STRENGTH DEVELOPMENT OF LIGHTWEIGHT STYROFOAM CONCRETE

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ABSTRACT : Styrofoam was widely used as food and manufacturing production equipments as packaging tools to absorb vibration during handling and transportation process. After this process, the Styrofoam used to protect the equipment normally serves as disposal waste. It is estimated that it produced large amount of wastes as it abundantly used in the market. Compared with natural lightweight aggregates which is porous material and adsorb huge amount of water, Styrofoam is artifial lightweight aggregate producing durable concrete. Four series of Styrofoam concrete were identified includes series of Styrofoam concrete with pulverized fly ash (PFA) as cement replacement. All the series been compared with conventional concrete. This paper will discuss the compressive strength of palm oil fibre in long-term up to 180 days. In this study, it shows that concrete series of using 10 square mm size styrofoam aggregates with 10% PFA replacement level gave highest compressive strength in long-term up to 180 days.

Keyword: Pozzolans, lightweight concrete, styrofoam, compressive strength, DOE Method

1. INTRODUCTION

Lightweight concrete have been chosen by many designers and contractors due to cost favors especially in high-rise buildings and long-span bridges. Basically, lightweight concrete is produced by introducing air inside the concrete; either by using gassing and foaming agent or using lightweight aggregate such as natural aggregate (pumice, shale, slate) or industrial by-product (palm oil clinker, sinterized fly ash) or plastic granules (styrofoam or polymer materials). Due to high porosity in many industrial by-product and natural aggregates, it commonly adsorbs much water and it will give less beneficial in terms of shrinkage and permeability.

Styrofoam is popular to be used as a good thermal insulation material in building construction. Besides, it widely produced as food packaging especially in storing hot servings and also as protective devices for securing goods and materials from vibration and damage during delivering and transporting process. Commonly, Styrofoam for delivering process was shaped according to the delivering item’s shape. Normally after delivering process, it commonly treated as waste product and it seldom to be recycled as a new Styrofoam as it is not economical to be reproduced. Styrofoam aggregate has a closed cell structure consisting essentially of 98% air. Styrofoam concrete is made from a mixture of cement, sand and Styrofoam aggregate. By using different volumes of waste styrofoam incorporated with fly ash, a range of densities and also compressive strength can be obtained.

As been reported by Mindess et.al [10], due to the porosity and buoyancy, the lightweight aggregates in fresh concrete tends to float on the concrete surface. This phenomenon is different in normal weight concrete which aggregate tend to sink and settle beneath the bottom layer. One of the commonly used approaches is adding the mineral admixtures like silica fume, fly ash, etc, to the fresh concrete during mixing stage. However, even preventive maneuver has been taken in advance during the concrete mixing; the extent of segregation issue of lightweight concrete to a certain degree is still commonly encountered.

Due to hydrophobic characteristics of Styrofoam in concrete mixture, there is one thing we have to look upon, i.e., the coatings. Earlier researchers have suggested that to compensate this characteristic either by bonding additives [8] or should be chemically treated [9]. In this findings, there is no bonding additive was used, and to avoid this problem, it is to be assured that the cement paste content was adequate and small quantity of superplasticizers were added. Due to discourage results from previous study [7], the physical properties of the Styrofoam need to be improvised. The lightweight Styrofoam aggregates been oven-dried to allow them to shrink about 1/5th of the original size to make it more solid and strong aggregates; at the same time it is light aggregates. The Styrofoam concrete produced was tested for its development of compressive strength up to 180 days.

2. EXPERIMENTAL DETAILS

2.1 Styrofoam as coarse aggregates

Used Styrofoam was used in this research. The Styrofoam that protects equipment during delivering process normally come in a big size and need to be cut into desired size suitable to be used as coarse aggregates. The big size of Styrofoam was cut into 150-60 square mm range of size and put inside the oven to allow them shrink into our desired shape for about 10 minutes. The Styrofoam obtained will be in the range of 10-20 mm size. This size will be sieve and divided into 2 major sizes, i.e., maximum size of 20 square mm and 10 square mm respectively. The shrinking Styrofoam will be stored in a barrel until its casting day. The styrofoam physical properties were shown in Table 1. Note that aggregate impact test cannot be done as the Styrofoam will be stick with other Styrofoam aggregate when compacted under compression machine.

Table 1: Physical properties of Palm oil Fiber used

Physical properties	Waste Styrofoam
Bulk density (kg/m^3)	638.9
Specific gravity	1.31
Aggregate Impact Value (%)	-N.A-
Aggregate Crushing Value (%)	17.6


Figure 1: Original cut Styrofoam aggregates (left) oven-dried Styrofoam used (right)

2.2 Other concrete mix components

River sand was used as fine aggregate which is in air-dried condition 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. The physical properties such as water adsorption, moisture content and bulk density are shown in Table 2.

Table 2: Physical properties of coarse and fine aggregates used

Physical properties	River Sand	Crushed stone
Specific gravity (SSD condition)	2.65	2.66
Moisture content (%)	0.02	0.01
Water adsorption (%)	1.65	0.79
Bulk density (kg/m^3)	1663.65	1585.23
Fineness Modulus	2.84	6.53

2.3 Test samples

Four series of styrofoam concrete test were conducted which is shown in Table 3. Series 1 was done as control mixture to compare the performance with Styrofoam concrete series. Each Styrofoam concrete series using oven-dried shrinking Styrofoam of maximum size of 20 mm Styrofoam square size or 10 square mm Styrofoam respectively as coarse aggregates and river sand as fine aggregates.

Table 3: Series of palm oil clinker concrete mix

No.	**Series**	**Description**
1	S1	control mix (conventional mix OPC)
2	S2	20 mm size styrofoam and 100% OPC as binders
3	S3	10 mm size styrofoam and 100% OPC as binders
4	S4	20 mm styrofoam and 100% OPC + addition of 10% fly ash as binders
5	S5	10 mm styrofoam and 100% OPC + addition of 10% fly ash as binders

Control mix was designed using British Method or commercially known as Department of Environmental (DOE Method) while lightweight series mixtures were design by using mix design FIP Lightweight concrete design Method. FIP design method is a mix-design which developed by lightweight research team from international organization for the development of structural concrete which is established in 1983. Both types of mix design were carried out based on targeted strength of 40 N/mm^2. The water-binders ratio (w/c) was fixed at 0.40. 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) content by 10%. Each series was chosen based on the best mix design that developed earlier [6].

Basically, there are two cases in design the lightweight mix design. For low specific gravity of lightweight aggregates like Styrofoam aggregates, it is better to design the mix by volume. The mix design in this paper was conducted based on volume due to low density. We have to look upon a cohesive design so that the Styrofoam that been produced will not floating on the top of the concrete mixture, thus by using pozzolans i.e., fly ash was used.

Table 4: Mix proportion of concrete samples

Series	**Proportion by weight**				
	$\frac{Water}{Binders}$	**Binders (kg/m^3)**		**Sand (kg/m^3)**	**Coarse Aggregates (kg/m^3)**
		OPC	**Fly ash (PFA)**		
S1	0.40	382	-	668	1090 (Crushed Gravel)
S2	0.40	440	-	760	868 (Styrofoam)
S3	0.40	440	-	760	868 (Styrofoam)
S4	0.40	396	44	760	868 (Styrofoam)
S5	0.40	396	44	760	868 (Styrofoam)

To increase the workability and to achieve flowing nature of low water content in Styrofoam concrete, 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 [4], the superplasticizer dosage went up to 1.75 litre per 100 kg binders, the one day strength of concrete decrease to a certain extent.

2.4 Description of mixing procedures

The mixing of concrete materials was done in a sequence manner which is illustrated below. Firstly, dry cut Styrofoam been added with a part of the water with superplasticizer in the mixture and mixed thoroughly in order for the aggregates wetted with water and plasticizer. Then, river sand, Ordinary Portland cement and fly ash (for Styrofoam fly ash series) were added to the mixer and the remaining water was gradually added while the mixing was still in progress. The mixing process was continued until a uniform mixture and flowing nature can be seen. Later, the fresh concrete was placed immediately into cube moulds that been prepared earlier and compacted by hand compaction as been described in BS 1881: Part 108: 1983 *Method for Making Test Cubes from Fresh Concrete*. The specimens were covered with wet gunny sacks for 12 hours after casting, the mould then been stripped after 24 hours and stored in water tank for curing purposes until its testing days. At the same time, fresh concrete performance was carried out by using slump test to determine its workability.

2.5 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 was measured throughout all the series mixes which follows BS 1881: Part 102: 1983, "*Method for Determination of Slump*" and BS 1881: Part 103: 1983, "*Method for Determination of Compaction Factor*". The fresh concrete properties are shown in Table 5.

Table 5: Fresh concrete properties

Series Designation	Slump (mm)	Compaction factor
S1	120	0.96
S2	133	0.97
S3	130	0.97
S4	143	0.98
S5	140	0.98

All the mixes are done after few 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. All the compressive strength was 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. The test procedures for compression test follow BS 1881: Part 115: 1986. *Specification for Compression Testing Machines for Concrete* Compressive test was carried out on the 3^{rd}, 7^{th}, 28^{th}, 56^{th}, 90^{th} and 180^{th} day upon casting.

3. RESULTS AND DISCUSSIONS

Figure 2 shows that relationship between the compressive strength development and curing period for all the concrete series that have employed. The designation for each series is given in Table 3. The highest compressive strength was obtained by Series 1 while samples from Series 3 gave the lowest strength throughout the curing time. The strength of the concrete will gets stronger with time as the hydration process progressed.

Due to lower modulus and porous characteristics of styrofoam as it exhibits high values of aggregate crushing value (ACV), lightweight palm oil clinker aggregate concrete produces lower strength compared with control concrete using crushed gravel as aggregates. Existence of air voids will trapped the water and therefore the moisture is higher and lower the compressive strength of the concrete. From the figure shown, we can observe that a significance lower compressive strength. All Styrofoam concrete performed 57-62% and 60-65% lower at 28 days and 180 days respectively than normal concrete. The increase of strength rate was significant for first 90 days and remains slower up to 180 days. The compressive strength for the 28-days samples in the range of 18-24 N/mm^2. Although Styrofoam concrete shows lower value compared to conventional aggregates concrete, the values obtained is beyond the minimum requirement for structural lightweight concrete purposes. BS8110 indicates that the range of concrete strength for structural purposes is within 17-35MPa.

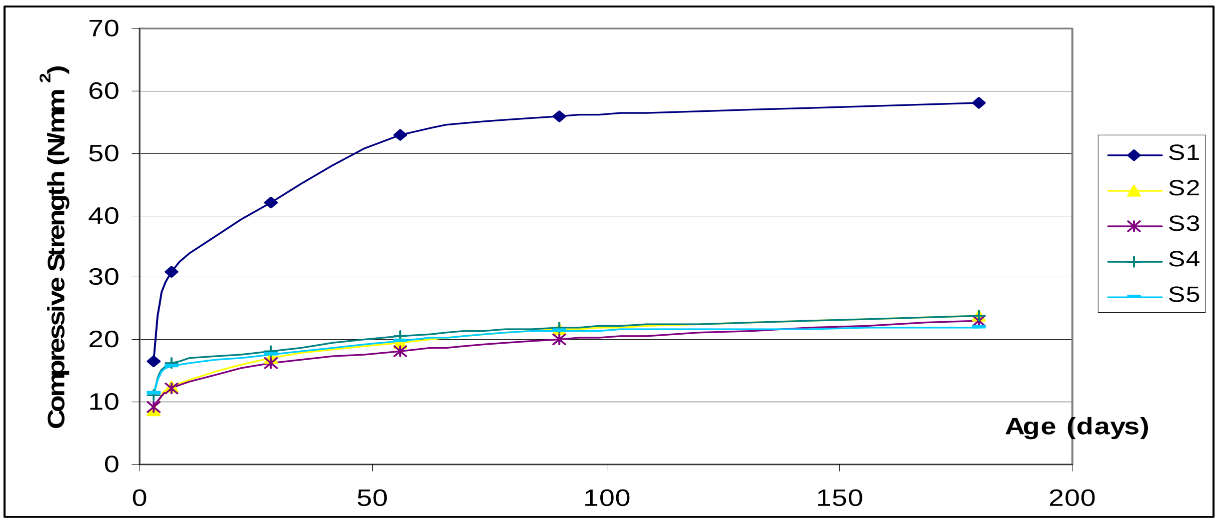

Figure 2: Compressive strength development of different series of styrofoam concrete and control concrete.

Pozzolans plays an important role to produce high performance concrete [4-5]. Due to pozzolanic reaction of PFA, extra formation of calcium-silicate-hydrate (C-S-H) will be produced from reaction by $Ca(OH)_2$ of hydration product with SiO_2 from pozzolans. This will produce a denser and yet, stronger concrete. The comparison of series using 10 percent PFA additions shows higher concrete strength than series using OPC alone. From the strength development, it shows that after 28 days, the rate of compressive strength development almost constant. This might due to pozzolanic reaction at earlier makes the concrete stronger but remains as usual at later stages. Series using 10% fly ash replacement shows a bit increase of 8-15% compared to series without PFA additions. This due to the denser Styrofoam concrete as explained earlier.

Basically, more surface area of the aggregate provides more area for bonding contact with the cement paste therefore; the strength of the concrete matrix will be higher. The higher surface area is given by the lower size of aggregates and hence provides higher surface for coating with binders. For series using smaller size of aggregates, it shows the reduction of 5-10% compressive strength from series using 20 square mm Styrofoam size. Due to uncoated or untreated Styrofoam used, it does not have a strong bond with the cement paste. As shown during compression strength cube test, the failure was due to bond between Styrofoam aggregates and cement paste matrix. This might be the cause of the reduction of strength tremendously.

However, comparison between size of Styrofoam used and addition of fly ash, using the pozzolan i.e., PFA gave the more significant influence in term of strength development. It is shown between series 2 with Series 3 and Series 4. Series 3 using 20 mm gave a difference of strength reduction about 6% compared to Series 2 using 10 square mm Styrofoam. On the other hand, comparison of PFA replacements shows that Series 3 gave lower strength compared to Series 5 of 10%.

4. CONCLUSIONS

After the entire test been done to determine the strength development of Styrofoam styrofoam, the following conclusions can be drawn from the investigation;

1. The highest compressive strength for Styrofoam series obtained by Series 3 that using 10 square mm Styrofoam as coarse aggregate and 10% additions of PFA followed by Series 5, Series 2, and Series 3. By using bigger Styrofoam size and pozzolans will produces denser and stronger concrete. However all the Styrofoam concrete series exhibits lower strength at any curing period compared to control concrete.
2. Only Styrofoam series using 20mm without addition of fly ash is not suitable to be applied as structural lightweight concrete as indicated in BS8110. Other series produces in the range of 17-22 MPa at 28-days which is beyond the minimum requirement for structural lightweight applications, therefore these series is suitable for structural use.
3. The long-term behavior of Styrofoam concrete is about similar to control concrete in any curing period.

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