

Properties of Concrete Containing Palm Oil Fuel Ash and Expanded Polystyrene Beads

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Abstract: This paper investigates the stress strain behaviour of concrete containing Palm Oil Fuel Ash and Expanded Polystyrene, axial compressive strength, tensile strength and modulus of elasticity. EPS-POFA concrete was prepared by substituting fine aggregates with EPS beads and cement replaced with POFA by 10%, 20% and 30%. Results of this study showed that EPS-POFA concrete exhibited low axial compressive strength, peak strain, tensile strength and elastic modulus when the EPS and POFA contents in concrete increased. However, the decrease in axial compressive strength of concretes with containing 10 to 20% EPS and POFA are suitable amount and acceptable to be applied on building structure as per stated in America Concrete Institute 318 with minimum specified compressive strength for structural concrete is 2500 psi (17 MPa). While, the failure of EPS-POFA concrete under axial compression gradually occurred and the concretes were able to retain the load after failure without full collapse. The slope of stress-strain curve of concretes with containing EPS and POFA was lower than that of normal concrete, demonstrating that the normal concrete more brittleness than EPS-POFA concretes.

Keywords: Expanded polystyrene, palm oil fuel ash, stress-strain behaviour, axial compressive strength, tensile strength and modulus of elasticity

1. Introduction

Concrete is a construction material or mixture which is composed of cement, fine aggregates (sand), natural coarse aggregates and water with proper ratio. Portland cement is the most commonly used type of cement for production of concrete. Through hydration, the mixture hardens and obtains strength to form the rock-like mass known as concrete. A chemical reaction which occurs between cement particles and water is known as hydration. The features of this reaction are the change in matter, energy level and rate of reaction [1].

However, the alternative building materials development utilizing waste or recycled materials as construction material is favourable owing to over utilization of natural resources as building materials. Hence, expanded polystyrene beads (EPS) and palm oil fuel ash (POFA) are discovered and added with certain percentage to produce better performance and sustainable concrete.

By adding different percentage of EPS and POFA, the characteristic, performance and behaviour of concrete may change. The concrete capacities were determined based on the analytical research. Since stress-strain relationship of the concrete is the foundation of structural analysis and design; thus, it is necessary to clarify the material characteristic of EPS-POFA concrete. The primary objective of this paper is to carry out a comprehensive experimental study on the

stress–strain behaviour of EPS-POFA concrete. The stress–strain behaviour of concrete replacing cement with POFA and fine aggregates with EPS beads, were determined through compression tests.

1.1 Palm Oil Fuel Ash (POFA)

Palm oil fuel ash (POFA) as shown in Fig. 1 is a waste material obtained from combustion of palm oil husk and palm kernel shell as fuel in palm oil mill boilers. It has been identified as a good pozzolanic material [1]. From one oil palm fresh fruit bunch, about 21% oil, 14–15% fibre, 6–7% palm kernel, 6–7% shell and 23% empty fruit bunch are produced [10]. Numerous researchers have studied the usage of POFA in normal concrete [13], [15], [17], high strength concrete [14], [18], and lightweight concrete including foamed concrete [2], [11]. It was revealed from the studies that high amount of silica contained in agricultural waste ashes could be used as pozzolanic material.



Fig. 1- Palm oil fuel ash

1.2 Expanded Polystyrene (EPS)

The cells of polystyrene beads are closed resulting in non-absorbent characteristic. The EPS as shown in Fig. 2 is easily compressible, and thus their direct contribution to the concrete compressive strength is negligible. The primary function of EPS is to act as filler in the concrete mix. Despite giving some desirable concrete properties, inclusion of beads in concrete also causes high thermal resistivity. Properties of expanded polystyrene beads for specific gravity is 0.011 and bulk density is 6.86 kg/m³ [16].



Fig. 2- Expanded polystyrene (EPS)

2. Test Program

The experimental work and testing for this study were carried out at Concrete Laboratory, Universiti Tun Hussein Onn Malaysia, Pagoh, Johor.

2.1 Materials and Mix Proportions

The materials used in this study were sand with finess modulus of 2.85, ordinary Portland cement is crushed granite with maximum size of 20 mm [8], palm oil fuel ash (POFA), and expanded polystyrene beads (EPS). The size of EPS beads used was mostly 3.0 mm [11]. POFA was obtained from the palm oil mill located in Pekan Nanas, Pontian and EPS was obtained from the Sri Gading Polystyrene Factory. In this study, the concrete cylinder with 150 mm diameter size was prepared different proportion of EPS and POFA as replacement material to study the compressive strength and strain at 28 days. The percentage of EPS and POFA used were 10%, 20% and 30 %. Concrete was designed to achieve

compressive strength equal to 25 MPa. The concrete mix was prepared in accordance to DOE method as shown in Table 1 and manually mixed to obtain homogenous concrete mix. Along with control mix (normal concrete), POFA and EPS of 10%, 20% and 30% were used as cement and sand replacement, respectively with producing different concrete mixes. POFA replaced the cement content based on weight, while EPS replaced the sand content based on volume due to the high difference in density between EPS and sand.

Table 1- Concrete mix design grade 25

Water cement ratio	0.5 [17]
Cement	320 kg/m ³
Water	160 kg/m ³
Fine aggregate	405 kg/m ³
Coarse aggregate	1440 kg/m ³

2.2 Specimens Preparation

The fresh concrete mix as shown in Fig. 3 was poured into the steel moulds and slightly compacted by hand. The specimens were demoulded 24 hours later, then cured in a curing tank until 28 days testing age. EPS and POFA were distributed uniformly to produce EPS-POFA concrete. The concrete cylinder with size of 150 mm diameter and 300 mm height was prepared for testing purpose. All cylinder specimens were tested 28 days and follow standard [4]. Concrete specimen preparation with different replacement percentage is shown in **Error! Reference source not found.**



Fig. 3 - Fresh EPS-POFA concrete

Table 2 - Concrete specimen preparation with different replacement percentage

Sample	Percentage of POFA and EPS replacement (%)	Age of testing (Days)	Number of specimens (concrete cylinder)	Slump (mm)
C25PE0	0	28	6	50
C25PE10	10	28	6	48
C25PE20	20	28	6	42
C25PE30	30	28	6	38
Total			24	

Remark: “C25” in “C25PE10” represents the concrete strength grade, “PE10” denotes 10% POFA and 10% EPS content by mass and volume, respectively.

3. Experimental Setup and Testing

After 28 days of curing, all concrete specimens were tested for compressive strength, splitting tensile strength, elastic modulus and stress-strain curve.

3.1 Compressive Test

Concrete axial compressive strength was determined using a compression testing machine. The strength value was taken from the average result of three specimens.

3.2 Elastic Modulus

To record strain change during testing, longitudinal strain gauges were attached at the two symmetrical side surfaces of specimens as shown in **Error! Reference source not found.**. The loading mode was stress controlled with 0.5 MPa/s speed. Specimens were pre-pressed three times from 0.5 MPa to one third of axial compressive strength to eliminate plastic deformation. The elastic modulus (E) is calculated by Eq. 1 [8] as the average result of three specimens.

$$E = \frac{F_a - F_o}{A\Delta\varepsilon} \quad (1)$$

where, E = elastic Modulus (Pa), F_a = final force (N), F_o = initial force (N), A = area (m^2), $\Delta\varepsilon$ = Change in stress.

3.3 The Stress-Strain Curve

The concrete stress-strain curve was determined using Universal Testing Machine as illustrated in Fig. 4.

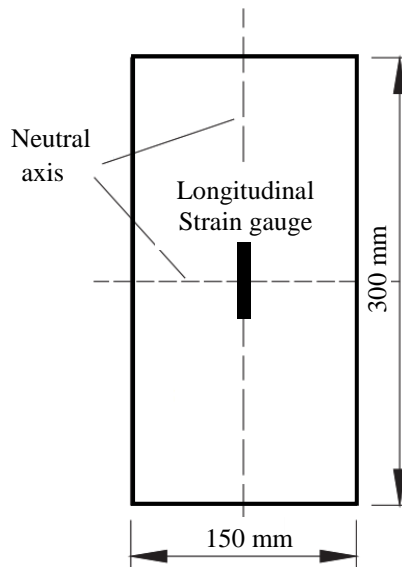


Fig. 4 - Strain gauges position on specimen for elastic modulus testing



Fig. 5 - Test set-up for stress-strain curve testing

3.4 Splitting Tensile Strength

Test set up for splitting tensile strength is shown in Fig. 4 . Calculation of splitting tensile strength (f_{ts}) is expressed by Eq. 2 [5]. Average result of three specimens was taken.

$$T = \frac{2P}{\pi LD} \quad (1)$$

where, T = splitting tensile strength (kPa), P = maximum applied load indicated by the testing machine (kN), L = average sample length (m), D = sample diameter (m).



Fig. 4 - Splitting tensile strength test setup

4. Results and Discussion

The test results of the basic mechanical properties of EPS-POFA concrete grade 25 are depicted in Table 3. From the results obtained, it seems that the mechanical properties of EPS-POFA concrete were affected by slump test in Table 2.

Table 3. Basic mechanical properties of EPS-POFA concrete grade 25

Sample	Density (Kg/m ³)	Axial compressive strength(MPa)	Splitting tensile strength (MPa)	Elastic modulus (MPa)
C25PE0	2835	27.62	3.21	26286
C25PE10	2700	25.23	3.08	22496
C25PE20	2413	24.84	2.81	20746
C25PE30	2057	19.36	2.72	16916

4.1 Axial Compressive Strength

Results of concrete axial compressive strength are shown in Table 3 and

Fig. 5. It was found that the compressive strength of concrete decreased as the percentage of POFA and EPS increased. Average strength reduction was 8% for concrete prepared with 10% EPS and 10% POFA. The average of strength reduction for 20% of EPS and POFA contents was 10%, whereas 29% strength reduction was recorded for concrete containing 30% of EPS and POFA. Generally, strength reduction occurs due to the presence of EPS in concrete creating non-homogeneity of concrete. The addition of POFA in concrete containing EPS was apparently not favourable in increasing the concrete strength due to the influent of EPS on concrete characteristics is greater than POFA. However, the concrete strength containing 10 to 20% EPS and 10 to 20% POFA exhibited slight reduction, thus acceptable to be used as structure material. The minimum specified compressive strength for structural concrete is 2500 psi (17 MPa) [3]. Hence, structural concrete must not have strength less than 2500 psi (17 MPa) and from the result it can be seen that the 10% of EPS and POFA comply the requirement.

In addition, the EPS-POFA concrete axial showed decreasing trend as the EPS beads were hydrophobic, resulting in poor bonds with the cement paste. The same result is reported by other author, where the optimum level of 10% replacement of cement with POFA is suggested for durability of concrete made with waste materials [19]. The result in Table 2 and Table 3 showed that the slump height of the concrete affects the strength of the concrete. It is because trend value of slump height decreased when ESP percentage increased and give effect to the result of compressive strength.

The density of EPS-POFA concrete (Table 3) demonstrated decreasing trends for EPS and POFA concretes of 0%, 10%, 20% and 30% replacement at 2835 kg/m³, 2700 kg/m³, 2413 kg/m³ and 2057 kg/m³, respectively. The use of POFA and EPS in concrete reduced the density of the concrete compared to that of normal concrete. Low density of EPS-POFA concrete was attributed to low density of EPS itself. The density of EPS-POFA concrete was directly proportional with the axial compressive strength.

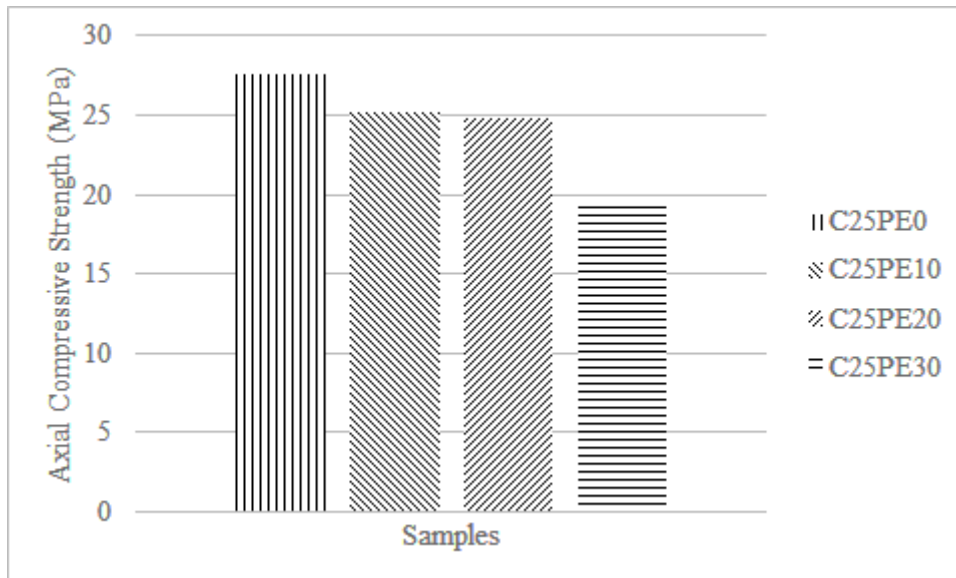


Fig. 5 - Axial compressive strength of EPS-POFA concrete

4.2 Elastic Modulus

Fig. 6 shows the elastic modulus of EPS-POFA concrete in the range of 27,000 to 16,000 MPa. In general, the elastic modulus almost linearly decreased as the EPS volume fraction increased and the result showed a linear relationship observed between the elastic modulus and EPS volume fraction [20]. This condition occurred due to the decreasing of concrete strength when the percentage of EPS increased.

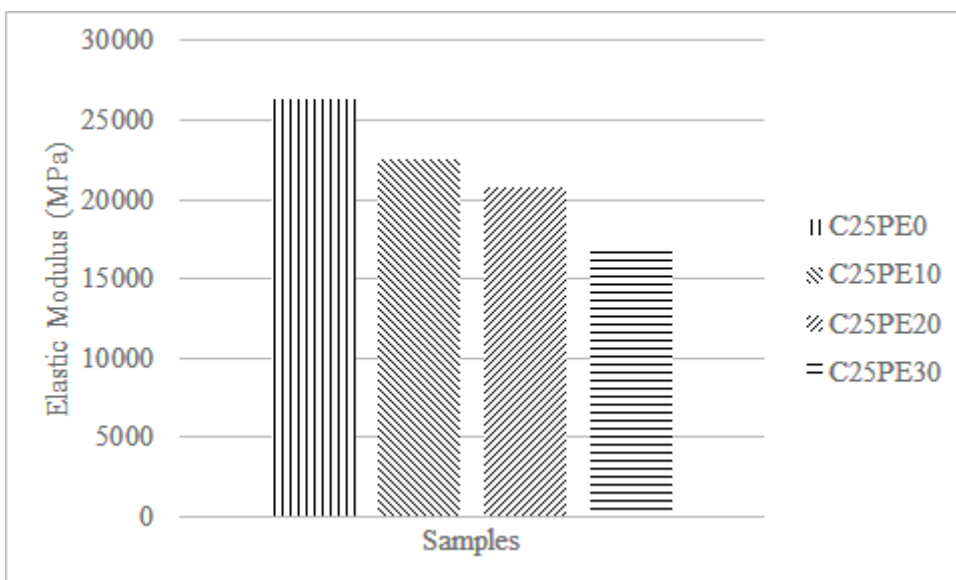


Fig. 6 - Elastic Modulus of EPS-POFA Concrete

4.3 Splitting Tensile Strength

The results of splitting tensile strength of EPS concrete are presented in

Fig. 7. The effect of EPS content on concrete tensile strength was similar as observed on the compressive strength. The splitting tensile strength decreased as the EPS content increased. This could be due to the EPS beads giving low compactness of concrete. This result can also be verified by other author, which indicated that the splitting tensile strength decreased as the EPS content increased [20].

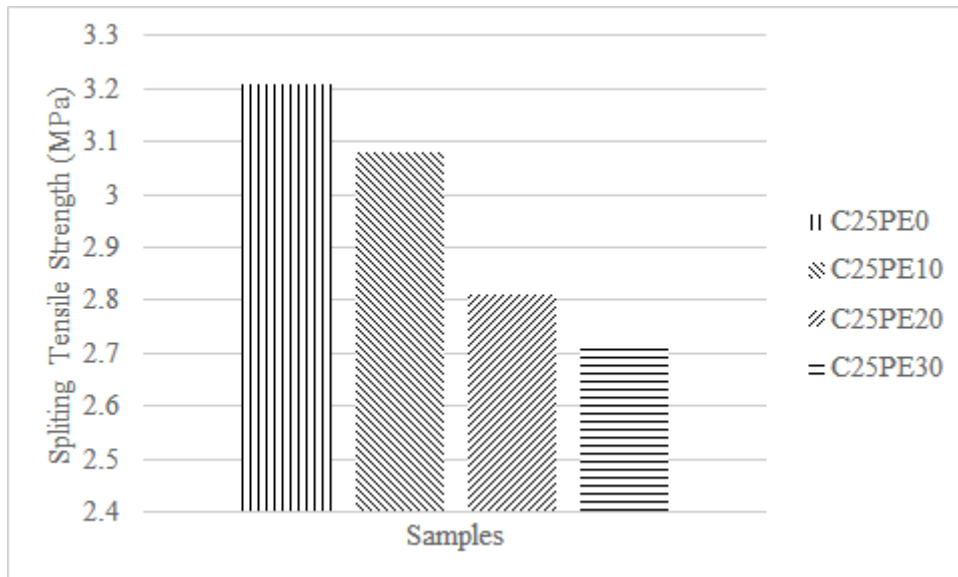


Fig. 7- Splitting tensile strength of EPS-POFA concrete

4.4 Axial Compressive Stress-Strain Curve

Fig. 8 shows the effect of EPS and POFA utilization on the stress-strain behaviour of concrete specimens. Three concrete specimens containing EPS-POFA were prepared. The axial strain was calculated through average displacement of two vertical strain gauges and then the axial stress was plotted against the axial strain. Gradual change in the shape of stress-strain curves when the EPS-POFA content increased in concrete is presented in Fig. 10.

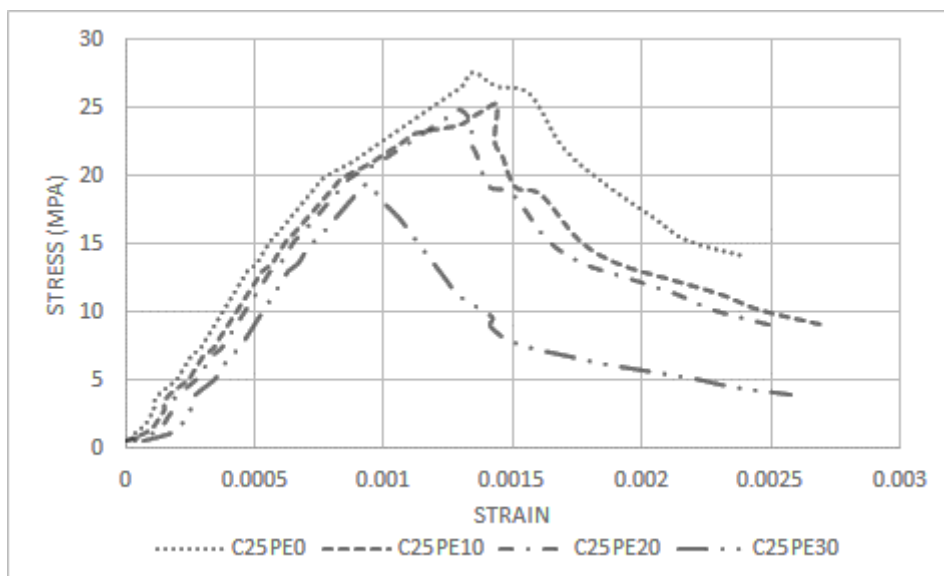


Fig. 8 - Axial stress-strain curves of EPS-POFA concrete

The increasing of EPS-POFA content led to low maximum peak and gave small initial slope of curves. Low maximum peak may lead to low compressive strength, while small initial slope may lead to small elastic modulus. The slope of curve was lower than the normal concrete indicating that the EPS-POFA concrete has lower brittleness compared to normal concrete. This trend is consistent with previous study [9] which stated that the stress of EPS concrete decreased slowly at larger strain area in descending branch of stress–strain curve. The failure condition of concrete containing EPS under axial compression occurred gradually and the concrete were able to retain the load after failure without full collapse. Therefore, concrete containing EPS may be considered to absorb vibrations. A similar type of failure was also reported by previous research [14] for EPS concrete. Although the other author reported that the compressive strength of concrete containing POFA tended to increase with curing age [13] but the influent of EPS on concrete characteristic seem greater than POFA which is gave lower strength compare to normal concrete but POFA used in this study was found to improve the bond between EPS beads and cement as well as increased the axial compressive stress-strain curve close to the normal concrete strength

5. Conclusions

In this study, the concrete cylinders containing EPS and POFA were prepared and tested. From the results obtained, it can be deduced that the axial compressive strength, elastic modulus, and splitting tensile strength inclined to decrease as the EPS and POFA content in concrete increased. POFA used in this study was found to improve the bond between EPS beads and cement as well as increased the compressive strength of concrete close to the normal concrete strength but low in density. To achieve axial compressive strength close to the normal concrete and requirement strength of structural concrete, the optimum replacement percentages for cement and fine aggregate were 10 to 20% for POFA and 10 to 20% for EPS. The characteristic of EPS with low density contributed to density of EPS-POFA concrete. Low slope of stress-strain curve for EPS-POFA concrete may perform lower brittleness compared to the normal concrete.

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