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Mix Design of 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. Due to its lightweight characteristics, it has potential to serve as aggregates replacement of coarse aggregates. The physical properties of waste Styrofoam were conducted before the mix design was done. The mixture of Styrofoam aggregates was design based on modified Department of Environmental (DOE) Method and Lightweight FIP Method; therefore few trial mixtures were conducted. This paper will discussed on the mix design and compressive strength was carried out based on 28-days age. Five series of mixture were identified and been compared with conventional concrete. The addition of pulverized fly ash (PFA) to the Styrofoam concrete also been discussed. It is found that no Styrofoam mix design can achieve to be suitable for structural applications. Physical properties need to be improvised in able to produced structural concrete.

Keywords: *Pozzolans, lightweight concrete, styrofoam, compressive strength, DOE Method*

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1. INTRODUCTION

Numerous researches have been carried out on natural or artificial lightweight aggregates in order to produce lightweight structural concrete. The objectives of mix design are to achieve desired workability, density, and most importantly, the strength of the concrete with the most economic proportions. In normal weight concrete mixture, there are many established mix-design methods and practically been used such as ACI Method, DOE Method, Indian Specification etc. Lightweight aggregates Concrete mix design is different and more complicated whereby it depends on types of lightweight aggregates employed. In normal weight concrete, the specific gravity of conventional aggregates is around 2.6, whereby in lightweight concrete will be much below of these figures. To achieve concrete strength for structural purposes is more complicated especially for very low lightweight specific gravity and density.

In this paper, the mix design of lightweight concrete made from Styrofoam was carried out and two mix-design and trial- and-error approach were used and been compared with conventional concrete made from crushed gravel and natural sand. Styrofoam which has its obvious advantages especially for its insulation characteristic characteristics have good potential to be developed as lightweight structural purposes. All the series conducted will looking at the performance of lightweight Styrofoam concrete incorporating with pulverized fly ash (PFA) and compared with series of using 100% OPC concrete. In the case of lightweight aggregate concrete, it is recommended that the compressive strength should be above 17 MPa in order to be used as structural concrete as indicated in BS8110. This paper will discuss the performance of specified mix design styrofaom concrete incorporating with fly ash to be used as structural concrete elements. Up to date, there is no literature available in the engineering properties of lightweight Styrofoam concrete containing PFA.

2. SIGNIFICANCE OF RESEARCH

Conventional aggregates such as crushed gravel stone as coarse aggregates and river sand as fine aggregates normally produced by sparing from the country side, river beds and beaches and beaches from the scarring and damaging activities of aggregate mining. This will destroy the beauty of natural resources and in certain countries, stringent environmental limitations are imposed on mining of natural aggregates in various parts of the world. By using alternative aggregates resources, it is capable to establish an industry with export potential especially to countries where natural aggregates are depleted.

Contractors and designers are looking upon lightweight self-weight concrete to reduce the production cost without sacrificing the safety of the structures. Knowledge of the characteristics of lightweight aggregates used is of prime importance to the designer and user of lightweight concrete. This reduction of self-weight load may result in reduced footing sizes and lighter and smaller upper structure. This will lead to the reduction in expensive quantity in concrete production i.e., cement quantity and possible reduction in reinforcement. In concrete pre-cast industry, this requires smaller and cheap handling and transportation process. Reduction in the dimensions sizes of structural member results in larger space availability. As reported by [8], lightweight concrete will gave high thermal insulation and enhanced fire resistance.

Many researches have been carried out mix design experiment to determine the performance of lightweight aggregates in terms of strength as well as its durability. However, the conventional lightweight aggregate which is porous in nature adsorb a large quantity of water especially during mixing process and more water have to be added in order to maintain its slump for full compaction to take place. This will affect to the concrete performance especially its durability of concrete due to large trapped water within the aggregates voids. Moreover, the increase in water content requires higher cement contents and this will increase the production cost without enhance the concrete strength.

From the point been mentioned above we have to look for a possible lightweight concrete which is less water adsorption and hence less cement content and therefore enhance its matrix characteristic. The potential lightweight aggregates to be used as concrete component is Styrofoam. Styrofoam has hydrophobic characteristics, non-absorbent, good insulation properties and closed cellular aggregates may have the potential to be developed as good commercial lightweight aggregates. Fly ash have been used extensively in concrete production due to its huge availability can enhanced the properties of concrete as supplementary cementitious material through pozzolanic reactions.

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 [11]. 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.

Pulverized fly ash (PFA) which is produced in coal combustion industry also capable to be used as pozzolans as indicated by many researchers [10-12]. Currently, the construction industry has widely used fly ash with cement and this reflected in various changes in the Standard Code of Practice worldwide. During hydration process, Ordinary Portland Cement will react with water to produce calcium-silicate-hydrate (which is the gel compound which contributes to the strength of the concrete) and calcium hydroxide (which is detrimental to the concrete strength). By pozzolanic reactions, the silica content in PFA will combines with calcium hydroxide to produce more calcium-silicate-hydrate and water. The more productions of calcium-silicate-hydrate will form a denser, durable and stronger concrete. This also gave the efficient way of recycled disposal of the PFA.

It is estimated that the world production of PFA was about 600 million tones but only 9% got to be utilized. The use of high volume PFA as a supplementary cementitious material in concrete production is much preferred however; in this case we replace a portion of OPC concrete with PFA. There may be some essential amounts of chemical composition which is reduced, but Malhotra [5] reported that only 10% replacement of PFA will gave the optimum results in term of strength and durability.

3. EXPERIMENTAL SET-UP

3.1 Concrete Constituents

Styrofoam was used in this study collected from UTHM Materials Lab store that been kept for disposal. It was collected mostly from lab equipment box which its purpose to adsorb vibration to ensure safe handling during delivering. Styrofoam that been used come in various shape according to the lab equipment and also some handling Styrofoam come in form of small piece or better known as “peanuts”. In this study, 10 mm and 20 mm square size of Styrofoam was used as conventional coarse aggregate replacement. Should bear in mind that when the mixing process occurs, the Styrofoam will be compressed and the average size of Styrofoam that been produced will be reduced to about 30%. All the waste Styrofoam then mixed together and stored in a barrel. The physical properties of Styrofoam used been determined based on British Code of Practice. The used Styrofoam is white in color and has close-spacing cells. The bulk density of Styrofoam obtained was 32.6 kg/m^3 and specific gravity 0.56. The bulk density used in the mixture will be a bit higher due to compression of Styrofoam during mixing process. Water adsorption and moisture cannot be determined due to the physical Styrofoam will be shrink when oven-dried. However, due to hydrophobic characteristic of Styrofoam, both properties can be neglected.

Figure 1: Styrofoam aggregates used

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

3.2 Materials and Properties

Table 1 and Table 2 shows the concrete constituents incorporating aggregates and binders used in this study.

Table 1. Physical properties of coarse and fine aggregates used

Physical properties	Styrofoam	River Sand	Crushed Gravel
Specific gravity (SSD condition)	0.77	2.65	2.66
Moisture content (%)	-	0.02	0.01
Water adsorption (%)	-	1.65	0.79
Bulk density (kg/m^3)	35.9 (20 square mm Styrofoam) 37.6 (10 square mm Styrofoam)	1663.65	1585.23
Fineness Modulus	-	2.84	6.31

Table 2. Physical properties of binders used

Physical Properties	Ordinary Portland Cement (OPC)	Pulverized Fly Ash (PFA)
Fineness (Blaine Specific Surface) (cm^2/g)	3200	1800
Standard Consistency (%)	(100% OPC) 25.6	(90% OPC + 10% PFA) 28.1

3.3 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 PFA (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.

3.4 Testing

With the mix design that been identified, the compressive strength at concrete age of 28 days were determine throughout the mix design which shown in Table 3. For compressive test sample, it was cast into a 100mm x 100mm x 100mm cube and was conducted by using Universal Testing Machine located in Material Lab, Universiti Tun Hussein Onn Malaysia. Three test specimens for each mix design were prepared for testing. 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.

4. RESULTS AND DISCUSSIONS

4.1 Mix Design

Mix design is purposely done to produce trial mix which measures it's possible to obtain our target strength. In this paper, two mix design approach were used; namely advanced DOE Method and FIP Lightweight aggregate design. Both designs were carried out based on targeted strength of 40 N/mm^2. It is then known as Series 1 and Series 2 respectively. Advanced DOE Method based on few modifications according to specific gravity. As mentioned in the BS8110, the cement content in concrete mixture should not exceeds 550 kg/m^3, all Styrofoam concrete mixture were designed with cementitious content of 453 kg/m^3, therefore the same amount of water-binders ratio. The slump of the fresh concrete prepared was measured using standard slump test and compacting factor apparatus. Few trial mix were carried out, and the focus is to determine the best mix design that produces lightweight aggregates concrete for structural purposes.

Table 3. Series of palm oil clinker concrete mix

No.	Mix Design	Size of Styrofoam used	% of PFA replacement	Mix Proportion (OPC:PFA:FA:CA)	Mix Designation
1	Advanced	20 square mm	0	1:0:1.38:0.19	S1A
2	DOE	20 square mm	5	1:0.05:1.47:0.20	S1B
3	Method	20 square mm	10	1:0.12:1.56:0.20	S1C
4	(Series 1)	20 square mm	15	1:0.19:1.66:0.21	S1D
5		10 square mm	0	1:0:1.38:0.21	S1E
6		10 square mm	5	1:0.05:1.48:0.21	S1F
7		10 square mm	10	1:0.12:1.56:0.22	S1G
8		10 square mm	15	1:0.19:1.66:0.22	S1H
9	FIP	20 square mm	0	1:0:1.72:0.098	S2A
10	Lightweight	20 square mm	5	1:0.05:1.82:0.10	S2B
11	Design	20 square mm	10	1:0.11:1.92:0.11	S2C
12	(Series 2)	20 square mm	15	1:0.18:2.03:0.11	S2D
13		10 square mm	0	1:0:1.72:0.10	S2E
14		10 square mm	5	1:0.05:1.82:0.11	S2F
15		10 square mm	10	1:0.11:1.92:0.11	S2E
16		10 square mm	15	1:0.18:2.03:0.12	S2F

In order to produce cohesive mix to restrain the Styrofoam from floating on the surface of the concrete mixture, pozzolans like PFA can be used to replace OPC. In this case, three mix design of lightweight Styrofoam concrete incorporating PFA replacement level; namely 0%, 5%, 10% and 15% were used. This range is normally used in cement replacement study by many researchers. However, there are few researchers doing studies on cement replacement with large volumes of pozzolans up to 70% [13]. Since lightweight Styrofoam has a hydrophobic nature and smooth surface, this will help the concrete to achieve required workability for full compaction during placing. This research aims at producing lightweight concrete for structural use; mix design was developed with less water-binders ratio for producing higher strength purposes.

All the mix design was fixed for their water-binders ratio at 0.40. Superplasticizers (sulfonated, naphthalene-formaldehyde condensate type) was added 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 [7], the superplasticizer dosage went up to 1.75 litre per 100 kg binders, the one day strength of concrete decrease to a certain extent.

4.2 Density

Density was taken based on BS1881: Part 114: 1983 *Methods for Determination of Density of Hardened Concrete*. .It was observed that the Styrofoam aggregates were compressed during its mixing process and yet, it will produced higher densities of concrete than the designed densities of concrete by about 50-100 kg/m^3. Styrofoam concrete produced in the range of 1297-1387 kg/m^3 i.e., about 45% savings in total dead load of a structural member compared to conventional concrete. Styrofoam concrete incorporating with PFA produced higher density than other Styrofoam concrete series due to pozzolanic reaction which produced more dense concrete which the concrete matrix become closer each other. However, compared to control series mixture, it still benefits about 37% of the total concrete self-weight. Density for all mix design was shown in Table 3.

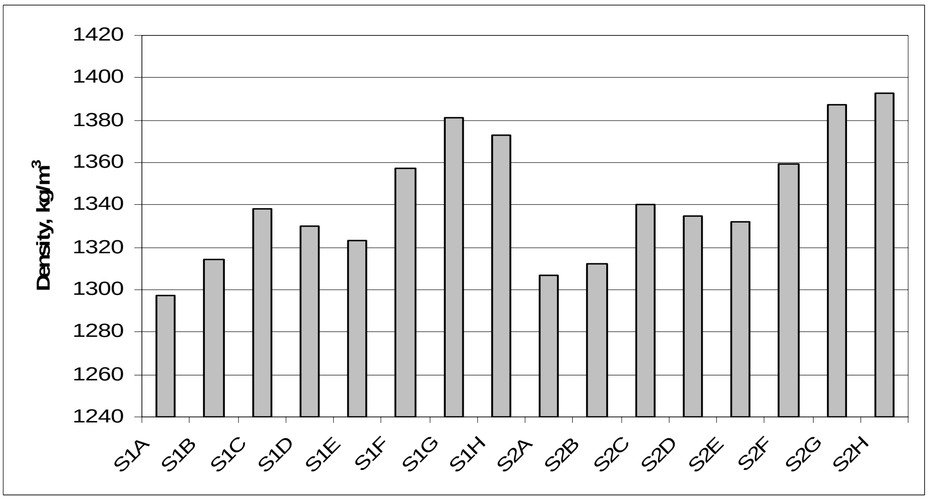

Figure 2: Density of lightweight Styrofoam concrete with different fly ash proportions

4.3 Workability

From the Styrofoam concrete series mixture, all the lightweight Styrofoam concrete shows good slump values if compared to the control concrete at constant water cement ratio and it is observed in all Styrofoam series mixture that no segregation was observed. This might due to the smooth surface of Styrofoam aggregates that eases the flowing in the concrete matrix. By adding PFA into the Styrofoam concrete mixture will increase the workability of the fresh concrete due to spherical shape of PFA particles and therefore the “ball bearing effects” coming into picture. From all the series, series of Styrofoam with cement replacement of PFA gave highest in terms of workability performance followed by series of Styrofoam concrete using 100% of OPC and control concrete gave the least.Properties of fresh concrete; i.e., workability were measured throughout all the series mixes. The fresh concrete properties are shown in Table 4.

Table 4. Fresh concrete properties

Series	**Slump (mm)**	**Compaction factor**
S1A	131	0.95
S1B	135	0.96
S1C	140	0.97
S1D	140	0.97
S1E	136	0.96
S1F	140	0.97
S1G	143	0.97
S1H	145	0.98
S2A	133	0.96
S2B	138	0.96
S2C	140	0.97
S2D	140	0.97
S2E	135	0.97
S2F	142	0.97
S2G	144	0.98
S2H	147	0.98

4.4 Compressive Strength

For two types of lightweight Styrofoam aggregates mix design; namely Advanced DOE Method and FIP Mix design, the compressive strength at testing day 28-days is shown in Figure 3 and 4 respectively. The compressive strength obtained was in the range of 3.1 – 6.9 N/mm^2 depends on its mix-design and PFA replacement level. For lightweight structural purposes, it is required to achieve at least 17 N/mm^2 to be suitable for structural use. All samples for the mix design were water-cured before testing to assure adequate hydration takes into place.

Comparison between Series 1 and Series 2 shows that Series 2 has higher strength developed at 28-days. This might due to the approach of mix design itself which FIP was tailored for lightweight concrete while DOE method is design for normal weight concrete. However, in this case, DOE Method was carried out based on the specific gravity of lightweight Styrofoam aggregate which might be too low and this method might seem not appropriate for Styrofoam mix design. Although design of FIP Method produced higher compressive strength than DOE Method, but it is still too far from the target strength of 40 N/mm^2 at 28-days as outlined in the guidelines. It is suggested that FIP Mix needs to be modified for Styrofoam use which has low bulk density and specific gravity. Both series shows that there was no mix design achieved compressive strength at 28-days more than 17 MPa; even far from reaching that value even for higher PFA replacement level which are not suitable for structural use.

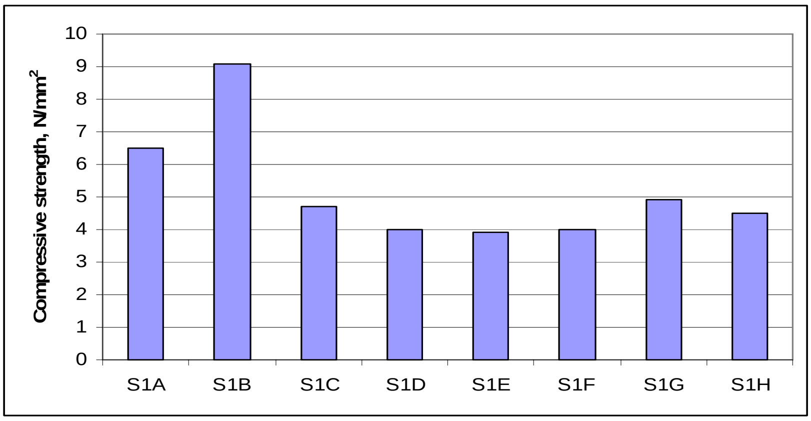

Figure 3: Compressive strength of lightweight Styrofoam concrete incorporating with different PFA replacements obtained for Advanced DOE mix design at 28 days.

Styrofoam aggregates has a low modulus due to it is compacted when compressed due its air-filled to make it lightweight. This can be shown during the mixing process. Although Styrofoam aggregates do not adsorbs much water and has hydrophobic characteristics, it has low modulus and affects its compressive strength. The concrete strength depends on the strength, stiffness and density of coarse aggregates. From the compression test at 28-days concrete age, it is observed that the failure is due to the bond between Styrofoam and cement paste. From here, we can conclude that, the Styrofoam should be bond with rough surface to make stronger bond with cement paste.

Basically, the denser the concrete, the higher is the density and therefore gave higher compressive strength. In this study, the objective is to produce lightweight concrete but at the same time it has good workability and strength. However, the relationship with density shows that, the more density will directly give the higher compressive strength. There are two types of strength that contributes to the compressive strength which is the strength of the aggregates and strength of the cement paste. In this study, we try to produce strong cement paste to bond with the Styrofoam aggregates.

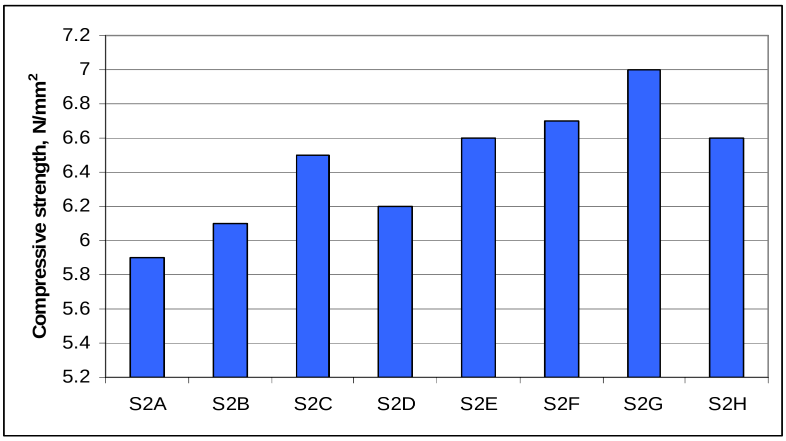

Figure 4: Compressive strength of lightweight Styrofoam aggregate concrete with different PFA replacements level using FIP Mix design at 28-days

FIP Mix design shows better results compared to advanced DOE Methods. Tests on the Styrofoam aggregates concrete shows that the compressive strength at 28-days increased from 0% PFA replacement, followed by 5% PFA replacement and the highest is 10% PFA replacement level. However, for 15% PFA replacement level, there is a drop in compressive strength. As founded by Neville, optimum compressive strength of PFA replacement level was obtained by 10% only. From Figure 4, 15% PFA replacement level in cement content can produce 0.3 and 0.4 N/mm^2 higher in terms of compressive strength.

Basically, the fly ash from its silica oxide components reacts with Calcium hydroxide which produces from hydration product combines to produces extra gel component calcium-silicate-hydrate that contributes to the strength of the concrete. It fills the micro voids within the cement-stone matrix that makes the concrete denser and stronger. This mechanism might be straight forward for addition of OPC without replacing any amount of pozzolans. For replacing pozzolans, there might be essential chemical composition of OPC that omitted and does not contributes to the process of hydration. Should be bear in mind that pozzlanic reaction is a secondary phase after the hydration process takes place. In this case only 10% of PFA replacement level gave the highest strength, i.e., 7.0 N/mm^2.

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 13-16% compared to series using 20 square mm Styrofoam size. From Figure 3 and 4 we can see that 10 square mm Styrofoam aggregates concrete gave higher compressive strength at 28 days compared to concrete using 20 square mm Styrofoam aggregates.

Figure 5: Compression test samples of lightweight Styrofoam aggregate concrete

During compression strength cube test, all the Styrofoam mix-design shows the failures was due the bonding between lightweight Styrofoam aggregates used and cement paste as shown in Figure 5. Since no mix design that can produce strength even closer to 17 MPa, we have to look into the physical properties for the Styrofoam that been employed or to enhanced the bond with cement paste, the Styrofoam used have to be treated in certain way. For untreated Styrofoam, the concrete produced is only suitable for general purposes and not for structural use applications.

5. CONCLUSIONS

The main findings upon the mix design of Styrofoam concrete have been carried out in this study are listed a follows:-

1. FIP Lightweight Mix design produces better compressive strength at 28-days compared to Advanced DOE Methods.
2. Lightweight Styrofoam concrete series with 10% fly ash replacement in cement content produce higher compressive at 28-days than other PFA replacement level.
3. 10 square mm lightweight Styrofoam concrete produces higher compressive strength at 28-days compared to 20 square mm Styrofoam aggregates used.
4. There is no single mix design can produce compressive strength more than 17 N/mm^2 to be used as structural members.
5. The Styrofoam need to be treated before it might be suitable for structural purposes applications.

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