Progress in Engineering Application and Technology Vol. 3 No. 2 (2022) 156-162

PEAT

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/peat
e-ISSN : 2773-5303

Properties and Optimum Percentage of Concrete Containing Expanded Polystyrene (EPS) and Palm Oil Fuel Ash (POFA) as Replacement Material

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DOI: https://doi.org/10.30880/peat.2022.03.02.015
Received 27 January 2022; Accepted 20 July 2022; Available online 10 December 2022

Abstract: Concrete is one of the effective and widely used developments materials in any construction all around the world and will continue as the dominant construction along with the growth of human civilization and the development of countries. This development can cause high demand for natural resources such as aggregate and also cement. Thus, the aim of this research is to determine the properties and optimum percentage of concrete when aggregate and cement content were replaced with Expanded Polystyrene (EPS) and Palm Oil Fuel Ash (POFA). Five (5) testing were used in this research which are XRD test, slump test, density test, water absorption test and compressive strength test. XRD test was used to compare the chemical composition of POFA and cement. Another four (4) testing were conducted to identify the mechanical and physical properties of concrete containing EPS and POFA. The DOE method [1] was used to prepare concrete mixtures with varying proportions of EPS and POFA replacement. The result shows that specimens' average compressive strength increase with the increase of the specimens' age. Moreover, as the amount of EPS and POFA in the concrete mixture increased, the slump, density and compressive strength decreased. However, water absorption increased as the POFA and EPS contents increased. In conclusion, the optimum percentage of EPS and POFA replacements can be replaced up to 10% respectively, and EPS and POFA can be used as replacement materials in concrete.

Keywords: Expanded Polystyrene (EPS), Palm Oil Fuel Ash (POFA), Properties, Optimum Percentage

1. Introduction

Concrete was made up of aggregates, water and cement with a standard ratio. Concrete is one of the continued dominant construction materials. The development of countries and civilization has

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caused a high demand for natural resources such as aggregate and also cement. Environmental damage and natural resource consumption will increase sharply as a result, and humans will face challenges to maintain the natural environment [2]. In addition, the global environment faces a challenge from the concrete industry as it consumes natural resources in large quantities. Besides, unwanted industrial waste materials such as EPS and POFA are another challenge to be faced in the protection of the natural environment. Malaysia produces about 10 millions tons of palm oil a year, making it one of the world's largest producers. [3].

Expanded polystyrene (EPS) has been used as packaging materials because it is a lightweight plastic that is rigid and thermoplastic. [4]. Like all plastics, EPS foams become a great environmental concern since it is non-degradable material. It is important to collect and recycle these substances whenever possible. Research has shown that high quality insulated concrete and lightweight brick can be made from waste EPS foams when they are used as concrete aggregate [5]. Nowadays, EPS lightweight concrete has a wide application in construction [6]. As well as reducing aggregate consumption, this application can reduce polystyrene waste as well.

Another waste material that may be substituted for concrete is palm oil fuel ash (POFA). POFA is rich in SiO_2, and it was pozzolanic material that can replace cement in concrete. A huge amount of CO_2 is released during cement manufacture, which has a significant negative effect on the environment. When compared to cement, palm oil fuel ash submission has a lower environmental impact [7]. As a result, the use of POFA to partially replace cement in concrete is environmentally friendly.

Therefore, with the waste of EPS and POFA we can use them as the replacement materials in concrete production. The study of properties of concrete containing EPS and POFA as replacement materials will prove the performance of concrete in building construction. The right amount of EPS and POFA to be used for maximizing the performance of the concrete can be ensured from the finding of the optimum percentage of EPS and POFA in concrete.

2. Materials and Methods

2.1 Flow chart

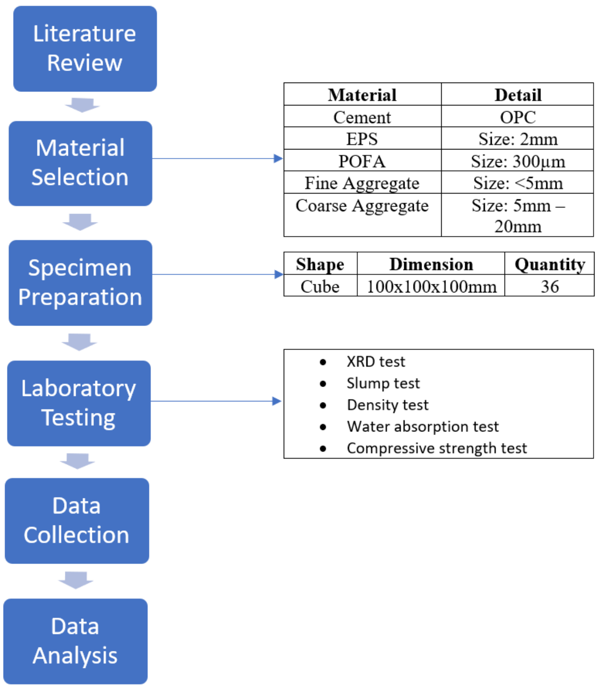


Figure 1: Flow chart of the methodology

2.2 Materials

Cement, fine aggregate, coarse aggregate, EPS, POFA and water were the major components used in this study to make concrete. According to the proportions set, EPS and POFA will be used to replace fine aggregate and cement respectively. The dimension of the concrete specimen was a cube with sides of 100mm. To prevent discrepancies across specimens, the raw materials were chosen in a standardised manner.

Cement is a binding agent that can be used to join different types of building materials. There are several types of cement in the construction industry but for this study, we used Ordinary Portland Cement (OPC). Cement becomes the most important material in concrete. Limestone, sand or clay, bauxite and iron oxide are only a few of the basic substances. Chalk, shells, shale, marl, slag and slate are some of the materials that can be found in it. In cement-producing plants, these various components are mixed and burned to make clinker, a rock-hard substance. After that, the clinker is ground into a powder that can be mixed with water to make a paste. To prevent moisture absorption from affecting the quality of the concrete, the cement was stored on a wood pallet off the ground and a safe distance from the wall.

One of the most important components of concrete is fine aggregate, which has a significant impact on mix design. The size of this aggregate is less than 4.75mm that can pass through a #4 sieve and is retained on a #200 sieve. Impurities such as organic substances were sieved out of the sand. The function of fine aggregate in concrete is to fill in the gaps between the coarse aggregate. This will reduce the space of voids in the concrete, which will decrease its strength.

Any aggregate particle larger than 0.19inch in diameter but usually between 0.38 and 1.5 inch in diameter is considered as coarse aggregate. The majority of coarse aggregate used in concrete is gravel. Same with the fine aggregate, this component also must be free from any impurities such as organic substances. Coarse aggregate is the primary load-bearing component of concrete, contributing significantly to its strength and durability.

Expanded polystyrene is a white foam substance made from solid polystyrene beads. These beads are used to provide insulation, packaging, and other similar uses. It is a closed-cell rigid foam material that consists of 97.00 % air and recyclable. EPS was used to partially replace fine aggregate in concrete for this study. Because of its lightweight, the percentage of replacement was calculated based on sand volume rather than weight. This study was used up to 10.00 % of EPS to replace sand.

POFA is a pozzolanic material that can be used to replace cement in the production of high-strength, low-cost concrete. The combustion of the husk and shell of the palm oil plant can produce POFA. Based on the weight of cement, the POFA was used to replace up to 20.00 % of the cement.

Water is an important role in this chemical process since it accelerates it by contributing 23.00 % to 25.00 % of the cement volume. It makes a paste of 15.00 % water-cement, commonly known as a gel to fill voids in concrete. The water used in the concrete mixture is ordinary tap water which is perfectly safe for concrete mixing. Because it is free of water pollutants and toxic chemicals, it is considered clean water.

2.3 Specimen

Specimens' concrete with various ratios of EPS and POFA replacement will construct for laboratory testing in this investigation. Concrete cubes with a side of 100mm are made for each replacement ratio. The EPS replace the fine aggregate up to 10.00 % by the weight of concrete but POFA up to 20.00 %. For comparison, a standard concrete sample will be made with 0.00 % EPS and POFA replacement as a control sample. Table 1 shows the quantity of concrete cubes that be prepared for each replacement ratio.

Table 1: The quantity of concrete cube specimens

POFA \ EPS	0 %	10 %
0%	6	6
10%	6	6
20%	6	6

2.4 Methods

Several tests were conducted to investigate the concretes' properties containing EPS and POFA as replacement materials. Workability, density, water absorption and compression strength are the mechanical and physical properties investigated in this study. The tests were carried out after the concrete specimens have been curing for 7 days and 28 days. These concrete's performance was compared with the ordinary concrete mixture. X-Ray Diffraction (XRD) research also was conducted on the POFA and cement samples to determine their crystal structure.

The workability of fresh concrete was determined using a slump test. Before the concrete was poured into the concrete mould, this test was carried out with followed the procedure stated in BS 1881: Part 102: Method of Determination of Slump. The main apparatus for this test was a cone-shaped metal mould with a base diameter of 200 mm, top diameter 100, and height of 300 mm. Another apparatus used was 600 mm long tamping rod with 16mm in diameter, scoop, sampling tray and ruler.

Besides that, 28 days after curing, the density test of concrete cube specimens were evaluated in this study. This density test was carried out according to the procedure as stated in the BS 1881: Part 114: Methods for Determination of Density of Hardened Concrete. After removing concrete cubes specimen from the curing tank, it was cleaned by wiping away any excess surface concrete water with a cloth. While according to BS 1881: Part 122: Method for Determining Water Absorption, water absorption tests were also carried out after the specimens of concrete cube had been cured for 28 days.

The compressive strength test was performed on concrete cube specimens that had been crushded to failure. This test was conducted after the specimens had been cured for 7 days and 28 days. The procedure of this test was carried out as stated in BS 1881: Part 116: Method for Determination of Compressive Strength of Concrete Cube. For chemical properties, the POFA and cement sample was subjected to XRD analysis using an X-Ray Diffractometer. The POFA sample was ground into a fine powder prior to examinations. Cu Kα radiation was used to analyse the ground sample at $3^{\circ} \geq 2\Theta \leq 90^{\circ}$ with a scanning rate of 0.05 ° per second 40 kV/20 A. Same test was used to the cement sample as a comparison.

3. Results and Discussion

3.1 XRD test

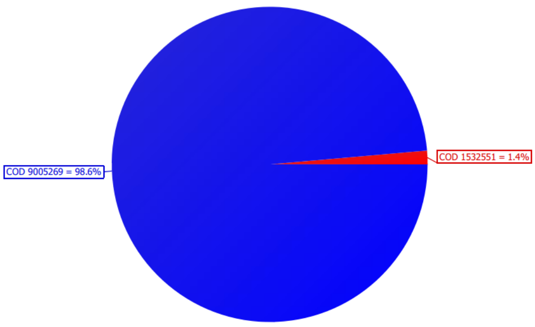


Figure 2: Tridymite percentage in POFA sample

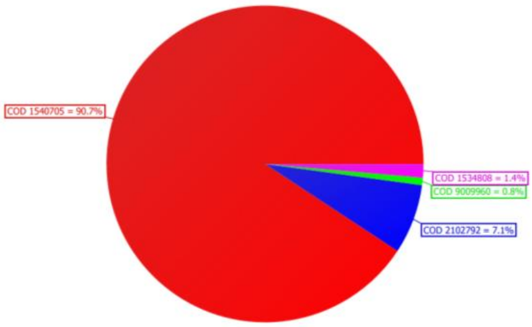
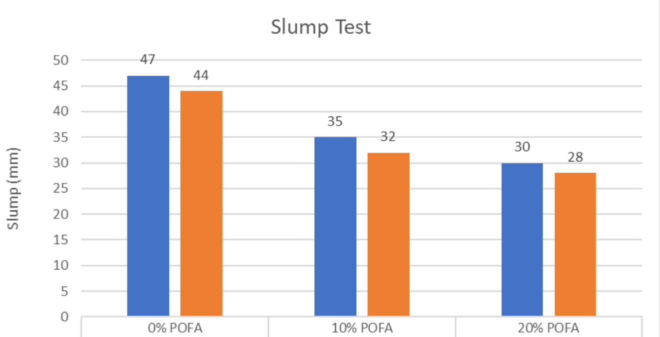


Figure 3: Alite percentage in OPC sample

Figure 2 shows that 98.60 % of the POFA sample contained tridymite. Tridymite has a high temperature-silica polymorph and also defined as a pozzolanic material that can have cementitious characteristics when water is present. Figure 3 shows OPC contained 90.70 % alite. Concrete's setting and early strength development are aided by alite, an impure type of tricalcium silicate.

3.2 Slump test

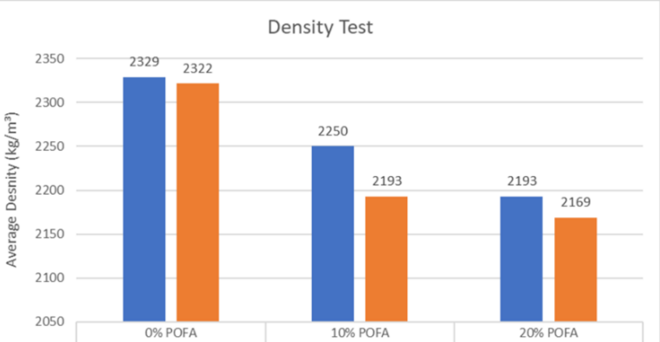


	0% POFA	10% POFA	20% POFA
0% EPS	47	35	30
10% EPS	44	32	28

Figure 4: Graph for slump test

The slump value for normal concrete was 47 mm, according to Figure 4. As the percentage of EPS and POFA increased, the slump value of fresh concrete dropped. When 10.00 % EPS and 20.00 % POFA were replaced, the result revealed a minimum slump value of 28 mm. Because the concrete was required to have a slump range of 30 mm to 60 mm, the results were acceptable.

3.3 Density test



	0% POFA	10% POFA	20% POFA
0% EPS	2329	2250	2193
10% EPS	2322	2193	2169

Figure 5: Graph for density test

As illustrated in Figure 5, concrete cubes' average density decreased as the ESP and POFA replacement ratio increased. Normal concrete cubes have an average density of 2329 kg/m³. Concrete cubes' average density decreased to 2169 kg/m³ when the percentage of EPS and POFA replacement reached 10.00 % and 20.00 %, respectively. Even though the concretes' average density containing EPS and POFA as replacement materials did not meet the requirements for lightweight concrete, the density of concrete specimens was significantly reduced.

3.4 Water absorption test

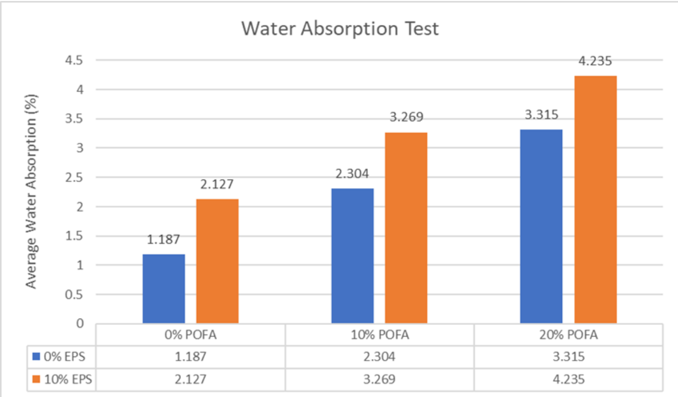


Figure 6: Graph for water absorption test

The finding showed that concrete with POFA replacement absorbs more water than normal concrete. Normal concrete has a water absorption rate of 1.187 %. When POFA was replaced up to 10.00 % and 20.00 %, the water absorption increased to 2.304 % and 3.315 % respectively. The result showed that as the EPS replacement ratio increased, the concrete cubes' water absorption increased. Water absorption increased to 2.127 % when the EPS replacement increased to 10.00 %, from 1.187 % in normal concrete. At a replacement ratio of 20.00 % POFA and 10.00 % EPS, maximum water absorption was obtained, which was 4.235 %. This was due to the increased voids within the concrete cubes caused by the EPS beads distribution.

3.5 Compressive Strength

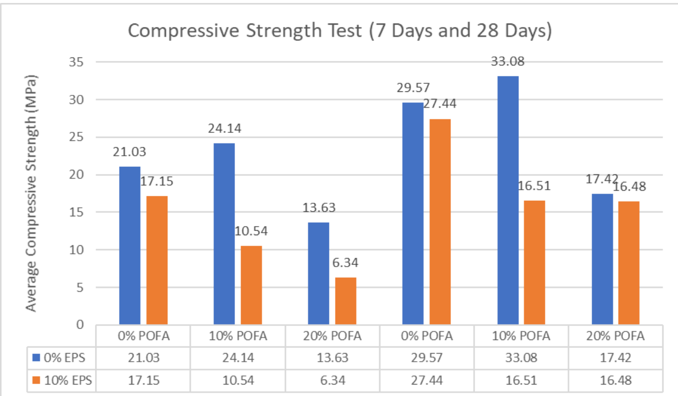


Figure 7: Graph for compressive strength test of 7 days and 28 days

The specimens' average compressive strength increased with the increase of specimens' age. The increasing of EPS contents leads to the decreasing of compressive strength; this could be because replacing volume concrete with EPS increased the fine particles' surface area, causing the interfacial transition zones between fine aggregate and cement paste to deteriorate. Furthermore, as the percentage of POFA replacement increased, the compressive strength of the concrete specimen decreased. This could be caused to the POFA particles' high porosity, which results to increase in water absorption, void content and a decrease of compressive strength.

4. Conclusion

In conclusion, the above-mentioned objectives were met when the laboratory test was completed. The chemical characteristic of POFA was successfully determined and compared with OPC using an XRD test. In terms of slump value, density, water absorption and compressive strength, the mechanical and physical properties of concrete containing EPS and POFA were determined. Lastly, the optimum percentage of EPS and POFA as concrete replacement materials can be replaced at a rate of 0.00 % EPS and 10.00 % POFA respectively. America Concrete Institute 318 [8] stated that minimum compressive strength for 28 days must not less than 17 MPa. For this study, only 0.00 % to 10.00 % of POFA and 0.00 % of EPS are acceptable with compressive strength 29.57 MPa, 27.44 MPa and 33.08 MPa respectively. The purpose of the study was to replace the sand and cement in concrete with ESP and POFA to limit the use of natural resources. Furthermore, this study aimed to create environmentally friendly, long-lasting concrete that performs similarly to normal concrete.

Acknowledgement

The authors would like to thank the Faculty of Engineering Technology, Universiti tun Hussein Onn Malaysia, for instrument support.

References

[1] DOE Method

[2] Kwek, S. Y., & Awang, H. (2018). Artificial lightweight aggregate from palm oil fuel ash (POFA) and water treatment waste. IOP Conference Series: Materials Science and Engineering, 431(8).

[3] Hamada, H. M., Jokhio, G. A., Yahaya, F. M., Humada, A. M., & Gul, Y. (2018). The present state of the use of palm oil fuel ash (POFA) in concrete. Construction and Building Materials, 175, 26–40.

[4] Priyanka, E., Sathyan, D., & Mini, K. M. (2021). Functional and strength characteristics of EPS beads incorporated foam concrete wall panels. Materials Today: Proceedings, (xxxx), 1–4.

[5] Bicer, A. (2021). Investigation of waste EPS foams modified by heat treatment method as concrete aggregate. Journal of Building Engineering, 42, 102472.

[6] Mulla, A., & Shelake, A. (2016). Lightweight Expanded Polystyrene Beads Concrete. International Journal of Research in Advent Technology.

[7] Rajesh, C., Narasimha Sameer, G., Sai Maheswar Reddy, M., Kumar Jagarapu, D. C., & Jogi, P. K. (2020). Consumption of palm oil fuel ash in producing lightweight concrete. Materials Today: Proceedings, 33, 1073–1078.

[8] America Concrete Institute 318