INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY VOL. 11 NO. 1 (2020) 151-163

IJSCET

http://penerbit.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Potential of Using Palm Oil Fuel Ash and Expanded Polystyrene as an alternative Concrete Substance

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DOI: https://doi.org/10.30880/ijscet.2020.11.01.015
Received 24 February 2020; Accepted 30 March 2020; Available online 7 May 2020

Abstract: Recently, the use of recyclable materials as concrete materials has become increasingly popular. Many researchers have interested on the use of different materials such as fibre, pozzolanic materials, plastic, polystyrene, food waste and so on for the replacement of cement, fine and coarse aggregates, as well as sand. This is because the disposal of industrial waste and non-biodegradable materials such as plastic or polystyrene has increased drastically in recent years, thereby causing many problems to the environment. In addition, the palm oil industry has also been contributing to the increasing amount of industrial waste. Previous studies have identified the potential of palm oil fly ash (POFA) and expanded polystyrene (EPS) as concrete substances. The purpose of this study was to determine the compressive strength, density and thermal conductivity of concrete made using partial percentages of POFA and EPS as cement and fine aggregate replacement, respectively. The proportions of POFA used as a cement replacement were 10%, 20%, 30% and 40% by weight. Meanwhile, the proportions of EPS used as fine aggregate replacement were 10%, 20% and 30% by volume. The mechanical properties between concrete containing POFA and EPS and that of normal concrete were compared. The concrete samples were designed to achieve the target strength of 25 MPa at the age of 28 days. Through this study, the higher proportions of POFA and EPS used showed the lower compressive strength and density of concrete. The optimum percentages for cement and fine aggregate replacement were determined as 20% of EPS and 20% of POFA, respectively. The concrete compressive strength containing 20% of EPS and 20% of POFA closely achieved the strength of 20 MPa which is the highest compressive strength at 28 days compared to other percentages of replacement and fulfilled the requirements strength of structural concrete. Through this study also, showed the decrease in thermal conductivity was mainly contributed by the volume of EPS used. The lower thermal conductivity occurred due to EPS particles characteristic which is lower thermal capacity.

1. Introduction

Generally, the increasing disposal of industrial waste and non-biodegradable materials such as plastic and polystyrene has been causing many environmental issues such as pollution. Besides that, an estimated 24% of plastic waste are disposed of landfills in Malaysia (Tuan Ismail *et al.*, 2013). Other than that, palm oil processing plants is the one of the contributors to this issue. These wastes should be managed properly and reused for other purposes.

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Waste produced by palm oil industries is normally burnt at temperatures between 800-1000 ºC to produce electricity in palm oil mills. This burning process produce about 5% of the residue weight palm oil fuel ash (POFA). In, Malaysia, it is estimated that 10 million tonnes of POFA waste is generated from this burning process (Khankhaje *et al.*, 2017).

Other alternative materials can be used to replace natural raw material resources to create a sustainable environment. Furthermore, the excessive use of cement can lead to adverse effects as it generated a high level of carbon dioxide due to the chemical content of concrete substances. Therefore, studies should be conducted to determine the appropriateness of using recycled materials as a cement substitute.

The purpose of this study is to produce lightweight concrete using polystyrene beads and palm oil fuel ash as fine aggregate and fine cement replacements, respectively. POFA was selected to replace cement because of its delicate properties and its suitability as a binder. Meawhile, polystyrene beads were used to replace sand. Several laboratory relevance tests were performed to identify the mechanical properties of these materials.

2. Utilization of POFA and EPS in Concrete

EPS was chosen as a replacement for fine aggregate due to its plastic properties that can potentially make concrete more durable, along with better thermal insulation and resistance towards chemicals. Meanwhile, POFA was selected to replace cement because of its chemical properties that make it suitable as a binder.

Various studies have been conducted on the usage of POFA and EPS in concrete production. The use of polystyrene aggregate has a number of advantages including the decrease of natural sand use, the recycling of unused plastic waste and also may decrease the density of concrete structures. Due to its mechanical characteristic such as lightness, rigidity, and formability, EPS can be used in a variety of applications. Besides, EPS concrete has the possibility to be applied as structural member such as exterior panels, curtain walls, load bearing wall, composite flooring systems, shielding layers, and isolated concrete (Coppola *et al.*, 2016).

POFA have pozzolanic properties are suitable used as a concrete constituent. Many researchers have studied the performance POFA in normal concrete, lightweight concrete and high strength concrete, together with foamed concrete. The studies have showed that POFA contain a high amount of silica and are thus able to be used as a pozzolanic material. POFA is the one of agriculture waste ashes which is chemical composition contains a huge amount of silica. Thus, it can theoretically be used as a cement replacement or as a filler to produce high strength and durable concrete (Munir *et al.,* 2015).

1.1 Expanded Polystyrene (EPS)

EPS is one of the materials used as packaging or insulation material. EPS has a very low density. The EPS beads are round and contain 2% polystyrene and 98% air. After growing, the beads will not absorb water and then, the beads can be used as a lightweight aggregate to produce lightweight concrete. Due to its closed cell structure which inhibits the passage of heat or cold, EPS has a high capacity for thermal insulation.

Lightweight concrete can be produced by mixing up to 50% of recyclable EPS, making an EPS-based lightweight concrete more attractive. EPS is a non-biodegradable material. Therefore, recycling EPS by incorporating it in concrete production can be a useful way to reduce EPS waste. Since EPS is a material that has a high energy content, it is useful to obtain a complete study of the potential of concrete containing EPS (Fernando *et al.*, 2017). The use of polystyrene aggregate has a number of benefits such as reduction in plastic waste use, natural sand use and also a reduction of concrete structures weight (Coppola *et al.*, 2016).

2.2 Palm Oil Fuel Ash (POFA)

The palm oil industry has given meaningful benefit to the country's income for many years. Moreover, palm oil has emerged as one of the most important oils in the world. About 90% of palm oil is used in food-related products worldwide while the other 10% is used as a basic raw material for making soap. The burning process of palm oil husks and palm kernel shells in the steam boiler produces POFA (Fernando *et al.*, 2017). Estimated 10 mil tonnes of POFA is generated in Malaysia every year (Khankhaje *et al.*, 2017).

Many studies have stated that oil palm ash has good pozzolanic properties and can be used as an additive in cement (Munir *et al.,* 2015). Therefore, recycling palm oil waste helps to mitigate environmental pollution problems and preserve the construction industry.

Since the use of POFA is still not commercialised, it is categorised as a waste material, potentially may give problems to future environmental. However, many researchers (Tay, 1960 & Ali *et al.*, 2016) stated that POFA had pozzolanic properties and could be used to substitute cement or as a filler in concrete. Many of previous studies reported that POFA has good potential in reducing the use of cement due to alkali-silica reactions (Ali *et al.*, 2016).

POFA are usually gray and darker with increased levels of non-combustible carbon. Although the particles have different sizes, they are generally taken into account and specific gravity less than the usual Portland cement (Liu &

Chen, 2014). Compared to the size of Portland cement particle size and the size of the palm oil ash particle size is smaller and the texture is porous (Adnan *et al.*, 2018).

There are significant variations in different POFA chemical compositions used by numerous researchers. These changes can be caused by different factors such as combustion temperature, particle fineness, burnt oil palm parts, and so on. High silica content is found by the burning of palm oil shells or fiber clarified by Johari *et al*, 2012 as shown in Table 1. The increase of POFA refinement may increase silica dioxide amount (Thomasa *et al*., 2017). The durability and strength of concrete containing POFA are directly proportional to the silica content found in POFA.

Table 1 - Chemical Composition of Ordinary Portland Cement and Palm Oil Fuel Ash (Johari *et al.*, 2012)

Chemical composition	POFA	OPC
Calcium Oxide (CaO)	5.61	68.14
Aluminium Oxide (AL_2O_3)	0.94	3.82
Magnesium Oxide (MgO)	4.91	2.03
Silicon Dioxide (SiO_2)	71.67	16.83
Sodium Oxide (Na_2O)	0.12	0.03
Phosporus Pentoxide (P_2O_5)	4.68	0.04
Potassium Oxide (K_2O)	7.89	0.19
Titanium Dioxide (TiO_2)	0.09	0.14
Manganese Oxides (MnO)	0.12	0.11
Ferric Oxide (Fe_2O_3)	2.77	3.75

2.3 Compressive Strength of Concrete

The concrete compressive strength is the most important mechanical characteristic of hardened concrete. Previous study on the compressive strength of concrete containing 10% to 50% POFA as cement replacement has fixed 0.6 of water to cement ratio. The compressive strength is decrease with the increasing amount of POFA in concrete. Based on the previous research, 10% POFA is proposed as the optimum cement replacement in concrete and it will not disturb the long-term strength formation of concrete (Manjunath, 2016).

Chindaprasirt *et al.* (2017) reported that concrete containing 10 to 30% POFA gave compressive strength higher than that of control concrete at 28, 90 and 180 days, and concrete containing 20% POFA showed the highest strength.

Lim *et al.* (2013) observed that lightweight foamed concrete compressive strength containing 20% and 10% POFA for 90 days were higher than concrete control. Bamaga *et al.* (2013) experiment showed small decrease in the compressive strength of POFA concrete at 7 days and 28 days, while it has increased at 90 days. The 90 days compressive strength of control concrete showed lower then concrete containing 20% POFA.

2.4 Thermal Conductivity

Thermal conductivity is the ability of a material to absorb heat. It can also be defined as the ratio between heat flux and temperature gradient. The thermal conductivity unit is a joule per second for one square meter ($J/s.m^2$) as per stated in Fraden (2004).

The thermal characteristic of EPS aggregates (98% air and 2% polystyrene) showed the lower thermal conductivity and the increase of the EPS volume in concrete may give lower thermal conductivity. The low thermal conductivity of 0.0848 W/MK was detected in specimens with 82% of EPS while this value was 2.5 times higher in samples with 28% of EPS. A lower fire resistance was found from specimens with higher EPS volume (82%) as a result of the fact that EPS particles shrank and lost their strength when exposed to temperature. A higher fire endurance was gained from specimens with lower EPS volume (28%) and higher cement content due to the fact that amorphous silica in the cement paste contributed to higher fire resistance (Liu & Chen, 2014).

2.5 Procedure summary

A procedure flow chart shown in Figure 1 was prepared to show the sequence of activities carried out from the initial stage until all laboratory test results were obtained and analyzed.

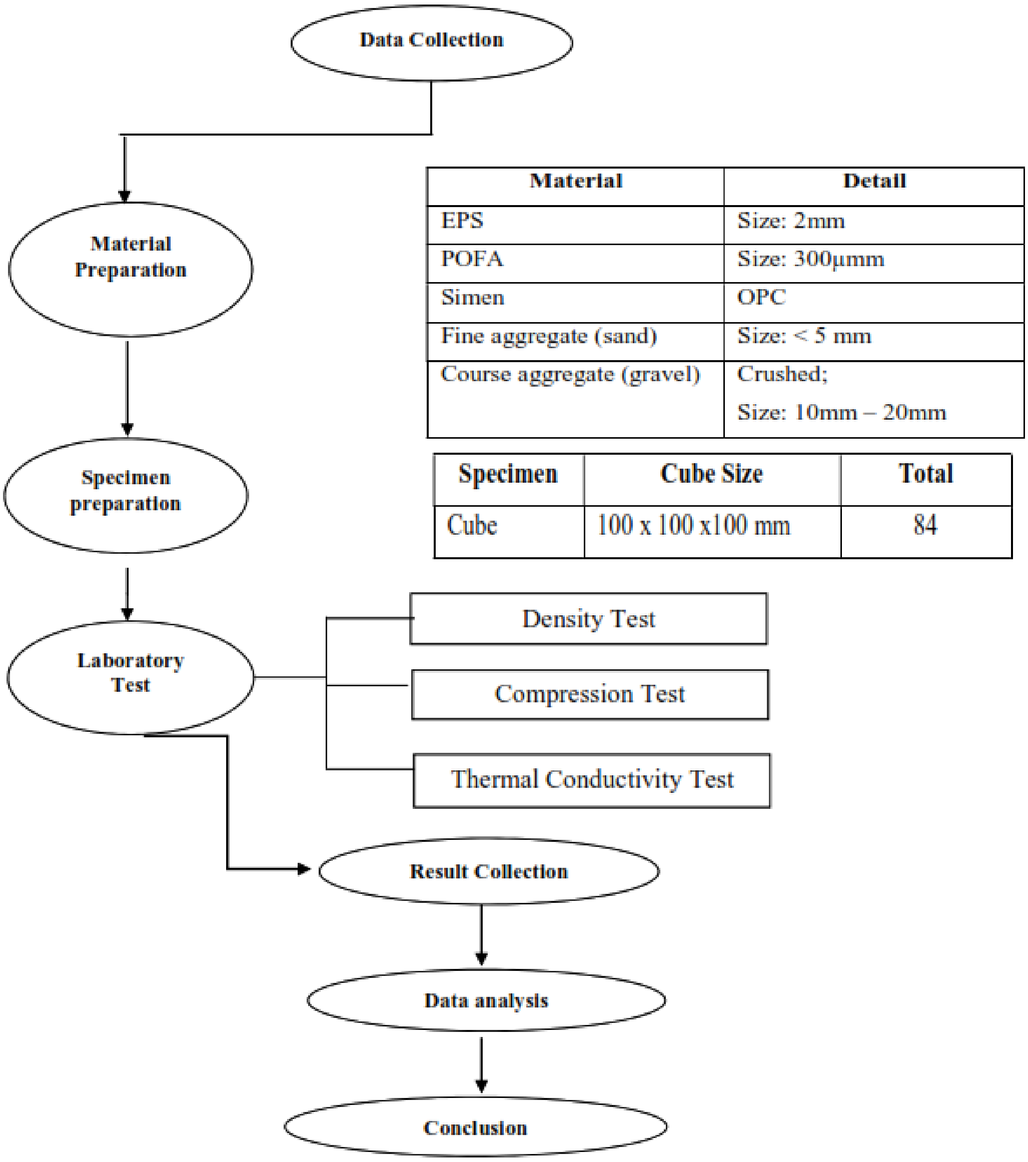


Fig. 1 - Procedure Flow Chart

2.6 Concrete Mix Design

The purpose of a concrete mix design is to select correct proportions of cement, fine aggregate, coarse aggregate and water-cement ratio to produce concrete with specified properties include workability, strength, density, durability requirements and so on. The DOE method was used as a guideline to design the concrete mix and Table 2 shown the concrete mix design for grade 25 as a normal concrete design mixes. The characteristic strength was 25 MPa at 28 days with an allowable slump between 30 mm to 60 mm.

Table 2 - Concrete Mix Design Grade 25 (Control)
(Normal Concrete Design Mixes)

Water cement ratio	0.5
Cement	320 kg/m^3
Water	160 kg/m^3
Fine aggregate	405 kg/m^3
Coarse aggregate	1440 kg/m^3

2.7 Preparation and Selection of Material

i. Cement

Type of cement used in this study was Ordinary Portland Cement (OPC) which is the most widely used cement in the construction industry as per illustrated in Figure 2. The main ingredients of OPC are clinker, lime, silica, with small proportions of alumina and iron oxide. Cement function as a binder to bind other material together. Cement is a crucial ingredient in concrete (Naqi & Jang, 2019).

Fig. 2 - Cement

ii. Fine Aggregate

Natural sand that can pass through 5 mm sieve was chosen to be used as fine aggregate in the concrete mixture for preparing concrete specimen as per illustrated in Figure 3. Grading of sand collected must be fall within the grading limit according to BS 882:1992 (BS 410). The sand collected must be washed to ensure it is free from chemicals and organic matter that may influence the hydration rate and bond with cement paste. The main function of sand in concrete mixture is to fill up the small spaces or voids between coarse aggregate to minimize honeycomb that can significantly reduce concrete strength. Grading of fine aggregate was determined using sieve analysis.

Fig. 3 - Fine Aggregate

iii. Coarse Aggregate

Coarse aggregate was prepared by selecting gravel that pass through a 20 mm sieve and retained on 5 mm sieve as per shown in Figure 4. Grading limit of coarse aggregate was in accordance to BS 882:1992 (BS 410). Coarse aggregate acts as main load bearing components that greatly contributing to the strength and durability of concrete. Gravel selected was crushed and angular shaped with rough surface. Rough surface gravel tends to provide stronger bond between aggregate and cement paste than smooth surface but with lower workability.

Fig. 4 - Coarse Aggregate

iv. Expanded Polystyrene

The substance that has been replaced with fine aggregate in concrete were expanded polystyrene (EPS) with a percentage of 10%, 20% and 30% as per shown in Figure 4. Polystyrene is one of packaging material in medical industry. Polystyrene is of the material that difficult to dispose, so it creates disposal problems. Utilizing crushed polystyrene in concrete is the best waste disposal method. The polystyrene beads can be easily combined into mortar or concrete to produce lightweight concrete with low density. The EPS was obtained from Styrofoam factory at Sri Gading, Johor, Malaysia.

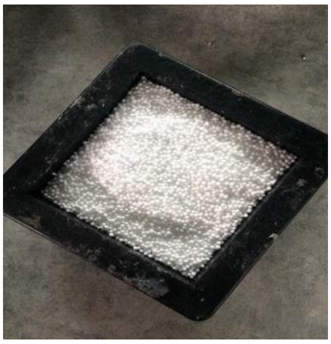


Fig. 5 - Expanded Polystyrene

v. Palm Oil Fuel Ash

Palm oil fuel ash were produced from the oil palm waste incineration that can be obtained from palm oil processing plant. In this study the palm oil has been replaced the cement by percentage of 10%, 20%, 30% and 40%. In practice, POFA produced in Malaysian palm oil mill will be disposed as waste without any commercial return. POFA has good pozzolanic properties, and it was used as replacement material for cement in concrete as per shown in Figure 6. The POFA was obtained from Bell Palm Industry, Batu Pahat, Johor, Malaysia.

Fig. 6 - Palm Oil Fuel Ash

2.8 Concrete Mixing

Cement, sand, gravel, water, POFA and EPS were mixed together to form concrete using concrete mixer with small revolving drum as shown in Figure 7. The use of concrete mixer made concrete to be mixed more uniformly and consistently with minimum effort and time. Before batching concrete, inner surface of the drum was sprayed with water to ease the batching process. After that, concrete materials were weighed according to concrete mix design, and they were manually put into the drum using shovel.

Fig. 7 - Concrete being mixed

Fig. 8 - Completely Mixed Concrete

2.9 Laboratory Test

i. Slump Test

Slump test was performed to determine the workability of concrete that affects concrete strength. This test was carried out follows the procedures in BS 1881: Part 102: Method of Determination of Slump. A metal cone shaped mold was filled up with 3 layers of fresh concrete. 25 strokes of tamping were applied for each layer using tamping rod to compact the concrete layer. Slump value was recorded by measuring height between top of the mold and the highest point of the specimen after removal of mold.

Fig. 9 - Slump Test

ii. Compressive Strength Test

The compressive strength test was performed on cube specimens according to BS1881, Part 116: Method for Determination of Compressive Strength of Concrete Cubes. Loading was applied on cubes at a constant rate until failure and maximum load applied was recorded. The compressive strength of each specimen was calculated using the equation:

$$\text{Compressive Strength, } F_{cu} = \frac{\text{Max load, P}}{\text{Area, A}} \ (\text{N/mm}^2) \qquad (1)$$

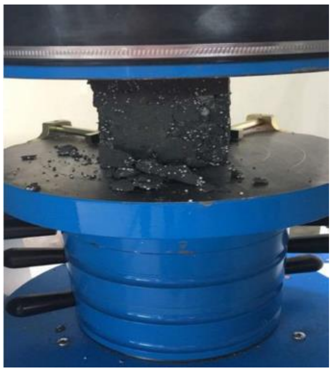


Fig. 10 - Compressive Strength Test

iii. Thermal Conductivity Test

A thermal test was performed on panel concrete specimens to determine the heat conductivity. This test was performed according to ASTM C 177 or ASTM C 236: Thermal Conductivity of Concrete. The specimen was inserted into the unit and clamped using a heating plate. Then, a temperature of 45℃ was set before the heater was switched on. When the reading became stable, the hot plate temperature, cold plate temperature and heat flux were recorded. Thermal conductivity of each specimen was calculated using the following equation:

$$\text{Thermal Conductivity, K} = \frac{\text{Head Flow Density} \times \text{Thickness}}{\text{Temperature Different}} \quad (2)$$

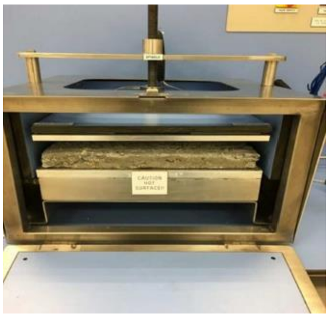


Fig. 11 - Thermal Conductivity Test

3. Results and Discussion

The results of this study were based on experimental findings obtained through laboratory tests. Results from the slump test, density test, compressive strength test and thermal conductivity test are discussed in this section.

i. Workability

In this study, 12 batches of concrete were mixed with different percentages of EPS and POFA. A slump test was done on each batch of fresh concrete before pouring it into moulds to identify its workability.

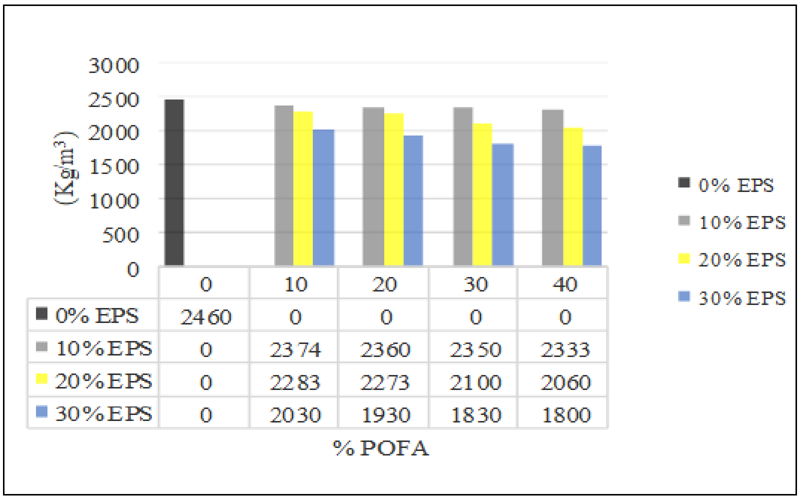
Table 3 - Slump test results

% EPS	% POFA	Slump Value (mm)
0	0	22
10	10	22
	20	22
	30	22
	40	21
20	10	22
	20	21
	30	21
	40	21
30	10	21
	20	20
	30	19
	40	19

According to Table 3, when the percentage of POFA and EPS increases, the workability of concrete decreases. This occurred due to the slower pozzolanic reaction between POFA and cement. Lower water absorption of EPS might also have affected the workability of concrete and higher water absorption in POFA also have affected the workability of concrete. However, all slump values obtained were acceptable as they fulfilled the slump value requirement.

ii. Density

The weight of cube specimens cured for 28 days was obtained before the compressive strength test was performed. The average density of specimens with different percentages of POFA and EPS was calculated and plotted in a bar chart as shown in Figure 12.



	0	10	20	30	40
0% EPS	2460	0	0	0	0
10%EPS	0	2374	2360	2350	2333
20%EPS	0	2283	2273	2100	2060
30%EPS	0	2030	1930	1830	1800

Fig. 12 - Graph of Density Versus Different percentages of POFA replacement

The density of cube specimens decreased as the replacement percentage of EPS increased. The reduction in density was due to the mass reduction of the mixture since the density of EPS was lower than that of fine aggregates. It can be proven that, there is a directly proportional between EPS volume and density as a higher volume of EPS results in lower density of concrete.

iii. Compressive Strength

For each proportion of EPS and POFA used to replace fine aggregate and cement respectively, 3 specimens were tested to obtain the average result in order to increase accuracy and minimize errors in data collection. 3 graphs were plotted to compare the average compressive strength of specimens cured for 7 days and 28 days respectively, as shown in Figures 13, 14 and 15.

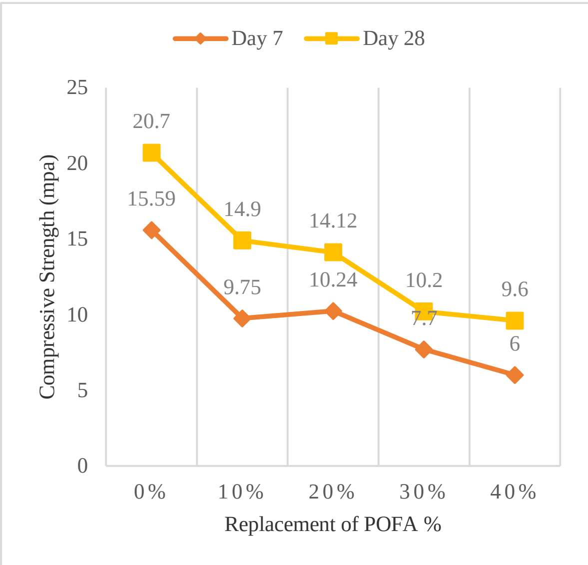


Fig. 13 - Compressive Strength graph for 10% of EPS replacement

The graph above shows the compressive strength of specimens containing 10% of EPS and 10%-40% of POFA at the age of 7 and 28 days. The compressive strength of the samples decreases as the percentage of POFA replacing cement increases. The decreasing rate started as cement was replaced in percentages between 10% until 40%.

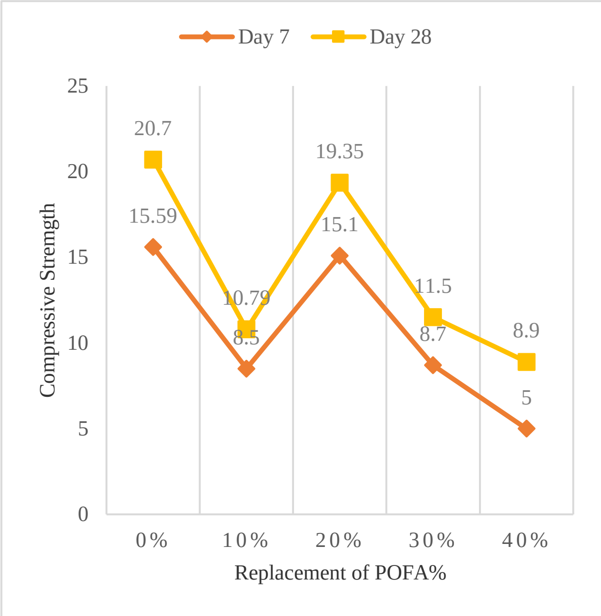


Fig. 14 - Compressive Strength graph for 20% of EPS replacement

The compressive strength of specimens containing 20% of EPS and 10%-40% of POFA at the age of 7 and 28 days both showed a fluctuating trend as the percentage of POFA replacing cement increased. Based on Figure 14, 20% of EPS and 20% of POFA achieved the highest compressive strength at day 28 compared to other percentages of replacement. The increase in compressive strength at 20% occurred due to the void filling capability of the fine POFA particles, while at the next stages, the SiO^2 existing in the POFA responds with the $Ca(OH)^2$, from extra calcium silicate hydrate (C-SH) and enhances the bonding among the pastes and the aggregates and consequently increases the concrete strength.

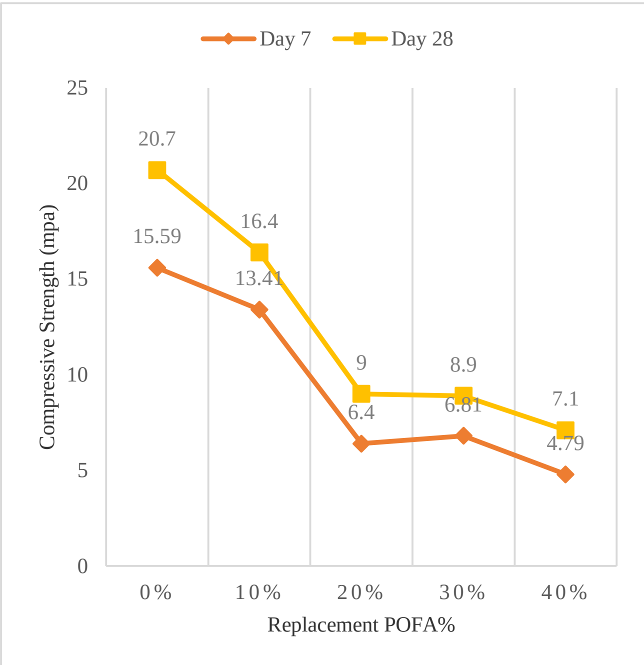


Fig 15 - Compressive Strength graph for 30% of EPS replacement

The compressive strength of specimens with 30% of EPS and 10%-40% of POFA at the age of 7 and 28 days showed a decreasing trend as the percentage of POFA replacing cement increases. The decreasing rate started at 10% of the cement was replaced, but a significant drop was observed when 20% of cement was replaced.

The increase of up to 20% POFA caused a reduction in compressive strength. This could be described that the delay in the cement hydration at the initial stage of curing due to the high replacement level of OPC with POFA in concrete mixes. This was also explained by Newman and Choo (2003) who found that pozzolanic materials like fly ash caused a delay in the hydration process. Thus, the lack of cement hydration in the initial stage of curing resulted in the slow development of strength in the OPC mixes containing POFA.

In addition, due to the greater loss on ignition of POFA which was 10.1 compared to OPC which was 0.1, a greater amount of water absorbed by POFA caused a reduction in free water for the cement hydration process (Johari et. al, 2012). It is noted that the loss on ignition of POFA is higher. As per ASTM C618, the loss of ignition should be less than 10. POFA contains a greater quantity of K_2O because palm trees consume K_2O from soil during the cultivation period. In all cases from various research papers, the sum of SiO_2+ $Al_2\ O_3$ + Fe_2O_3 was greater than 50%, which makes it a class C pozzolan according to ASTM C618. In exceptional cases, the sum was greater than 70%, which makes it a class F pozzolan.

Besides, there can be a large portion of unburnt carbon in the remaining part of ground POFA which can absorb a large amount of water and reduce the workability of concrete. The unburned carbon will affect the potential pozzolanic characteristics of the sample. Thus, carbon particles should be eliminated by heating the ground POFA at 500 °C for one hour (Islam et. al, 2016). If the brunches are present in the burning process, there will be more carbon that may give disadvantages to increase concrete strength. The quantity of SiO2 increases with the increase in the fineness of POFA. The strength and durability of concrete containing POFA directly proportional to the amount of reactive silica found in POFA.

In addition, the reduction in compressive strength was due to the increasing fluidity of concrete caused by the hydrophobic property of plastic with low water absorption (Sata et. al, 2004). Thus, the lack of cement hydration caused by POFA and the low water absorption of EPS directly affects concrete strength. Besides, the smooth surface of the EPS and its poor bonding characteristic result in failure, which takes place in the transition zone at a much lower stress level (Liu & Chen, 2014). Thus, increasing the volume of EPS directly affects the compressive strength and density of polystyrene foam concrete due to the close to zero strength of EPS particles and high compressibility behavior.

iv. Thermal Conductivity

A thermal test determines the conductivity of concrete and identifies the difference between normal concrete and mix design concrete. In this study, 2 specimens were tested to obtain the k value and bar chart was plotted as shown in Figure 16 for comparison and data analysis.

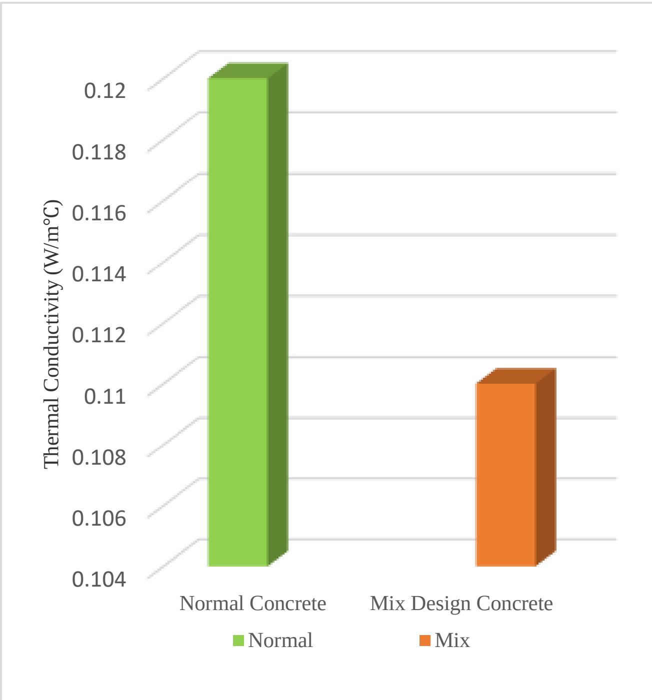


Fig. 16 - Graph of Thermal Conductivity with Normal and Mix Design Concrete

The first specimen contained 0% replacement (normal concrete) whereas the second specimen was the mix design concrete with the highest value of compressive strength. The conductivity of the control concrete was 0.12 W/mºc while that of specimens containing 20% of EPS and 20% of POFA was 0.11 W/mºc. Thus, the reduction in thermal conductivity was mainly contributed by the volume of EPS used. Furthermore, the lower thermal conductivity was due to EPS particles with a lower thermal capacity.

4. Summary

The following summaries can be made based on the result analysis of density, compressive strength and thermal conductivity of concrete containing EPS and POFA as replacement materials:

i. Factors such as cement content, POFA content and EPS volume directly affected the mechanical properties of the proposed concrete. 20% of EPS and 20% of POFA achieved the highest compressive strength at 28 days compared to other percentages of replacement. The compressive strength of concrete increasing due to the void filling capacity of the fine POFA particles and the next points, the SiO2 existing in the POFA reacts with the Ca(OH)2, from additional calcium silicate hydrate (C-SH) and enhances the bonding between the pastes and the aggregates and consequently increases the concrete strength.
ii. Higher percentages of EPS and POFA as fine aggregate and cement replacement in concrete decrease the slump value and workability of concrete. This is because the adhesive strength of EPS with cement becomes weaker. The smooth surface of the EPS and its poor bonding characteristic resulted in failure, which takes place in the transition zone at a much lower stress level. Also, the delay in the hydration process reduces the workability of concrete. However, all slump values were still acceptable as they fell within the slump value range.
iii. The replacement of fine aggregate using EPS reduced the density of concrete due to the density of EPS is lower than that of sand. The volume of EPS particularly affects the density of concrete. A higher volume of polystyrene in concrete results in lower density and unit weight.
iv. When the percentages of fine aggregate and cement replacement increase, the compressive strength of the specimens decreases regardless of curing age. This was due to pozzolanic materials like fly ash, which may slow down the hydration process.
v. The strength of concrete reduces as EPS volume increases due to the low strength of EPS compare to natural fine aggregates and low interfacial bond strength at the interaction zone of mix concrete as a result of the hydrophobic nature of EPS aggregates.
vi. The increasing of the EPS volume showed the lower thermal conductivity of concrete due to the thermal properties of EPS aggregates. The lower thermal conductivity of 0.12 W/mºc was observed in specimens with 0% EPS while this value was higher compared to samples with an EPS volume of 20%.

Acknowledgement

The author would like to give truthful recognition to Office for Research Management Centre (RMC), Universiti Tun Hussein Onn Malaysia for the commitments especially on giving the budget for fee through tier 1 research grant (Grant code H177).

References

Adnan, S. H. Abadalla, M. A. S., & Jamellodin, Z. (2018). The Mechanical and Physical Properties of Concrete Containing Polystyrene Beads As Aggregate And Palm Oil Fuel Ash As Cement Replacement Material. Malaysian Construction Research Journal, Construction Research Institute of Malaysia (CREAM), 1, 114.

Ali A. Sayadi, Juan V., Tapia, Thomas R. Neitzert a, & G. Charles Clifton. (2016). Effects of expanded polystyrene (EPS) particles on fire resistance, thermal conductivity and compressive strength of foamed concrete. Construction and Building Materials, 112, 716–724.

ASTM C 177. *Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus.*

ASTM C 236. *Standard Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box*

ASTM C 618. *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*

Awal, A. S. M. A & Hussin, M. W. (1997). The effectiveness of palm oil fuel ash in preventing expansion due to alkali-silica reaction. Cem Concr Compos, 19, 367.

Bamaga, S. O., Hussin, M.W., & Ismail, M. A. (2013). Palm oil fuel ash: promising supplementary cementing materials. KSCE J Civil Eng, 17, 1708–1713.

British Standard Institution (1992). *Specification for Aggregates from Natural Sources for Concrete*. London: BS 882.

Chindaprasirt, P., Homwuttiwong, S., & Jaturapitakkul, C. (2017). Strength and water permeability of concrete containing palm oil fuel ash and rice husk–bark ash. Constr Build Mater, 21, 1492–1499.

Coppola B., Courard L., Michel F., Incarnato L.C, & di Maio L. (2016). Investigation on the use of foamed plastic waste as natural aggregates replacement in lightweight mortar. Composites Part B, 99, 75-83.

Fernando, P. L. N., Jayasinghe, M. T. R., & Jayasinghe, C. (2017). Structural feasibility of Expanded Polystyrene (EPS) based lightweight concrete sandwich wall panels. Construction and Building Materials, 139, 45-51.

Fraden, J. (2004). *Handbook of Modern Sensors: Physics, Designs, and Applications*. 3rd Ed. New York: Springer-Verlag New York Inc. 2004.

Islam, M. M. U., Mo, K. H., Alengaram, U. J., & Jumaat, M. Z. (2016). Mechanical and fresh properties of sustainable oil palm shell lightweight concrete incorporating palm oil fuel ash. Journal of Cleaner Production, 115, 307-314.

Johari, M. A. A., Zeyad, A. M., Bunnori, N. M., & Ariffin, K. S. (2012). Engineering and transport properties of high-strength green concrete containing high volume of ultrafine palm oil fuel ash. Constr Build Mater, 30, 281–8.

Khankhaje, K, Salim, M. R. S., Mirza, J., Husin, M.W., Siong, H. C., & Rafieizonooz, M. (2017). Sustainable Pervious Concrete Incorporating Palm Oil Fuel Ash as Cement Replacement. Chemical Engineering Transactions, 56, 445-450.

Lim, S. K., Tan, C. S., Lim, O. Y., & Lee, Y. L. (2013). Fresh and hardened properties of lightweight foamed concrete with palm oil fuel ash as filler. Constr Build Mater, 46, 39–47.

Liu, N. & Chen, B. (2014). Experimental study of the influence of EPS particle size on the mechanical properties of EPS lightweight concrete. Construction and Building Materials, 68, 227–232.

Manjunath, B. A. (2016). Partial replacement of E-plastic Waste as Coarse-aggregate in Concrete. Procedia Environmental Sciences, 35, 731 – 739.

Munir, A. Abdullah, Huzaim, Sofyan, S., Wahab, I., & Safwan. (2015). Utilization of palm oil fuel ash (POFA) in producing lightweight foamed concrete for non-structural building material. Procedia Engineering, 125, 739–74.

Naqi, A. & Jang, J. G. (2019). Recent Progress in Green Cement Technology Utilizing Low-Carbon Emission Fuels and Raw Materials: A Review. *Sustainability*, 11, pp. 537.

Newman, J., & Choo, B.S. (2003). Advanced Concrete Technology, Elsevier Ltd.

Sata, V., Jaturapitakkul, C., & Kiattikomol, K. (2004). Utilization of palm oil fuel ash in high-strength concrete, J. Mater. Civ. Eng., 16, 623–628.

Tay, J. (1990). Ash from oil-palm waste as concrete material. J. Mater. Civ. Eng., 2, 94-105.

Thomasa, B. S., Kumar, S., & Hasan, S. A. (2017). Sustainable concrete containing palm oil fuel ash as a supplementary cementitious material – A review. Renewable and Sustainable Energy Reviews, 80, 550–561.

Tuan Ismail, T. N. H, Wijeyesekera, D. C., Lim, A. J. M. S., & Ismail, B. (2013). Recycled PP/HDPE Blends: A Thermal Degradation and Mechanical Properties Study. Applied Mechanics and Materials **,** 465-466, 932-936.