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Selecting of Cementing Material in Green Lightweight Concrete with Oil Palm Shell (OPS)

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Abstract: Floating urbanization could be the subject of a green flood mitigation strategy. The main part of any floating house is the buoyant part, which is made from concrete pontoons. Aggregates play the most important role in making concrete a lightweight material. Oil Palm Shell (OPS) is an agricultural waste material, which is widely available in South East Asia. This study tries to select the best cementing material from waste and produced pozzolans, to improve the specifications of green lightweight concrete with Oil Palm Shell (OPS), using decision-making methods. The decision making model was conducted by the application of a Fuzzy Preference Selection Index (PSI). Quantitative data was obtained from laboratory testing, which was translated into fuzzy functions, and qualitative data was obtained through verbal interviews. Silica Fume (SF) contributed the best performance of all pozzolans, with a 25% replacement in green lightweight concrete, with Oil Palm Shell (OPS).

Key words: Concrete technology and manufacture, floods and flood works, materials technology, strength and testing of materials

INTRODUCTION

Today, humans seek methods of developing society and improving living conditions (Hosseini, 2009). However, flooding has led to many natural disasters, affecting a great number of people and causing incalculable economic losses. Every year, flooding causes more property damage than any other type of natural disaster (Caraballo-Nadal *et al*., 2006). There are several different methods for reducing flood vulnerability. One of these flood protection methods is floating urbanization. Floating urbanization can potentially reduce the vulnerability of delta areas. Floating houses adapt to rising water levels and can potentially function as emergency shelter during flood events. Dyson (2006) warned about the increasing risk of flooding, due to global warming in the UK. This researcher suggested innovative floating houses as a possible solution for the UK (Ray, 2010). Furthermore, Weijgert (2007) presented floating platforms for building floating houses on floodplains. The platform consisted of a polystyrene raft that provides buoyancy, topped with a concrete floor. Providing environmentally safe buildings and prevention from getting wet to settlers, was introduced as a preference to attain in this different building approach (Weijgert, 2007). Other research defined amphibious houses as houses standing or laying on piles and divided floating mobile houses and amphibious houses, into separated categories (Schuwer, 2007).

The above could reveal the importance of amphibious housing as a green flood mitigation strategy. However, as the main portion of any amphibious house is the buoyant part, in most literatures, it is advised that concrete pontoons be used in floating structures (Holdsworth, 2007a, b, c; Holdsworth, 2008; Koh and Seow, 2008).

Yang (2007) divided floating houses into three categories. The first is low-cost floating houses that are normally constructed without any proper design specifications, by fully counting on the light density of the floating structure. Yang mentioned recyclable materials, such as empty oil tanks, disposed construction cladding/hoardings and wood, formed the platforms of

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this type of floating house. These houses were recommended for temporary usage only. The researcher highlighted the lack of safety associated with these types of structure (Yang, 2007).

The second category referred to the design of a floating pontoon, using hollow fibre glass blocks or concrete blocks, depending on their application. He also offered the usage of expanded polystyrene blocks, within concrete blocks, to prevent leakage into the concrete hollow.

The last category is a new type of floating house that was recently developed in Holland. They incorporate a hollow concrete cube at the base, to give them buoyancy. A vertical pile keeps them anchored to the land (Yang, 2007). For this reason, the potential of using green lightweight concrete blocks should be investigated in this research. There are numerous functionalities for concrete structures and due to worldwide popularity, approximately 10 billion tons of concrete is produced and consumed annually (Meyer, 2009).

Lightweight aggregate: One way of making non-structural and lightweight concrete for buoyancy, is to incorporate lightweight aggregates. These aggregates can be classified into three main groups:

- Natural lightweight aggregates, such as pumice [most widely used], scoria, volcanic cinders, tuff and diatomite
- Rotary kiln produced lightweight aggregates, such as expanded clays, slates, slagand perlite
- Artificial aggregates, such as Expanded Polystyrene (EPS)
- Agricultural waste materials, such as Oil Palm Shell (OPS) (Shafigh *et al*., 2011)

Lightweight concrete is more expensive than normal concrete, unless waste materials are used. Another disadvantage of lightweight concrete is lower strength; which is unimportant for this specific project.

The replacement of normal gravel by waste material(s) has the positive potential of greening by itself, to reduce natural resource consumption. In addition, it avoids the loss of assets by using free waste materials, instead of natural gravel. However, in the lightweight concrete industry, using EPS is more common and as such, has a production process and resultant gas emissions. Furthermore, concerning polystyrene's inherent specifications, it cannot be recycled naturally and is thus assigned as an environmental pollution. Although based on very low density, the price of this material is not particularly high (around 50 Ringgit Malaysia per 5 Kg). When compared to other free waste materials, it should not be considered as an economic material at all. Table 1 shows the green factor analysis summary, for each material. Oil palm shell is a crushed agricultural waste material, which is available in large quantities in South East Asia (Shafigh *et al*., 2011).

CEMENTING MATERIALS

Manufacturing and developing cement-based materials have strong negative effects on the environment. The production process, transportation and concrete casting, are associated with both energy consumption and pollution. Thus, the main defects of using cement-based materials can be summarized as Natural Resource Destruction, Waste of Assets and Environmental Pollution. However, using waste powder materials, disposed of by other industries as pozzolanic materials, for cement replacement makes an acceptable reduction in the demand for cement (Ahmad *et al*., 2008; Cyr *et al*., 2007; Saraswathy and Song, 2007).

According to the inherent effect of agricultural waste material on concrete specifications, the application of cement replacement with pozzolan should be considered for any further improvement. For instance, the strength of concrete could be improved by replacing pozzolans, such as Silica Fume (SF) (Khedr and Abou-Zeid, 1994; Jalal *et al*., 2012), Metakaolin (MK) (Brooks and Megat Johari, 2001; Siddique and Klaus, 2009; Poon *et al*., 2006), Fly Ash (FA) (Sata *et al*., 2007; Thomas *et al*., 1999), Rice Husk Ash (RHA) (Ramezanianpour *et al*., 2009; Sata *et al*., 2007) and Palm Oil Fuel Ash (POFA) (Sata *et al*., 2007; Budiea *et al*., 2010; Chalee *et al*., 2010), with OPC. However, the workability of concrete using these pozzolans, changed based on literatures (Khedr and Abou-Zeid, 1994; Brooks and Megat Johari, 2001; Nochaiya *et al*., 2010; Sata *et al*., 2007; Ramezanianpour *et al*., 2009). Using the pozzolans mentioned above, could improve durability of concrete and decrease permeability, depending on the percentage of replacement (Alexander and Magee, 1999; Khatib and Clay, 2004; Chindaprasirt *et al*., 2008; Bui *et al*., 2005; Chalee *et al*., 2010).

The environmental impacts of pozzolans can be evaluated in two main categories. First, is the amount of pollution emitted by them and second, is the level of cement replacement. Cement production is acknowledged as being the most polluted stage in the lifecycle of concrete. Therefore, a lower consumption of cement can reduce the pollution created during the lifecycle of concrete products. However, CO_2 emissions, as a main component of pollution during cement production, are raised.

Table 1: Different aggregates in lightweight concrete

Material	Specific density (Kg/m^3)	Relation of less-permeability with replacement	Ref.	Environmental impact base on production procedure	Economy factor in Malaysia
Normal gravel	2450	-	-	Negative	Cheap
EPS	16	Descending	(Babu *et al*., 2006)	Negative	Cheap
Oil palm shell	500-600	Descending	(Mannan and Ganapathy, 2002; Teo *et al*., 2007)	Positive	No price

This study attempts to evaluate the potential of utilization of Oil Palm Shell (OPS) (Malaysian agricultural waste material) instead of EPS, as an approach to green lightweight concrete. The objective of this study is to identify the best cementing material, amongst waste and artificial pozzolan(s), to improve the specification of green lightweight concrete, by using decision-making methods. For this reason, the fuzzy Preference Selection Index (PSI) method has been chosen.

METHODOLOGY

Qualitative criteria: Since this study attempts to evaluate the performance of different cementing materials with OPS, some qualitative criteria should be considered for their evaluation. Environmental impact is the most important factor that provokes researchers to apply waste material in concrete. Therefore, in this study, environmental impact is one of the major factors considered, for qualitative evaluation. Another factor is that of economic impact. Although the price of each material represents a piece of quantitative data, prices can vary with respect to geographical locations. As a result, this research considered economic impact as qualitative data, in the range of cheap (free) to expensive.

Conversation scales are the most applicable tools applied to transform linguistic terms into fuzzy numbers. In Liang's (1999) study, the decision maker employed a five member linguistic weighing set {VL, L, M, H, VH} to weigh criteria, where VL=Very Low = (0, 0, 0, 3), L = Low = (0, 3, 3, 5), M = Medium = (2, 5, 5, 8), H = High = (5, 7, 7, 10) and VH = Very High = (7, 10, 10, 10) (Liang, 1999). In this study, all criteria (both qualitative and quantitative) have been weighed by a panel of experts, with respect to the effectiveness of their idea, for improving the performance of green lightweight concrete.

In 2010, another study was conducted on supplier selection. The researchers used normal fuzzy linguistic variables, based on seven stages, including VL = Very Low = (0, 0, 0.1, 0.2), L = Low = (0.1, 0.2, 0.2, 0.3), ML = Medium Low = (0.2, 0.3, 0.4, 0.5), M = Medium = (0.4, 0.5, 0.5, 0.6), MH = Medium High = (0.5, 0.6, 0.7, 0.8), H = High = (0.7, 0.8, 0.8, 0.9) and VH = Very High = (0.8, 0.9, 1, 1). These linguistic rating scales were used as fuzzy ratings for each alternative versus each criterion (Sanayei *et al*., 2010). The structured interview was performed to unite the expected behaviour from three types of pozzolans (i.e., Silica Fume (SF), Fly Ash (FA) and Palm Oil Fuel Ash (POFA)) according to the literatures and their performance in reality, based on the experience of six experts. The interviewees were three professors from Iran and Malaysia, who are well known in concrete technology and three experts, who worked in mega international concrete structure projects. They ranked the performance of each material using the qualitative criteria for using green lightweight concrete, by the linguistic variables.

Quantitative criteria: Three important criteria should be achieved from the laboratory test results, for performance evaluation of green lightweight concrete. Although the concrete, which is used for concrete pontoons, should not satisfy the structural reason, compressive strength contributes more to a durable green light weight concrete. Compressive strength was measured for 10 cm cubed specimens over 7, 28 and 120 days. Any cementing material, which is replaced by cement, should make the concrete easy to use. Workability is a parameter that is measured by slump-test, based on BS EN 12350-2:2009, for testing fresh concrete. The final criterion is permeability. Since the pontoons are designed to float on water, permeability should be avoided. However, pozzolans improve the waterproof specification of concrete (Chindaprasirt *et al*., 2008; Chindaprasirt *et al*., 2007). An effective test to quantify this criterion determines the initial surface absorption of dried specimens (ISAT test), based on BS 1881-5:1970, for non-oven dried samples.

Materials characteristics: Oil palm shells are the waste material of palm oil factories in Malaysia. These lightweight shells were collected from a palm oil factory in Kota Tinggi, Malaysia. The oil palm shells were sieved and aggregated into three categories (i.e., 9.5 to 4.75, 4.75 to 2.36 and 2.36 to 1.18 mm). The use of crushing OPS aggregates was recently recommended in literatures (Shafigh *et al*., 2011). The coarse aggregate of concrete in specimens, obeys the size number of 89 from C 33-03 Standard of Specification for Concrete Aggregates-ASTM. The lightweight aggregate (OPS) was replaced by 50% (volume) of the coarse aggregate. Table 2 presents the physical properties of the coarse aggregates used in this study.

9.5-4.75 mm 4.75-2.36 mm 2.36-1.18 mm

Fig. 1: Aggregated OPS used in green light weight concrete

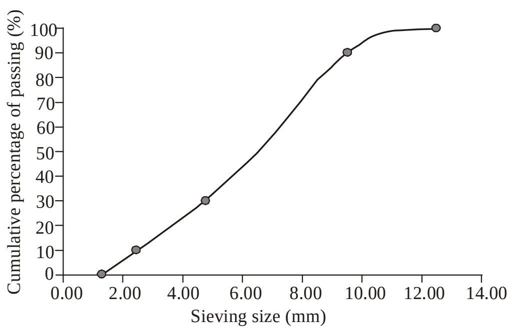

Fig. 2: Cumulative percentage of passing coarse aggregate through sieves

Table 2: Physical properties of coarse and lightweight aggregates

Physical property	OPS	Crushed stone
Specific gravity (saturated surface dry)	1.19	2.61
Water absorption (24 h)	21.2%	0.75%
Bulk density	590 kg/m^3	1472 kg/m^3

Table 3: Chemical and physical properties of binders

	Chemical properties			
Item	Cement	Silica fume	Fly ash (FA)	POFA
SiO_2	23.5	93.7	51.2	43.5
Al_2O_3	5	0.29	24	11.5
CaO	62	0.4	5.6	8.4
Fe_2O_3	3.4	0.36	6.5	4.7
MgO	2.8	0.85	2.4	4.6
SO_3	1.4	0.35	0.88	2.5
K2O+Na2O	1	-	3.6	3.9
	Physical properties			
Density (g/cm^3)	3.10	2.20	2.1	2.30
Specific surface area (m^2/g)	0.37	20~23	0.212	0.53
Average particle size	15 µm	0.1~0.3 µm	6.4 µm	20-35 µm

The fine aggregate sizing also obeys aggregating, regarding C33-03 Standard of Specification for Concrete Aggregates-ASTM. Figure 1 shows the different aggregations for OPS. The passing diagram of coarse aggregate is illustrated in Fig. 2.

Rather than using Ordinary Portland Cement (OPC) complying with BS4550: Part 2, three different pozzolans were applied in this study. Silica fume was purchased from a Malaysian factory. The properties of silica fume are listed in Table 2. Fly ash and Palm Oil Fuel Ash (POFA) are the other two waste materials, which were used to replace cementing materials, in the green lightweight concrete. POFA, which was provided from the palm oil factory in Kota Tinggi, required graining and sieving. However, the characteristics of the processed POFA over that of the purchased FA, are illustrated in Table 3.

Preference Selection Index (PSI) method: Jahan clarified that MCDM methods are divided into two main groups, namely; Multiple Objective Decision Making (MODM) and Multiple Attribute Decision Making (MADM) approaches. Each method has its own characteristics, which can both be combined with fuzzy methods. MADM is a technique, which evaluates the performance of alternative materials versus multiple criteria. There are numerous techniques introduced as a subset of this method in previous studies and literatures (Jahan *et al*., 2010). The PSI method was introduced as a systematic scientific method (Maniya and Bhatt, 2010). Previous studies used normal ranking methods for their alternatives and did not make any considerations for their weighing criteria. Fussy linguistic terms have been used for weighing criteria and rating materials under qualitative indicators. Materials were also rated using quantitative criteria. The detailed PSI procedure, used in this research, is as follows:

Step 1: Identification of the final goal-identifying all possible cementing material alternatives and selecting related criteria for achieving the highest performance.

Step 2: **(only where qualitative data is applicable):** Determining the degree of effectiveness of the researchers' career or background ($\tilde{e}r$), based on their own linguistic ideas and assuming that there is a committee of 'k' researchers, responsible for assessing 'm' alternatives, which $\{C_i; C_1, C_2,..., C_m\}$ under each of the 'p' criteria $\{F_j; j = 1; 2; . . . ; p\}$.

Step 3: Assessment of criteria importance and computation of aggregated fuzzy weights of individual criteria. Let $\tilde{w}_{jr}$, j = 1; 2; ...; p and r = 1; 2; ...; k be the linguistic weight for each category given to criteria F_j; j =1; 2; . . . ; p by researchers in qualitative data and $\tilde{w}_{jr}, r = 0$ is the linguistic weight for quantitative data. The aggregated fuzzy criteria weight $\tilde{w}_j$; j = 1; 2; . . . ; p; of attribute F_j for qualitative data assessed by the committee of k professionals (researchers) is defined as illustrated in Eq. (1):

$$\tilde{w}_j = \left(\tilde{e}_1 \otimes \tilde{w}_{1j}\right) \oplus \left(\tilde{e}_2 \otimes \tilde{w}_{2j}\right) \oplus ... \oplus \left(\tilde{e}_k \otimes \tilde{w}_{kj}\right) \quad (1)$$

Step 4: Using linguistic rating variables, including seven member weights, for researchers to assess fuzzy ratings of alternatives with respect to individual indicators and then collect them to obtain the aggregated fuzzy ratings for each category. In, $\tilde{x}_{ijr}$ 'i' is the index for alternatives, 'j' is the index for criteria, 'r' is the index for researchers in qualitative criteria and 'r' is considered zero for quantitative data. In this current study, the author define $\tilde{x}_{ij}$ as the aggregated fuzzy rating of alternative Ci for indicator Fj. Equation (2) illustrates the procedure of extracting aggregated factor $\tilde{x}_{ij} = (a, b, c, d)$. A defuzzifying process was applied to all aggregated fuzzy ratings and Xij was developed by COA methods, as illustrated in Eq. (3) (Sanayei *et al*., 2010). Table 4 shows the decision matrix after the defuzzification procedure:

$$\tilde{w}_j = \left(\tilde{e}_1 \otimes \tilde{w}_{1j}\right) \oplus \left(\tilde{e}_2 \otimes \tilde{w}_{2j}\right) \oplus ... \oplus \left(\tilde{e}_k \otimes \tilde{w}_{kj}\right) \quad (2)$$

$$X_{ij} = d\left(\tilde{x}_{ij}\right) = \frac{\int x.\mu\tilde{x}_{ij}(x)dx}{\int \mu\tilde{x}_{ij}(x)dx} = \frac{-ab + cd + \frac{1}{3}(d-c)^2 - \frac{1}{3}(b-a)^2}{-a-b+c+d} \quad (3)$$

Step 5: Since, in any decision matrix, the data should be assigned in compatible modes and a different data measurement is required to apply the rating numbers in each part; a process of normalization is required in multi-criteria decision-making methods, where values change into a range of 0-1. If the larger amount gains better results, then the aggregated value Xij can be normalized for each criterion as follows:

Table 4: Decision matrix

Cementing alternatives	Indicators F_1	F_2	...	F_p
C_1	X_{11}	X_{12}	...	X_{1p}
C_2	X_{21}	X_{22}	...	X_{2p}
⋮	⋮	⋱	⋱	⋮
C_n	X_{n1}	X_{n2}	...	X_{np}

$$R_{ij} = \frac{X_{ij}}{X_j^{Max}} \quad (4)$$

In addition, if the smaller amounts get better results (same as cost) Eq. (5) would be applied to the normalization process:

$$R_{ij} = \frac{X_j^{Min}}{X_{ij}} \quad (5)$$

Step 6: The study used variance analogy to compute the Preference Variation index (PV_j). Since, $\bar{R}_j$ is the mean of normalized raking values Eq. (6) and (7) uses the variance process for all R_{ij} values:

$$\bar{R}_j = \frac{\sum_{i=1}^{n} R_{ij}}{n} \quad (6)$$

$$PV_j = \sum_{i=1}^{n} \left(R_{ij} - \bar{R}_j\right)^2 \quad (7)$$

Step 7: Preference Values (PV_j) are related to straightforward ranking, even though interviewees responded to the importance of each indicator, based on their research experience independently. It is a requirement to find deviation (Φ_j) in the preference value (PV_j), which can combine with the weighting factors for each indicator ($\tilde{w}_j$). The overall preference value ($\tilde{\psi}_j$) is determined based on these two factors, which are considered more precise, since the interviewees' opinion was engaged with the straight forward ranking results for each

Table 5: Mechanical properties for different concrete mixtures

ID	Cementing (%) OPC	SF	FA	POFA	W/C (%)	Fine aggregate (Kg/m^3)	Coarse aggregate (Kg/m^3)	OPS volumetric replacement (%)	Compressive strength (MPa) 7 days	28 days	120 days	Slump (mm)
OPS/O	100	0	0	0	0.55	845	422.5	50	9.83	16.99	22.97	76
OPS/S	75	25	0	0	0.55	845	422.5	50	9.25	14.7	17.82	52
OPS/F	75	0	25	0	0.55	845	422.5	50	4.95	8.48	9.805	108
OPS/P	75	0	0	25	0.55	845	422.5	50	6.09	7.94	11.745	67

indicator. To obtain the overall preference value, it is required to find deviation (Φ_j) in the preference value (PV_j). The deviation in preference value for each criterion is determined using Eq. (8):

$$\Phi_j = 1 - PV_j \tag{8}$$

The overall preference value ($\tilde{\psi}_j$) is determined by applying Eq. (9).

$$\tilde{\psi}_j = \frac{\Phi_j \otimes \tilde{w}_j}{\sum_{j=1}^{p} \Phi_j \otimes \tilde{w}_j} \tag{9}$$

Step 8: Calculation of the preference selection index (I_i). The preference selection index can be determined for each alternative using Eq. (10) and then defuzzified using the COA method:

$$\tilde{I}_i = \sum_{j=1}^{p} \tilde{\psi}_j \otimes R_{ij} \tag{10}$$

Step 9: According to the preference selection index, calculated for each alternative, the materials in each category can be ranked either in a descending or ascending order. The first ranked is considered as a result and can be monitored by any related literature, in parallel lines.

RESULTS AND DISCUSSION

Compressive strength: A minimum of three specimens, sized 10×10×10 cm, were tested, in order to estimate the compressive strength over 7, 28 and 120 days, respectively. Table 5 illustrates the results for the different types of green lightweight concrete. To avoid any possible variations in strength, due to surface moisture, all strength specimens were tested in saturated surface dry conditions.

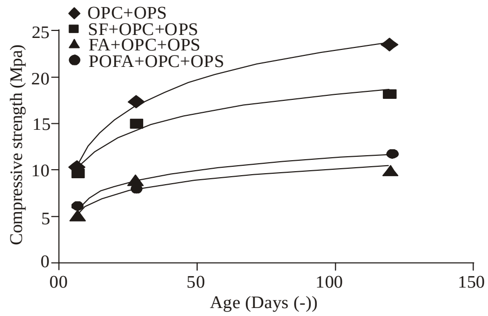

Fig. 3: Comparative results for compressive strength by effect of different cementing materials in different ages

The compressive strength of the control specimens (OPC+OPS) after 7 days was nearly 10 MPa, which kept increasing and reached more than 20 MPa after 120 days; which constitutes a 100% increase. The compressive strength of all specimens kept increasing during the increasing lifetime of the concrete. The application of silica fume in the green light weight concrete achieved the highest strength of all cementing materials, by a 25% replacement. Figure 3 shows the comparative results for all specimens with different cementing materials and a fixed percentage of replacement (i.e., 25%).

To transpose the quantitative data into fuzzy numbers, a trapezoidal function was applied. The membership function for a trapezoidal fuzzy number $\tilde{A}$; $\tilde{A}$ = (a, b, c, d), a<b<c<d on universe R is defined for compressive strength, as a = 7 days comp. Strength (MPa), b = 28 days 7 days comp. Strength (MPa), c = 120 days comp. Strength (Mpa) and d = Maximum comp. Strength (MPa) among all specimens in that category.

Workability: The results of the slump-test for fresh concrete are shown in Table 5. According to the results, fly ash achieved the best improvement for both workability and flow-ability of green lightweight concrete. In contrast, the application of silica fume exposed the necessity of using supper plasticizers in concrete. Five classes of slump were designated by the European Standard EN 206-1:2000, as shown in Table 6. However, the transposing of these ranges into fuzzy numbers by using linguistic variables was applied in this research.

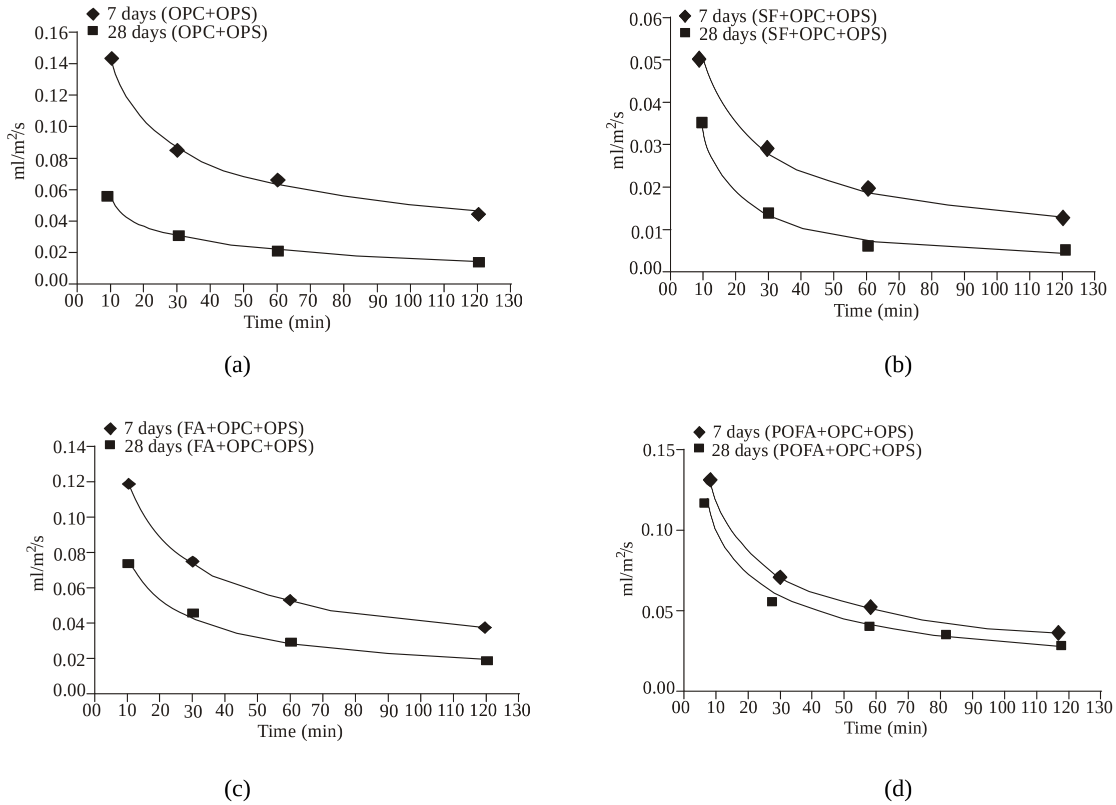

Fig. 4: ISAT results for different mixture after 7 and 28 days curing a) OPC+OPS, b)SF+ OPC+OPS, c) FA+ OPC+OPS, d) POFA+ OPC+OPS

Table 6: Classes of slump according to European Standard EN 206-1:2000 and transposing to fuzzy linguistic terms

Classes of slump according to European Standard EN 206-1:2000						
Consistence Class	Class Range (mm)	Typical Target Value	Maximum Variation Allowed (mm)	Fuzzy Translation Linguistic Terms	Abbreviation Linguistic Terms	Fuzzy Number Fuzzy Terms
S1	10 to 40	25mm	-20 to +30	Low Flow-ability	L	(0,0,0,3)
S2	50 to 90	70mm	-20 to +30	Moderate-Low Flow-ability	ML	(0,3,3,5)
S3	100 to 150	125mm	-20 to +30	Moderate Flow-ability	M	(2,5,5,8)
S4	160 to 210	185mm	-20 to +30	Moderate-High Flow-ability	MH	(5,7,7,10)
S5	>220	-	-	High Flow-ability	H	(7,10,10,10)

Permeability or Initial Surface Absorption Test (ISAT): Figure 4 shows the variation of ISA, with the test duration of OPS and control concretes, for 7 and 28 day ages. In contrast with most artificial lightweight concretes, the application of pozzolans exhibits a significant reduction in water absorption. In green lightweight concrete, moisture movement is governed by the fineness of the cement, the richness of the mixture, the w/c and the curing environment during the early ages. Otherwise, the pozzolans improved the permeability of concrete at an older age. Clearly, the application of silica fume with OPS exhibits the best waterproofing results. However, POFA and fly ash also provide reasonable results.

The quantitative results, which are achieved from laboratory tests, transpose into fuzzy numbers $\tilde{A}$; $\tilde{A}$ = (a, b, c, d), a<b<c<d on universe R. Since the effect of the older specimens is more than that of the younger ones (i.e., 7 days), each of the results have been weighted by their age. It is defined for permeability, as a = (water absorption for first 10mins in 7 days * 7 + water absorption for first 10mins in 28 days * 28)/(7+28), b = (water absorption for first 30 min in 7 days * 7 + water absorption for first 30 min in 28 days * 28)/(7+28), c = (water absorption for first 60 min in 7 days * 7 + water absorption for first 60 min in 28 days * 28)/(7+28) and d = (water absorption for first 120 min in 7 days * 7 + water absorption for first 120 min in 28 days * 28)/(7+28).

Economical impact: The economical factor is one of the most important factors, whilst the project is deducted to low cost housing and cheaper solutions for mitigating flood vulnerability. Ordinary Portland Cement is cheaper than some other materials. However, rising cement prices has become a major worldwide issue, especially in developing countries. Nevertheless, the application of waste materials and pozzolans as replacements to currently available cement opens new windows of opportunity for the future of construction technology. Some of these materials, such as fly ash, are cheaper than others, such as silica fume. Moreover, some of the new pozzolans are the same as POFA, but even though are waste materials and can be achieved free of charge, they still need to undergo processes, such as sieving and graining, to become fine enough for using in concrete.

Interviews were held in front of a panel of experts. The prices of each material and man-hours for each (if they need to be processed) were mentioned. Subjects were asked to respond with their level of appropriateness of each of the cementing materials, using economic considerations in linguistic terms, with the seven members (i.e., VL, L, ML, M, MH, H and VH, respectively).

Environmental impact: The environmental impact of pozzolans can be evaluated in two main categories. Firstly, the amount of pollution emitted by them and secondly, the level of cement replacement. Cement production has been identified as the most polluted stage in the lifecycle of concrete. Therefore, a lower consumption of cement can reduce the pollution created during the lifecycle of concrete products. However, CO_2 emissions, being the main component of pollution during cement production, are raised (i.e., one ton of CO_2 is developed for each ton of cement production). Therefore, reduced consumption of cement leads to a decrease in CO_2 emissions. If the pozzolan is a by-product of another major material, no pollution impact will be considered for that material.Therefore, in this case, the pozzolan has a neutral pollution factor.However, if the pozzolan's production were accompanied by heating and burning, a raw material pollution factor would be associated. This heating also leads to energy consumption, energy production, as well as environmental pollution (especially air pollution). So in order to make pozzolan production more environmental friendly, the production of less heat should be considered.Consequently, fly ash, silica fume and POFA, are pollution neutral.

The second aspect, of the environmental effects of pozzolans, is the cement replacement levels. More replacement means a greater effect on the environment. However, this factor is related to an optimum rate of replacement. Since in many projects, the optimum rate of pozzolan replacement is not calculated, the ability of each pozzolan is not realized by its optimum rate.Nevertheless, performance could be improved by modifying the characteristics of each pozzolans, for example; a pozzolan with finer grains and lower water to cementing materials, could be achieved. Table 4 illustrates environmental impact, based on energy consumption and heating temperatures; however, the replacement rate of pozzolans depends on the optimum rate stated in the strength evaluation.

Interviews were held in front of a panel of experts and the appropriateness of each material, in regards to the environment, was evaluated. Respondents were asked to offer their level of environmental impact for each of the cementing materials, in linguistic terms using the seven members (i.e., VL, L, ML, M, MH, H and VH, respectively).

Decision making by modified preference selection index (PSI) method: All qualitative and quantitative factors were evaluated experimentally or by a panel of experts. Quantitative data was subjected to fuzzy linguistic terms, as defined in Table 7. All of the linguistic data for qualitative factors that was obtained from the experts was modified and is shown in Table 7.

The following steps were carried out and the PSI method proceeded.

Step 1: To define the optimum performance of the cementing material, when OPS was used as a lightweight aggregate in the concrete. All possible cementing materials are defined as Silica Fume (SF), Fly Ash (FA) and Palm Oil Fuel Ash (POFA). Compressive strength, workability, lower permeability, environmental impact and economic impact, are selected as related criteria for selecting the highest performance.

Step 2: The panel of experts were selected from specific areas of expertise. Three of them are well-known professors in the concrete field from Southeast Asia and the Middle East, who get high degree of effectiveness. The other three experts are professional technicians, working with a well-known concrete research institution in the Middle East, who get medium high degree of effectiveness.

Step 3: Table 8 shows the importance of criteria using aggregated fuzzy weights. Since the floating houses could be used as a low cost solution, most of the experts agreed with a higher weight of economy impact. Thus, the effect of environmental impact, due to green lightweight aggregate, rose up. However, the compressive strength of concrete pontoons should obey the obligation of the non-structural reasons. Therefore, the weight of strength amongst the criteria is slightly lower than that of the others.

Step 4: $\tilde{x}_{ij}$ is defined as the aggregated fuzzy rating of alternative C_i for indicator F_j. Table 9 illustrates the defuzzified rating X_{ij} developed using COA methods.

Step 5: The normalized aggregated value X_{ij} for each criterion is shown in Table 10.

Table 7: Fuzzy terms regarding to different cementing materials with 25% of replacement

	Quantitative													Qualitative							
	Compressive strength				Workability				Least permeability					Environmental impact				Economy impact factor			
SF	9.25	14.7	17.82	18.56	0	3	3	5	0.0065	0.0089	0.017	0.038	R1*	0.7	0.8	0.8	0.9	0.5	0.6	0.7	0.8
													R2	0.7	0.8	0.8	0.9	0.4	0.5	0.5	0.6
													R3	0.7	0.8	0.8	0.9	0.2	0.3	0.4	0.5
													R4	0.7	0.8	0.8	0.9	0.1	0.2	0.2	0.3
													R5	0.7	0.8	0.8	0.9	0.2	0.3	0.4	0.5
													R6	0.7	0.8	0.8	0.9	0.4	0.5	0.5	0.6
FA	4.95	8.481	9.81	10.28	5	7	7	10	0.0225	0.0346	0.052	0.083	R1	0.7	0.8	0.8	0.9	0.5	0.6	0.7	0.8
													R2	0.8	0.9	1.0	1.0	0.7	0.8	0.8	0.9
													R3	0.8	0.9	1.0	1.0	0.7	0.8	0.8	0.9
													R4	0.7	0.8	0.8	0.9	0.4	0.5	0.5	0.6
													R5	0.5	0.6	0.7	0.8	0.4	0.5	0.5	0.6
													R6	0.7	0.8	0.8	0.9	0.5	0.6	0.7	0.8
POFA	6.09	7.938	11.75	12.01	0	3	3	5	0.036	0.047	0.065	0.126	R1	0.7	0.8	0.8	0.9	0.5	0.6	0.7	0.8
													R2	0.7	0.8	0.8	0.9	0.7	0.8	0.8	0.9
													R3	0.7	0.8	0.8	0.9	0.7	0.8	0.8	0.9
													R4	0.7	0.8	0.8	0.9	0.5	0.6	0.7	0.8
													R5	0.7	0.8	0.8	0.9	0.5	0.6	0.7	0.8
													R6	0.7	0.8	0.8	0.9	0.7	0.8	0.8	0.9

*R: respondent number

Table 8: Level of importance and weight regarding to the criteria

	Strength	workability	Less-permeability	Environmental impact	Economy impact
$\tilde{w}_j$	(104, 281, 281, 490)	(129, 309, 309, 540)	(228, 459, 459, 600)	(144, 323, 323, 560)	(163, 368, 368, 560)
Normalized & defuzzified weights (W_j)	0.166	0.186	0.245	0.195	0.207

Table 9: Defuzzified rating for alternatives due to criteria

Alternatives cementing materials	Compressive strength	Workability	Least permeability	Environmental impact	Economy impact factor
Silica fume (SF)	14.887	2.667	0.019	40.000	21.671
Fly ash (FA)	8.227	7.333	0.049	40.437	32.282
Palm oil fuel ash (POFA)	9.417	2.667	0.071	40.000	36.109

Table 10: Illustration of normalized aggregated values Xij for each criterion

Normalized numbers	Compressive strength	Workability	Least permeability	Environmental impact	Economy impact factor
Silica fume (SF)	0.458	0.2105	0.134	0.332	0.241
Fly ash (FA)	0.253	0.579	0.353	0.336	0.358
Palm oil fuel ash (POFA)	0.289	0.211	0.513	0.332	0.401

Table 11: Related indicators and R_{ij}

Alternatives cementing materials	Compressive strength	Workability	Least permeability	Environmental impact	Economy impact factor	Indicators
Silica fume (SF)	1	0.364	1	0.989	0.600	R_{ij}
Fly ash (FA)	0.553	1	0.381	1	0.894	
Palm oil fuel ash (POFA)	0.633	0.364	0.261	0.989	1	
	0.1139	0.26998	0.3144	7.77929E-05	0.0858	PV_j
	0.8861	0.7300	0.6856	0.99992	0.914	Φ_j
	(0.0526, 0.142, 0.142, 0.248)	(0.054, 0.129, 0.129, 0.225)	(0.089, 0.180, 0.180, 0.235)	(0.082, 0.184, 0.184, 0.320)	(0.085, 0.192, 0.192, 0.292)	$\tilde{w}_j$

Table 12: Preference selection index

	Silica fume (SF)	Fly ash (FA)	Palm oil fuel ash (POFA)
$\tilde{I}_i$	(0.293, 0.666, 0.666, 1.056)	(0.274, 0.632, 0.632, 1.032)	(0.242, 0.558, 0.558, 0.908)
I_i	0.6717	0.646	0.569
Rank123			

Steps 6-7: Normalized ranking values (R_{ij}) were obtained and are defined in Table 11. Based on variance analogy, the preference variation index (PV_j) was computed and is shown in Table 12. Moreover, the deviation (Φ_j) in the preference value (PV_j), which is combined with the weighting factors for each indicator ($\tilde{w}_j$) and the overall preference value ($\tilde{\psi}_j$) for all of the criteria, are defined in Table 11. Clearly,

silica fume and fly ash, with two $R_{ij} = 1$ under specific criteria, has more opportunity for selection than POFA, which is only preferred under the economical factor. Based on the preference value (PV_j) results, environmental consideration has the lowest variance in the decision procedure. However, by applying the weighting values, the amount of $\tilde{\psi}_j$ acquires the highest level for the least permeability factor.

Steps 8-9: The preference selection index (I_i) for each alternative was calculated and defuzzified using the COA method. Based on the values obtained for each type of cementing material, the highest value was achieved by Silica Fume (SF), followed by Fly Ash (FA) in second place. Table 12 illustrates the results of the preference selection index.

CONCLUSION

The application of lightweight concrete, for concrete pontoons in amphibious houses, is a major issue based on available literature. However, whilst the amphibious house is a green method of lowering flood vulnerability without an environmental effect, the material to be used in this technology is prospected to be replaced with green materials in the future. Based on the literatures, concrete as the main structural material in a floating house contains most of the negative factors and halts the movement of floating structures towards a green industry and strategy. Oil Palm Shell (OPS) has a very high potential of greening for lightweight concrete, based on the comparison of green factors. For instance, it causes the reduction of natural resource consumption, without pollution and could help us to achieve both a green and clean lightweight concrete industry. However, the performance of OPS should be improved by replacing the cement with fine pozzolans in lightweight concrete. Different criteria, towards sustainable and green production, were considered in this study, such as strength, workability, lower-permeability, economy and environmental factors. Since strength is not such an important factor for this type of concrete (i.e., to be used in pontoon structures), lower permeability and economy play significant roles as decision-making criteria. This issue was even proved by the weighting values collected from the panel of experts.

A fuzzy Preference Selection Index (PSI) method was used to compare and evaluate the best replacement cementing material for green light weight concrete, with a 25% of replacement. Fuzzy linguistic terms were used for the qualitative data (i.e., economy and environmental). The results from the quantitative data were translated into fuzzy terms using a trapezoidal function. Based on the fuzzy PSI results, silica fume was the most suitable material, amongst all other criteria, for the production of a sustainable and green floating pontoon. However, fly ash, which is achieved second place, conducts the highest level of appropriateness for the environment and workability to produce concrete pontoons. As a result, it is advised that the application of silica fume, with 25% of replacement, should be used in green lightweight concrete, with Oil Palm Shell (OPS).

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