of the member under that load. Deflection is one of the main criteria for the serviceability requirements of a structural member. [6] In normal concrete case, deflection is directly related to the slope of the deflected shape of the member under that load. However, in the case of OPS concrete, the condition might be different since oil palm shell is introduced as aggregate, hence, integration of characteristics of oil palm shell may occur and affect the deflection behavior of concrete.

Laboratory tests have been conducted over the years to investigate the deflection of concrete components. Even so, same as flexural test, most researches were carried out on beams and little on slabs. Besides, deflection behavior on oil palm shell high strength lightweight concrete is rarely researched on and is very limited. Tests on deflection of concrete with geogrids as reinforcement were carried out; however, none has been conducted with geogrid reinforced in OPS lightweight concrete.

3- Methodology

In this research, oil palm shell (OPS) is adopted in replacing conventional aggregates in casting of concrete. Fully replacement of oil palm shells is adopted and hence, no conventional aggregates will be needed in this laboratory testing. Besides, geogrids will be used as substitution of concrete reinforcement by replacing steel bars. Both oil palm shells and geogrids will be the main materials in this project in casting of slabs which will be tested by conducting laboratory experiments to determine the flexural behavior as well as its deflection.

Since the main purpose is to determine the effects of oil palm shells as aggregates and geogrids as reinforcement towards the flexural strength and deflection of the slab by using the mix design to produce high strength lightweight concrete, percentage of oil palm shells and amount of geogrids enhanced in concrete will be set as the affecting parameters while others will be held constant to compare the data obtained. During the laboratory testing, different samples of slabs with varying percentage of the parameters determined will undergo flexural test to determine the deflections as well as flexural strengths. Meanwhile, other parameters that may affect the results such as percentage of silica fumes, types of geogrids used, water to cement ratio and size of slabs will be held constant and remain the same in all slabs samples so that the effects of solely the percentage of oil palm shells and amount of applied geogrids can be determined. All materials needed in this project include geogrids as concrete reinforcement, oil palm shells as aggregates, Ordinary Portland Cement (OPC), sand, water for mixing and curing, silica fumes and super plasticizer as chemical admixture. Other materials such as woods, nails and grease will be needed to construct formworks for the casting of the OPS lightweight concrete slabs.

Along the process of the project of mixing, casting and testing of concrete, apart from the main test which is the flexural test to determine the flexural behavior and deflection of oil palm shell lightweight concrete, there are other laboratory tests as well that are needed to be carried out to ensure that the concrete mixed or casted falls within the standard guidelines of ASTM (American Society of Testing of Materials) or BS (British Standards). These experimental tests can be divided into three categories which consist of aggregate tests, fresh concrete test and hardened concrete tests. These different tests were carried out in different stages of the progress to determine certain criteria that needs to be fulfilled as part of the testing standards.

The main and significant test in this research is the flexural test which falls in the category of hardened concrete tests. The method of this flexural test is three point load test where the slabs will be supported at both ends while load will be applied at the midpoint until failure. From the test, the maximum flexural strengths of the slabs can be determined. During the test, deflections of the slabs will be monitored as well by using dial gauge installed and enhanced with the testing machine. The machine used for flexural test is 30kN Self Reaction Test Frame available in the laboratory.

Mix design of oil palm shells high strength lightweight concrete were determined through a series of testing of concrete compressive strength. In the different mix designs, varying parameters of percentage of oil palm shells and percentage of silica fumes were adopted in casting to determine the compressive strengths of the concrete respectively to find the optimum mix design. Alterations on water content were made as well to determine the suitable water content. From the compressive strengths, mix design with parameters that fulfill the criteria as lightweight concrete with the highest compressive strength was selected as the mix design for flexural test where concrete density below 2000kg/m^3 is categorized as lightweight concrete. The mix design finally settles with mix that achieved averagely 19.53 MPa in 7 days, which is estimated to be approximately 27.9 MPa in full strength.

4- Results and Discussion

4.1- *Finalized Mix Design*

From the trial samples to develop a mix design that fulfills the requirement of lightweight high strength OPS concrete, it can be noticed that it is hard to balance the need in compliance to lightweight properties of concrete and at the same time achieving high strength of above 30 MPa. The mix designs that successfully achieved high strength properties failed to fall within the requirement of lightweight, while some are at the edge of becoming non-lightweight. In order to alter the density, concrete strength is compromised instead.

Due to time constraint, a mix design of OPS concrete needed to be finalized for casting of slab, the finalized mix design is as shown below:

Minimum OPS Content = 0.45
Water/ Cement Ratio = 0.4
Sand Content = 1.5
Silica Fumes Percentage = 5%
Super Plasticizer Percentage = 2%

This mix design is based on alteration of OPS content from 0.4 to 0.45. With OPS content of 0.4, densities of the product are at the edge of becoming non-lightweight with values very close to 2000 kg/m3. Hence, to make sure concrete casted achieve definite lightweight properties, minimum OPS content is slightly increased to 0.45, which successfully yields average density of 1972.84 kg/m3. Nevertheless, by increasing OPS content, concrete strength is compromised and reduced to average value of only 27.69 MPa in age 28 days, which fails to fulfill the requirement of high strength of minimum 30 MPa. Although concrete strength fails to chart within high strength range, the value exceeds the minimum requirement of concrete grade in industry use, which is 25 MPa, thus making the mix design eligible to be adopted for slab casting, albeit not for purpose of high loading. With 0.45 serving as the minimum requirement of OPS content, the OPS varying content among slab samples has set to be 0.45, 0.5 and 0.6 to test the effect of OPS towards flexural strength of slab.

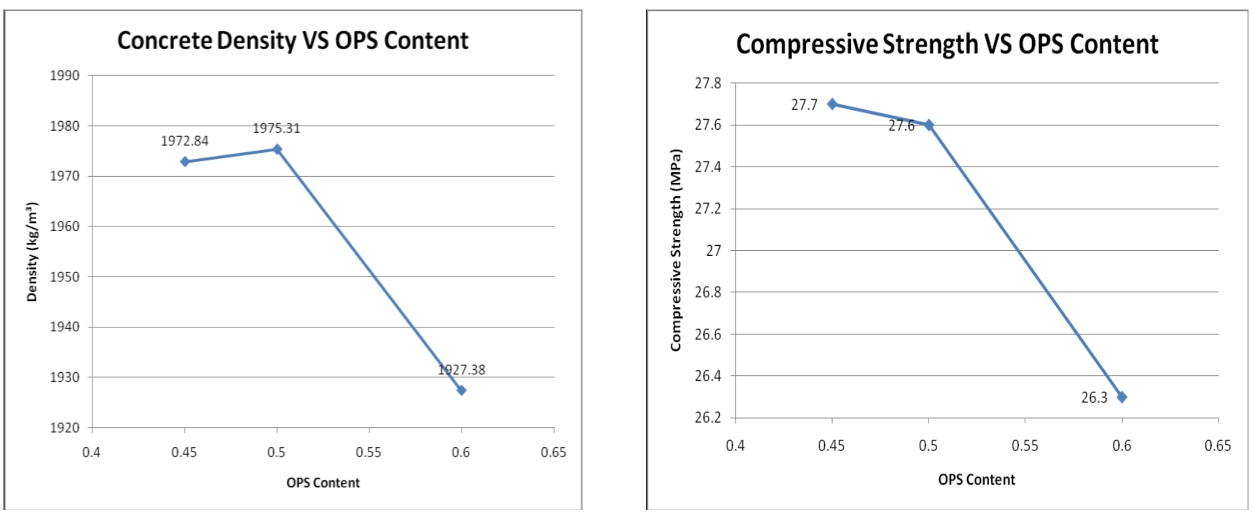

Fig (1) Graph a-Concrete Density versus OPS content, b-Compressive Strength versus OPS content

Although concrete density is expected to reduce with increment in OPS content, graph on Figure 1-a shows inconsistency in data obtained. When more OPS content is used for a certain mix design, the concrete mix matrix will be occupied with more OPS rather than other materials such as cement and sand. By nature, OPS are lightweight and are lighter than cement and sand, hence, concrete is expected to weigh less and concrete density is lower.

Based on Figure 1-b, it is observed that with increment in OPS content, compressive strength achieved by concrete gradually decreases. This is explained by the weak bonding between OPS and cement paste due to organic effect as well as smoothness of OPS surface, which is further explained by the fact that the concrete failure observed is due to the breakdown in the bond between concrete paste and OPS aggregates. Therefore, with higher content of OPS, concrete strength is reduced with more weak zones available between cement paste and OPS aggregates that initiates concrete failure. Besides that, OPS with higher porosity also lower the strength and stiffness of concrete.

4.2- *Three Point Load Test Data*

As described above, all slab samples were tested with by applying load as specified by three point load test until failure. Load cell is increased with increment of 1 kN and slab deflection is recorded at each increment. Note is taken when crack is first observed. Data collected for each sample are shown in Tables 1- 6.

Table (1): Data of Sample 1 (0.45 OPS, 1 layer geogrid)

Load (kN)	Deflection (mm)	Remarks
0.0	0.000	
0.8	0.119	
1.6	0.277	
2.8	0.454	
3.6	0.549	
4.1	0.667	
5.1	0.769	
5.8	7.933	First crack observed
6.0	20.569	
7.0	31.556	Ultimate load

Table (2): Data of Sample 2 (0.45 OPS, 2 layers geogrid)

Load (kN)	Deflection (mm)	Remarks
0.0	0.000	
1.2	0.189	
2.8	0.399	
4.3	0.629	
5.0	0.769	
5.8	0.889	
6.7	1.059	
7.5	3.239	
8.6	9.569	First crack observed
8.9	14.168	
9.2	17.118	
10.2	25.477	
11.0	39.166	Ultimate load

Table (3): Data of Sample 3 (0.5 OPS, 1 layer geogrid)

Load (kN)	Deflection (mm)	Remarks
0.0	0.000	
0.9	0.237	
1.4	0.316	
2.1	0.411	
3.0	0.507	
3.9	0.611	
4.7	0.824	
5.1	1.763	
5.7	10.228	First crack observed
6.9	31.046	Ultimate load

Table (4): Data of Sample 4 (0.5 OPS, 2 layers geogrid)

Load (kN)	Deflection (mm)	Remarks
0.0	0.000	
1.3	0.213	
2.5	0.345	
3.4	0.617	
4.2	0.891	
5.2	1.479	
5.9	2.573	
6.6	5.331	
7.4	7.186	
8.3	10.585	First crack observed
9.1	21.763	
10.3	38.274	Ultimate load

Table (5): Data of Sample 5 (0.6 OPS, 1 layer geogrid)

Load (kN)	Deflection (mm)	Remarks
0.0	0.000	
0.5	0.102	
1.1	0.177	
1.9	0.373	
3.0	0.455	
4.2	0.796	
5.3	1.632	
6.0	10.798	First crack observed
6.7	30.246	Ultimate load

Table (6): Data of Sample 6 (0.6 OPS, 2 layers geogrid)

Load (kN)	Deflection (mm)	Remarks
0.0	0.000	
0.9	0.172	
2.1	0.315	
3.1	0.523	
3.9	0.624	
4.8	0.879	
5.7	1.596	
6.6	5.993	
7.8	11.117	First crack observed
8.4	23.546	
9.0	36.636	Ultimate load

From data obtained in Tables 1-6, it is observed that load applied to each sample does not follow the increment of 1 kN. Increment of load cell is inconsistent and value fluctuates during testing. This was due to limitations of the equipment that requires manual application. Overall data collected through this test nonetheless managed to comply with the expected outcome and overall patterns are able to be identified through graphs plotted as well as tables.

The three point load tests were carried out on slabs at age of 14 days instead of 28 days due to time constraints. It is expected that the maximum load that can be taken by slab samples is lower at 14 days strength compared to 28 days strength because concrete is still at curing stage and concrete gain strength development is still occurring. This shows that the data collected does not mean represents the full capacity that can be taken by slab at full strength. Even so, flexural strength of the slab samples can be predicted by correlation of concrete strength developed at 14 days to 28 days based on results of compressive strength test. From Table (7), OPS concrete strength gain is consistent and strength developed at age 14 days is averagely 0.8647 of the strength gained by OPS concrete at 28 days. Hence, by correlating the flexural strength of slab samples using the ratio of strength development, flexural strength at 28 days can be predicted.

Table (7): OPS concrete strength gain development

<table>
<tr><th rowspan="6">Compressive Strength (MPa)</th><th rowspan="2">OPS Content</th><th colspan="2">Concrete Strength (MPa)</th><th rowspan="2">Ratio Of Strength Development</th></tr>
<tr><th>14 Days</th><th>28 Days</th></tr>
<tr><td>0.45</td><td>23.45</td><td>27.69</td><td>0.8469</td></tr>
<tr><td>0.50</td><td>23.98</td><td>27.57</td><td>0.8698</td></tr>
<tr><td>0.60</td><td>23.04</td><td>26.26</td><td>0.8774</td></tr>
<tr><td colspan="3">Average</td><td>0.8647</td></tr>
</table>

In this research, the value of ratio of OPS concrete strength development is rounded off to 0.85 for correlation as a safer estimation. With strength correlation available, the summaries of results of three point load test conducted on all slab samples for 14 days and 28 days strength are portrayed in Table (8) and (9) respectively.

Flexural strength of concrete slab can be expressed in terms of modulus of rupture in MPa, which is defined as the measure of the force necessary to break a given substance across slab.

Table (8): Ultimate load of slab samples at age 14 days

Ultimate Load Taken By Slab (kN)			
Geogrid Layer	OPS Content		
	0.45	**0.50**	**0.60**
1	7.0	6.9	6.7
2	11.0	10.3	9.0

Table (9): Correlated ultimate load of slab samples at age 28 days

Ultimate Load Taken By Slab (kN)			
Geogrid Layer	OPS Content		
	0.45	**0.50**	**0.60**
1	8.24	8.12	7.88
2	12.94	12.12	10.59

Table (10): Modulus of rupture of slab samples at age 28 days

Modulus Of Rupture (MPa)			
Geogrid Layer	OPS Content		
	0.45	**0.50**	**0.60**
1	2.4706	2.4353	2.3647
2	3.8824	3.6353	3.1765

Table (10) shows the flexural strength of concrete slab in terms of modulus of rupture. Modulus of rupture is converted from ultimate load of slab, hence represents the highest stress experienced within the concrete slab at its moment of rupture when load reaches ultimate mode. Formula of modulus of rupture (σ) in terms of stress is given by the (eq.1):

$$\sigma = 3PL / 2bd^2 \quad \ldots\ldots \text{(eq.1)}$$

Where; P= is the ultimate load experienced by slab samples,

L= is the length of slab samples, which is constant 2000 mm in this research,

b= is the width of the slab sections, which is constant 1000 mm is this research,

d= is the thickness of the slab samples, which is constant 100 mm in this research.

4.3- ***Effect of OPS Content towards Slab Flexural Strength***

By monitoring the pattern of data from Table (10), at constant amount of geogrids, concrete slab samples with varying OPS content produces varying flexural strength. This shows that OPS content does indeed contribute not only to concrete compressive strength but flexural strength of slab as well, even though the effect may not be significant. From Figure (2-a) and (2-b), which shows the effect of OPS content towards slab flexural strength enhanced with constant 1 layer and 2 layers of geogrids respectively, it is observed that when OPS content increases, flexural strength of slab samples is gradually reduced. This effect is verified when both figures above

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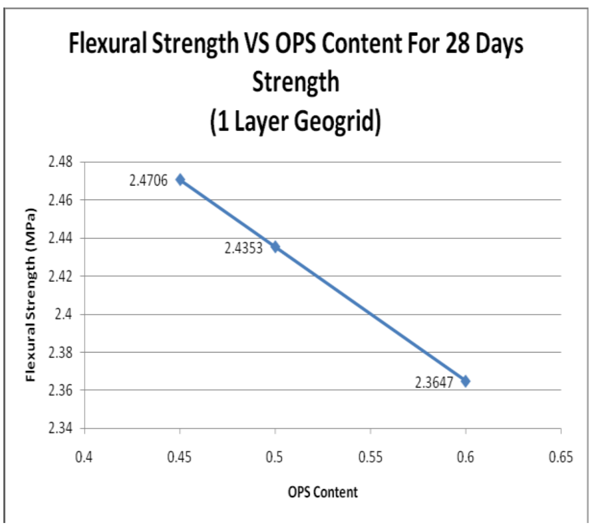
produces the similar pattern of graphs. Both graphs produce almost perfect linear graph where ultimate load taken by slab reduces when OPS content increases.

The effect is due to the weak properties of OPS. OPS generally consist of higher percentage voids with higher porosity compared to conventional granite aggregates. High porosity within OPS fibers makes the product itself weak in strength as well as toughness, therefore reducing flexural strength of concrete.

Apart from that, organic effect of OPS as well as the smoothness of its surface creates weak zones within concrete that more easily initiates failure zones when concrete slab is applied with load. This causes reduction of the maximum loading that can be carried by concrete, hence reducing the flexural strength as well. Same as compressive strength test, the failure of all slab samples at early age occur at the breakdown of bonding between OPS surface and cement paste. Based on previous research, it is observed that when OPS concrete samples are cured for longer period of time exceeding 56 days, the bonding between OPS aggregates and cement paste becomes stronger that concrete failure eventually fails through the OPS aggregates instead. Nevertheless, in both cases of failure at earlier age and later age, more content of OPS will bring effect by reducing concrete flexural strength, where in later case, more OPS can more easily initiates the crack failure through OPS aggregates due to low strength of OPS.



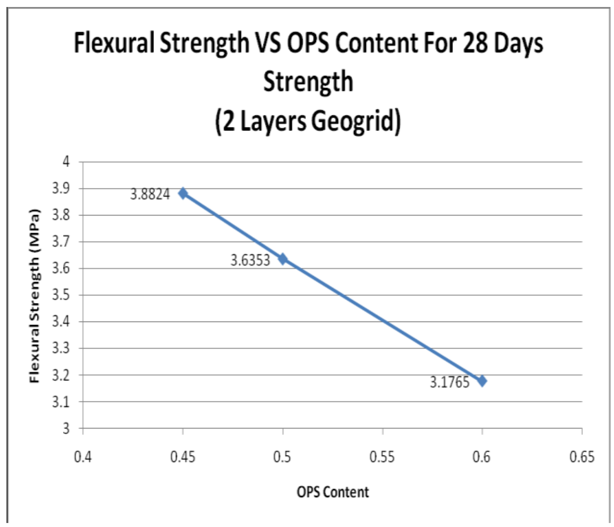


Fig (2): Graph flexural strength of slab enhanced with 1 and 2 layers geogrid versus OPS content

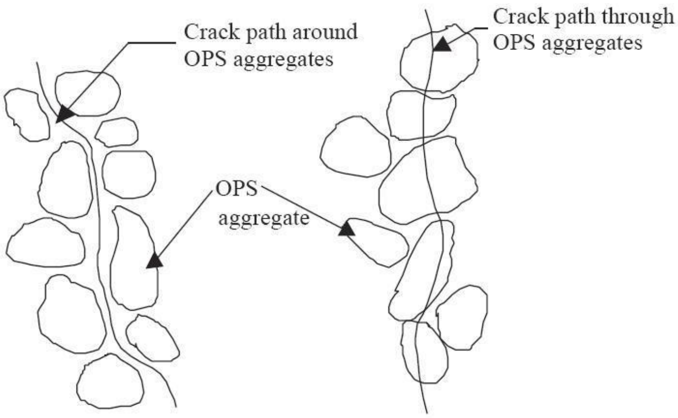


Fig (3): Failure path at earlier ages (left) and at later ages (right).

When OPS content is increased from 0.45 to 0.6 (approximately 33 % of OPS content increment), the flexural strength of concrete slabs with one layer of geogrid is decreased by only 4.3%. While for concrete slab with two layers of geogrids, flexural strength is reduced by 18.2 %. The reduction of flexural strength that ranges between 4.3 to 18.2 % shows inconsistency of data collected, which is probably due to errors during casting or limitations by testing equipment. Nonetheless, the values manage to show that the effect of OPS towards flexural strength of OPS concrete slabs is less than effect of geogrids, with increment in flexural strength of up to 57.1 % by enhancing extra layer.

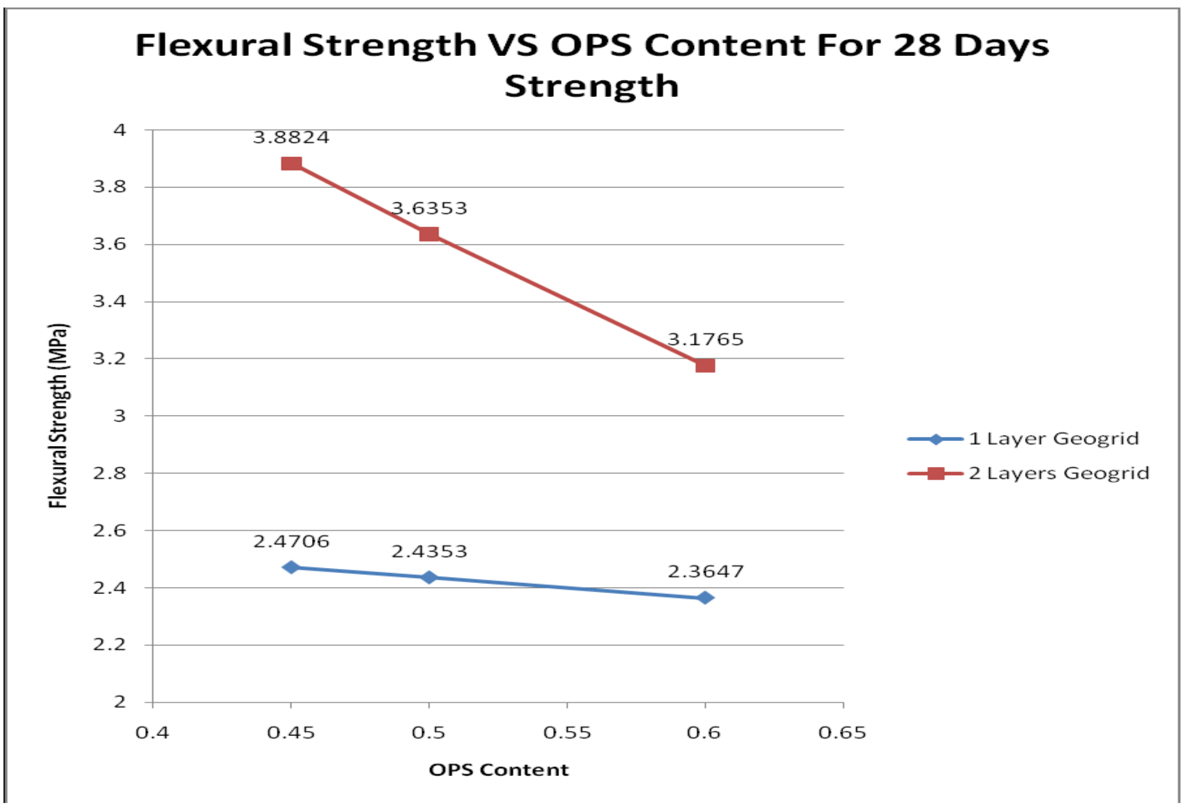


Fig (4): Relationship between flexural strength and compressive strength of OPS concrete

4.4- *Relationships between Compressive Strength and Flexural Strength*

By monitoring the trend of data from Table (10), at constant content of OPS, concrete slab samples with varying amount of geogrids produces varying flexural strength. This shows the contribution of OPS content towards flexural strength of OPS concrete slabs.

Figure (5) portray the effect of amount of geogrid towards slab flexural strength enhanced with constant OPS content of 0.45, 0.50 and 0.60. It can be noticed that when there are more layers of geogrids enhanced in OPS concrete slabs as reinforcement, flexural strength of slab samples is increased as well. All three lines show consistency and hence can verify the explanation above.

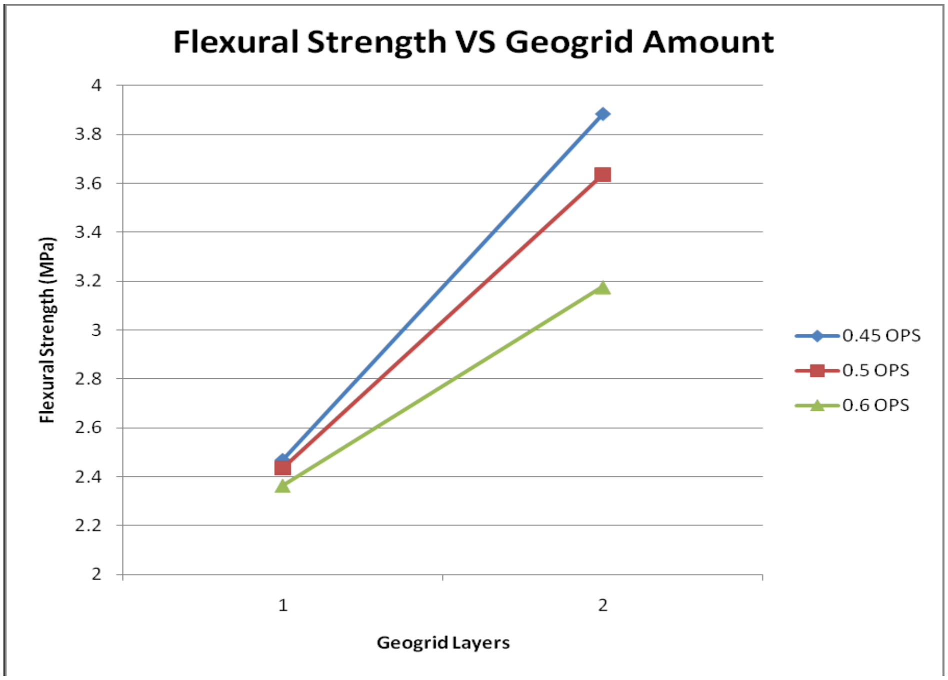


Fig (5): Flexural strength of slab versus geogrid amount

Test results show the feasibility and effectiveness of geogrid as reinforcement in enhancing flexural strength in OPS concrete, with as high as 57.1 % of strength increment when geogrid amount is increased. This represents the potential of geogrid as concrete reinforcement. Test result will be compared to design requirement of residential floor to verify its feasibility in construction use.

4.5- *Comparison of Test Results with Design Requirement*

In this research work, test results are compared to the design requirement of slab of a residential floor which does not require very high loading, since the OPS concrete mix design adopted does not achieve high strength. Comparison is carried out between the design requirements of a similar residential floor slab based on BS 8110: Part 1: 1997 with the ultimate conditions that the slab samples can take in terms of load, modulus of rupture, moment and tensile strength.

Table (11): Ultimate conditions of slab samples

Sample	OPS Content	Geogrids (Layers)	Ultimate Load (kN)	Modulus of Rupture (MPa)	Ultimate Moment (kN.m)	Tensile Force (kN)
1	0.45	1	8.2353	2.4706	4.1177	54.18
2	0.45	2	12.9412	3.8824	6.4706	90.82
3	0.50	1	8.1176	2.4353	4.0588	53.41
4	0.50	2	12.1176	3.6353	6.0588	85.04
5	0.60	1	7.8824	2.3647	3.9412	51.86
6	0.60	2	10.5882	3.1765	5.2941	74.30

For comparison purposes, the ultimate load that can be taken by each slab sample is first converted into modulus of rupture, ultimate moment that can be taken by slabs and tensile force available within slab samples enhanced with geogrids. These ultimate conditions of each slab is shown in Table (11), where the fig (3) represents the ultimate condition experienced by each OPS concrete slab sample at failure mode.

Table (12): Design condition of residential slab based on BS code

OPS Content	Load (kN)	Flexural Strength (MPa)	Moment (kN.m)	Tensile Force (kN)
0.45	7.258	2.1774	3.6290	56.81
0.50	7.265	2.1796	3.6325	56.81
0.60	7.199	2.1596	3.5993	56.81

By comparing the ultimate conditions in Table (11) with design conditions of a residential floor in Table (12), it can be observed that the ultimate load that can be taken by all slab samples successfully surpass the required load to be taken by a residential floor slab. With adequate load capacity for flexural strength, modulus of rupture of slab samples that ranges between 2.3647 to 2.4706 MPa for slabs with one layer of geogrid, and 3.1765 to 3.8824 MPa for slabs with two layers of geogrids, therefore exceed required flexural strength as high as 2.1796 MPa as well, with ultimate moment of each samples enough to accommodate for moment requirement of up to 3.6290 kN.m.

Results show that OPS concrete slab reinforced with geogrids is feasible in terms of flexural strength for construction for residential purposes. It fulfills the ultimate limit state condition of residential floor based on BS 8110: Part 1: 1997.

4.6- *Deflection of OPS Concrete Slab Reinforced With Geogrids*

Deflections of OPS concrete slab samples reinforced with geogrids are determined during three point load test in order to check and verify whether the concrete samples fulfill the serviceability requirement as described in British Standard BS 8110: Part 1: 1997.

Table (13): Maximum deflections of slab samples at failure mode

Maximum Deflection At Failure (mm)			
Geogrid Layer	**OPS Content**		
	0.45	0.50	0.60
1	31.556	31.046	30.246
2	39.166	38.274	36.636

A summary of maximum deflection recorded for each slab sample is listed in Table (13). The maximum deflection achieved by slab samples with single layer of geogrid reinforcement ranges within 30.246 to 31.556 mm, while for slab samples with double layers of geogrids, the value ranges between 36.636 to 39.166 mm. It is noticed that maximum deflection of slab samples with double layers of geogrid is generally around 21.13 to 24.12 % higher than those with single layer of geogrid. This shows the effectiveness of geogrid in enhancing strength in concrete slab to take higher load and hence fails at higher deflection.

Table (14): Deflection at serviceability limit of slab samples

Sample	Load at Serviceability Crack (kN)	Deflection (mm)
1	5.8	7.933
2	8.6	9.569
3	5.7	10.228
4	8.3	10.585
5	6.0	10.798
6	7.8	11.117

Table (14) shows the load at first observed serviceability crack for each OPS concrete slab sample with the deflection achieved at respective load. For slab samples with single layer of geogrid, failure in terms of serviceability occurs between load of 5.8 to 6 kN, while for slab samples with double layers of geogrids, serviceability failure occurs at load between 7.8 to 8.6 kN, which shows that slab samples with double layers of geogrids fail at serviceability load higher than those with only single layer of geogrid, with around 30 to 48.3 % higher. Deflection at serviceability crack recorded shows data inconsistency and but overall ranges between 7.933 to 11.117 mm.

In order to ensure the feasibility of OPS concrete reinforced with geogrids in terms of serviceability limit condition in construction industry, test results of the slabs are compared to the reinforced concrete slab design serviceability limit condition based on BS 8110: Part 1: 1997.

Table (15): Deflection of slab samples at residential loading

Sample	Equivalent Serviceability Load (kN)	Deflection (mm)
1	4.9700	0.75
2	4.9700	0.75
3	4.9750	1.5
4	4.9750	1.3
5	4.9275	1.3
6	4.9275	0.95

Table (15) shows the converted equivalent serviceability loading for residential floor, as well as the deflection at respective equivalent load determined from deflection curves for all samples as shown in Figure (4). By comparing Table (15) to Table (14), it can be noticed that the maximum serviceability load capacity of all slab samples exceed the requirement of serviceability load of a residential floor by up to 73 % for double layer geogrid slabs and up to 21.8 % for single layer geogrid slab.

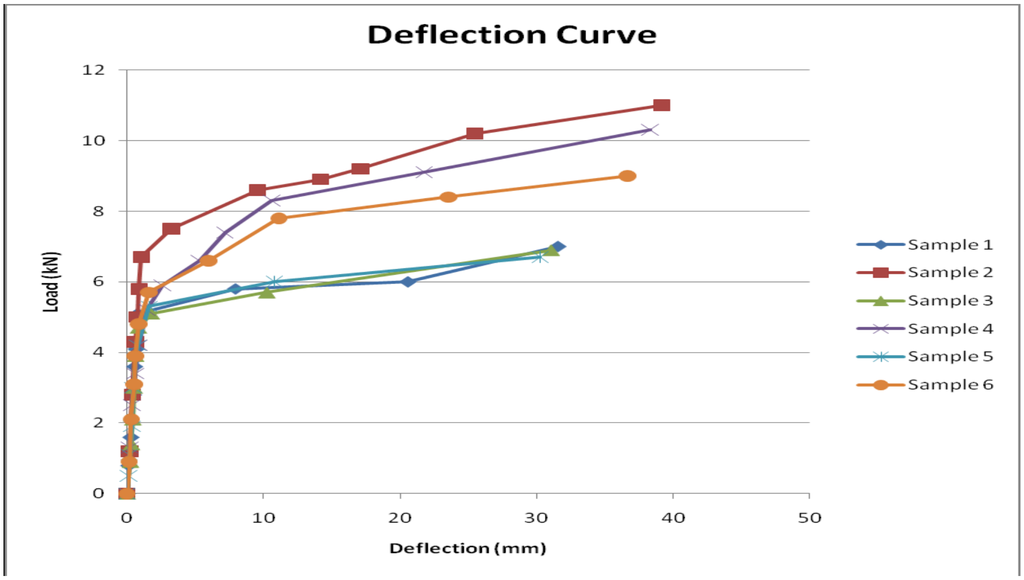


Fig (6): Deflection Curve for All Six Slab Samples

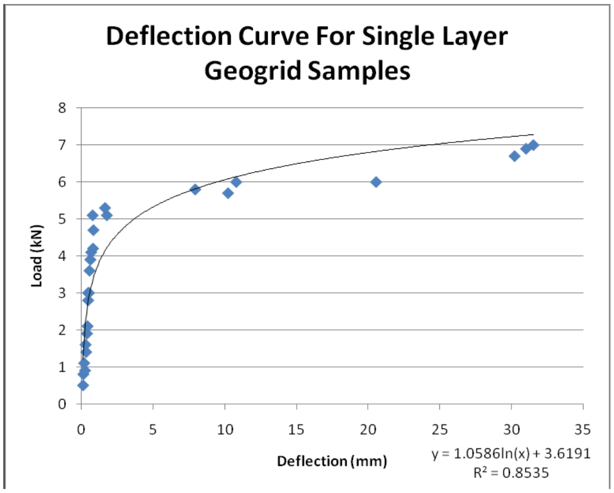
4.7- *Behavior of OPS Concrete Slab Reinforced With Geogrids*

Fig (4) portrays the deflection curve and behavior for samples 1, 2, 3, 4, 5 and 6. Based on the pattern of the deflection curves, the trend of graphs follow the same graph trend produced by conventional normal steel-reinforced concrete. This shows the similarity between both steel bars and geogrids as reinforcement. Geogrid can be classified as ductile material where based on the deflection curves, ductility of the material can be seen. Ductile material displays linear elastic behavior at initial region of the graph where strain is small. At this region, the deformation of geogrid can be completely recovered and will return to its original shape and size when load applied is removed.

During three point load test on OPS concrete slab samples reinforced with geogrid, the samples experience deformation and cracking before reaching failure mode. Failure mode is thus classified as ductile failure. This shows the ductility of the material as conforming to the deflection curves of all slab samples as shown in Fig (6).

Behavior of OPS concrete slab reinforced with single layer of geogrid can be expressed by the equation $y = 1.0586 \ln(x) + 3.6191$with regression of 0.8535, which is determined from the fitting deflection curve plotted integrating data of samples with single layer of geogrid. As for double layer slab samples, the behavior can be predicted with the equation $y = 1.5814 \ln(x) + 4.5256$, with regression of 0.9351. The fitting log graphs are presented for single layer geogrid samples and double layers geogrids samples in Fig (7).

The efficiency of geogrid catering for requirement in terms of deflection can be determined from the load/deflection ratio from the log equations. The efficiency of single layer geogrid is 0.23048 while efficiency for double layers geogrids is 0.26364, with approximately 14 % more efficient in terms of deflection than single layer.



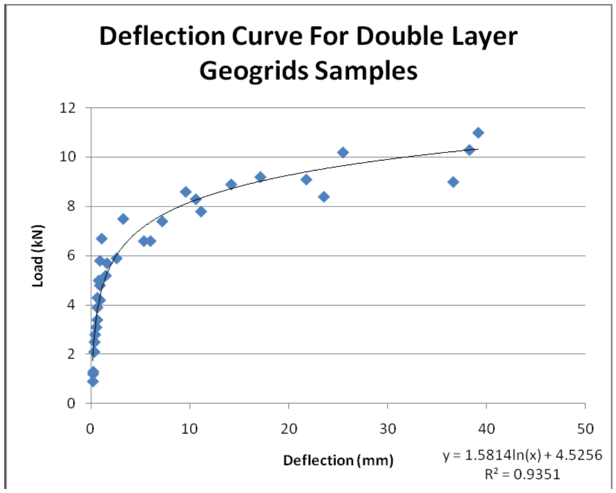


Fig (7): Deflection curve for single and double layers geogrid slab samples

CONCLUSION

This research integrates the use of oil palm shell and geogrid in concrete slab casting. Properties of oil palm shells and geogrid that is light in weight becomes the ideal materials to produce lightweight concrete. Besides, geogrid being high tensile strength material makes it the potential replacement for concrete reinforcement while for oil palm shell which is hard and naturally sized can help achieving sustainability development as well as reducing pollution rate by replacing conventional aggregates in concrete.

The main conclusions of this study are:

1- The highest average density of OPS concrete casted was 1975.31 kg/m3 and falls under 2000 kg/m3, hence successfully meet the requirement of lightweight concrete based on British Standard BS 5328: Part 1: 1990.
2- With increment in oil palm shells content, compressive strength achieved by concrete gradually decreases. Highest average compressive strength achieved was 27.69 MPa. Hence, concrete slab fail to achieve high strength properties requirement as explained in BS 5328-1:1997. Nevertheless, the strengths achieved do surpass the minimum requirement of 25 MPa as adopted in construction industry.
3- Flexural strength of slab samples expressed in modulus of rupture shows the effect of OPS content and amount of geogrids towards flexural strength. When OPS content is increased, flexural strength of concrete slab reduces, while it increases when amount of geogrid is increased.
4- Geogrid becomes the governing factor over OPS content in enhancing flexural strength in concrete when increment in flexural strength of up to 57.1 % by enhancing extra layer while varying OPS content brings effect of only up to 18.2 %. Flexural behavior of slabs follows the similar trend portrays by concrete compressive behavior. The 28 days flexural strength of slabs with single layer geogrid is

approximately 8.9 to 9 % of its compressive strength and is approximately 12 to 14 % for slabs with double layers geogrids. Modulus of rupture of slab samples that ranges between 2.3647 to 2.4706 MPa for slabs with single layer geogrid, and 3.1765 to 3.8824 MPa for slabs with double layers geogrids, exceed the required flexural strength of a residential floor up to 2.1796 MPa, hence is adequate to cater for ultimate limit state design of structures for residential purposes.

5- The ultimate deflection achieved by slab samples with single layer of geogrid ranges from 30.246 to 31.556 mm, while the values ranges from 36.636 to 39.166 mm for slab samples with double layers of geogrids. The ultimate deflection of slab samples with double layers of geogrid is approximately 21.13 to 24.12 % higher than those with single layer of geogrid. The maximum serviceability load capacity of all slab samples exceed the requirement of serviceability load of a residential floor by up to 73 % for double layer geogrid slabs and up to 21.8 % for single layer geogrid slab. The deflection recorded for all slab samples at equivalent serviceability load of a residential floor ranges from 0.75 to 1.5 mm, which safely fall within the allowable maximum deflection of 8 mm by BS 8110: Part 1: 1997. Hence, OPS concrete reinforced with geogrid is adequate to cater for serviceability condition design of structures for residential purposes.

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