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The Performance of Reinforcement Concrete Beam Containing Palm Oil Fuel Ash (POFA) and Expanded Polystyrene (EPS) in Term of Strain and Stress

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Abstract: The concrete in the construction industry requires advanced technology to overcome the problems of pollution emission and exploitation of natural resources, while palm oil fuel ash (POFA) and expanded polystyrene (EPS) which are left unhandled by the manufacturers and bring environmental impacts are ideal to be used in producing concrete because of their characteristics. The aim of this study was to investigate the potential of POFA and EPS to produce decent concrete which is lighter in weight. The objectives of this study were to compare the compressive strength, investigate the strain and stress performance, and determine the optimum percentage of POFA and EPS replacement for reinforced concrete beam. The samples of reinforced beams were designed to be 1000 mm × 150 mm × 150 mm with replacement of 10.00 % or 20.00 % POFA and 10.00 % EPS. Compressive strength test was carried up by using concrete cubes while strain and stress test was carried up using concrete beams. The workability of concrete mix replaced with POFA and EPS decreased as the percentage of replacement increased. The mass of the concrete beams decreased with the substitution of POFA and EPS. While 10.00 % POFA replacement gave best performance in compressive strength and strain and stress of the concrete, the further increasing of the percentage of POFA and EPS showed decrease in performance, while concrete with 10.00 % POFA and 10.00 % EPS gave similar results as normal concrete. Although the performance did not improve much, it proved that it could maintain the performance while promoting waste products as materials to save cost and reduce environmental problems.

Keywords: POFA, EPS, Concrete Beam, Stress, Strain

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1. Introduction

Concrete is a greyish mushy material which is widely used in construction industry. Portland cement as the most popular type of cement, used to produce concrete with aggregates with the addition of water. There are several ratios of composition of concrete can be found in the industry which are widely used and they are standardized with grades of concrete. Moreover, the raw materials can also be replaced with other materials or different types of specification, such as weight and shapes of aggregates. In Malaysia and other countries in South East Asia, palm oil fuel ash (POFA) and expanded polystyrene (EPS) are produced in mass as the sub products of many manufacturing industries and left unhandled. This is because the consumption of natural materials decreases the available resources for the future generations and forces them to slow down the development before they found alternatives for replacements. Moreover, production of concrete involves a series of procedures and harmful gases especially greenhouse gases, this harm living things and causes global warming or acid rain. Other problem is the wrongly disposal of POFA into landfill bring negative impact to the environment as pollution. The EPS also requires solution to the landfill problems and disposal problems to reduce chemical pollution during combustion. Hence, POFA and EPS were selected as replacement in concrete.

Palm oil fuel ash (POFA) is a common sub product treated as waste in the palm oil industry. POFA is a greyish product which has less economical function, commonly seen in this industry. Previous studies show that POFA can be used in concrete to produce lightweight concrete which is lighter and more durable than the normal concrete. It is pozzolans in characteristics. The mechanical properties of the POFA modified concrete enables it to reduce the cost of transportation, the cost of construction and waste issues.

On the other hand, expanded polystyrene (EPS) is an artificial product produced by the industry during polymerisation process as plastic waste. Previous studies show that concrete with EPS is also a possibility to produce lightweight concrete. EPS is suitable to be used as a substitution of fine aggregates. The mechanical properties of the EPS modified concrete can be described as hydrophobic, high thermal insulation and higher structural design. This again improves the lifespan of the concrete, along with additional impacts such as resistance to chemical, heat and water attacks.

1.1 Objective

This research aimed to study the properties of stress and strain in a modified concrete beam. A successfully modified concrete beam using expanded polystyrene (EPS) and palm oil fuel ash as replacement materials can be promoted to the industry. This study investigated the patterns of the modified concrete beam using laboratory experiments by applying the theories.

- To compare the compressive strength of concrete containing expanded polystyrene (EPS) and palm oil fuel ash (POFA) with normal concrete.
- To investigate the stress and strain behavior of reinforced concrete beam containing expanded polystyrene (EPS) and palm oil fuel ash (POFA) as replacement materials.
- To determine the optimum percentage of reinforced concrete beam containing expanded polystyrene (EPS) and palm oil fuel ash (POFA) as replacement materials.

1.2 Scope of Study

This study focused on investigating the effect of composite ratio of concrete beam mixed with expanded polystyrene (EPS) and palm oil fuel ash (POFA) affected the performance of the concrete beam in term of strain and stress. The concerns of the experiments were of the weight, the workability, the strength, the strain and the stress of the concrete beam containing expanded polystyrene (EPS) and palm oil fuel ash (POFA) to be produced. As shown in Table 1, this research focused on observing the concrete beams which are made of absence or 10.00 % of expanded polystyrene (EPS) and 0.00 %, 10.00 %, and 20.00 % of palm oil fuel ash (POFA). The concrete was shaped into reinforced concrete beam with dimension of 1000 mm x 150 mm x 150 mm and were reinforced with Y12 steels and R8 links. The mixing of concrete with POFA and EPS was decided by DOE method. Each specification was prepared with 3 specimens to undergo workability test, compressive strength test and strain and stress test.

Table 1: Number of specimens for different percentage ratio of POFA and EPS

EPS POFA	0%	10%
0%	3	3
10%	3	3
20%	3	3

2. Materials and Methods

The Figure 1 shows the methodology flow chart of this study.

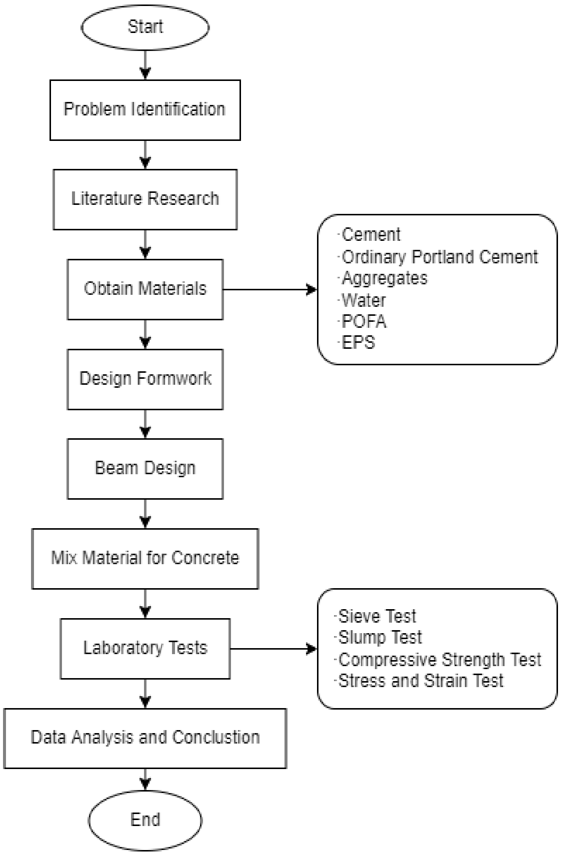

Figure 1: Activity flow chart

2.1 Materials

The normal concrete is the concrete composite of cement, aggregates, and water. The common materials used are Portland cement, sands, gravels and pure water. The concrete beams were designed according to the specification of the grade 25. Cement is available in form of greyish powder and gives a strong smell. The raw materials of producing cement is phosphorus-bearing limestone (PL), normal limestone (NL), clay, iron ore, and fly ash [1]. The cement used in this experiment was ordinary Portland cement (OPC). Aggregates can be categorised as coarse aggregates and fine aggregates, fine aggregates are normally less than 4mm size while coarse aggregates are larger than 5mm. Water is used in associating to the cement to produce cement paste which can bind the aggregates.

2.1.1 Palm Oil Fuel Ash (POFA)

POFA is the result of burnt palm kernel shell and palm oil husk. The formation of POFA is by burning the palm oil fiber, kernels, empty fruit branches, and shells to generate energy. POFA can enhances the durability and decrease permeability by acting as filler or cement replacement [2]. Normally, cement or POFA are used as binder [3]. The ground POFA is normally dark grey in colour, and the unground POFA is light grey due to the exposure to low temperature, however can be heated to be greyish [4]. Concrete modified with POFA has several advantages in properties, such as higher resistance to chloride attack and sulfate attack, increasing of drying shrinkage, decreasing heat development, and reducing acidic environment [4]. Due to its high pozzolanic reaction, it can obtain high compressive strength.

Figure 2: POFA

2.1.2 Expanded Polystyrene (EPS)

Expanded polystyrene (EPS) is a common substance used in packaging and insulation material in various industries. EPS is a spongy plastic grain which is round-shaped and used for production of lightweight concrete [5]. EPS concrete is made by mixing of cement, natural aggregates and expanded polystyrene beads [6]. The density of expanded polystyrene (EPS) is normally less than 30kg/m^3, and is classified as artificial ultra-light aggregate [5]. EPS carries characteristic of being hydrophobic. By increasing the amount of EPS beads in concrete, the water absorption also increases due to the air bubbles contribute to better porosity [6]. With the drop of strength, the heat insulation increases for EPS concrete [7]. Normally, the structural elements in EPS concrete can be fabricated directly on construction site [8].

Figure 3: EPS

2.2 Methodology

2.2.1 Preparation of reinforced concrete beam

18 concrete beams were produced for tests. The Portland cement, sand, water, palm oil fuel ash and expanded polystyrene was first prepared and weighted according to the design of each specimen. After that, the materials were placed on a large tray and mixed together and mixed with water. Shovel was

used to mix the materials. The formworks were brushed with oil so that it was easier to remove the beam after harden. Next, placed the reinforcement bar into the formwork and poured the fresh concrete into the formwork. While pouring concrete, compacting rod was used to compact the concrete between layers. After pouring, the excessive concrete was wiped out and the surface was flattened. The well shaped concrete was left in the lab for 28 days to be harden.

2.2.2 Laboratory test

2.2.2.1 Sieve analysis

Sieve analysis test was carried out to determine the percentage and composition of the aggregate in a mix and determine the quality of the aggregate. The sieve set for coarse aggregate was prepared with sieve size in arrangement of a lid, 37.50 mm, 25.00 mm, 14.00 mm, 10.00 mm, 5.00 mm, and a pan. The sieve set for fine aggregate was prepared with sieve size in arrangement of 10.00 mm, 5.00 mm, 2.36 mm, 1.18 mm, 0.60 mm, 0.30 mm, 0.15 mm, 0.075 mm. The sieves sets were placed on vibrator machine supplied with electric power. The aggregates mix were poured into the sieve set. The sieve analysis is fulfilled with ASTM C136. In this research, sieve analysis was mainly used to separate the aggregates.

2.2.2.2 Workability test

Slump test is a popular experiment to be carried out due to its simplicity and efficiency. To carry out slump test on fresh concrete, a mould with internal dimension of 200 mm bottom diameter and top 100 mm diameter was used, typically with 300 mm height. The fresh concrete was poured in layers and tamped between layers. The mould was removed carefully once it was full. The concrete deformed and the subside and the slump were measured. The difference of the height of the mould and that of the highest point of specimen were recorded and analysed for workability of the specimens.

2.2.2.3 Compressive test

Compressive strength test is a test on hardened concrete to analyse the strength. The cube test had standard of BS EN 12390-1:2000, which the mould was filled in with layers compacted with hammer. The fulfilled mould was stored for 7 days and 28 days of curing to carry out compressive test. After 7 days and 28 days of curing, the specimens were taken out from the water and compacted with compression machine. The specimens were carried out compressive test by crushing the specimens until failure occurred. The moment of failure is the maximum load can be supported by the concrete and it was recorded to analyse the compressive strength.

2.2.2.4 Stress and strain test

To study the relationship between strain and stress of the concrete beam, progressive damage test was used. The beams were placed on the equipment and supported by roller. The beams were damaged in the middle by the machine. The beam is equipped with strain gauge, to automate the reading of strain connecting to data logger. The pressure applied at the center of the beam was recorded as the stress. The strain and stress were determined by compacting the beam until failure, which the cracks occurred. The beam cracked once the stress has surpassed the maximum capacity of bearing, and the beam lost its plasticity and deformation occurred. The relationship of strain and stress can be affected by the mechanical properties of the concrete, mainly compressive strength and tensile strength.

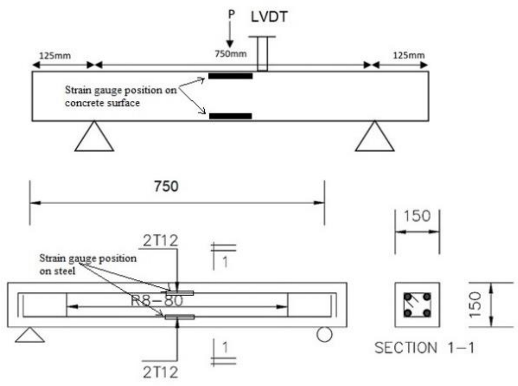

Figure 4: Test setup

3. Results and Discussion

3.1 Sieve analysis

Table 2: Sieve analysis result for coarse aggregate

Sieve size (mm)	Weight of Pan (g)	Weight of Pan and Sample (g)	Mass Retained (g)	Percentage of mass retained (%)	Cumulative of percentage mass retained (%)	Cumulative of passing percentage (%)
37.5	1157	1157	0	0.00	0.00	100.00
20	1198	1452	254	12.37	12.37	87.63
14	1246	2005	759	36.95	49.32	50.68
10	1272	1800	528	25.71	75.02	24.98
5	1185	165	465	22.64	97.66	2.34
Pan	852	900	48	2.34	100.00	0.00
	Total		2054	100		

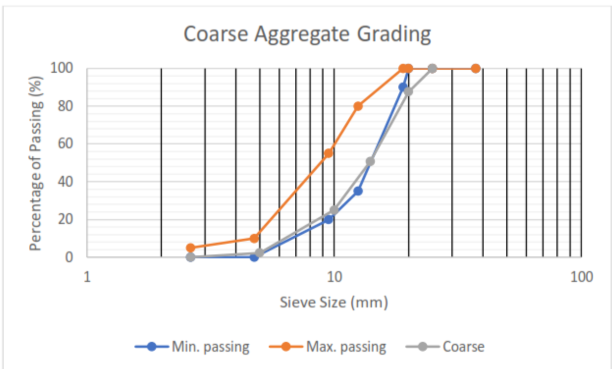

Figure 5: Coarse aggregate grading

Table 3: Sieve analysis result for coarse aggregate

Sieve size (mm)	Weight of Pan (g)	Weight of Pan and Sample (g)	Mass Retained (g)	Percentage of mass retained (%)	Cumulative of percentage mass retained (%)	Cumulative of passing percentage (%)
10	585	585	0	0.00	0.00	100.00
5	551	552	1	0.05	0.05	99.95
2.36	540	633	93	4.61	4.66	95.34
1.18	507	1128	621	30.76	35.41	64.50
0.6	438	1127	689	34.13	69.54	30.46
0.3	493	786	392	19.42	88.95	11.05
0.15	361	522	161	7.97	96.93	3.07
0.075	382	429	47	2.33	99.26	0.74
Pan	244	259	15	0.74	100.00	0.00
	Total		2019	100		

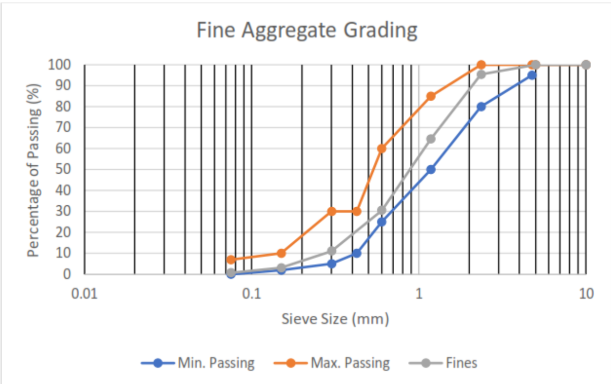

Figure 6: Fine aggregate grading

Based on the Table 2 and Figure 5 for coarse aggregate, and Table 3 and Figure 6 for fine aggregate, the coarse and fine aggregates are compatible to the standard of ASTM C33-03. This indicates that the coarse aggregates and fine aggregates are effective and suitable to produce concrete as the required sizes of aggregates can be filtered.

Regardless of the result of sieve analysis, the main purpose of carrying out sieving activities in this research is to obtain required amount of rock and sand to be used as coarse aggregates and fine aggregates respectively as the raw materials of concrete.

3.2 Mass of Sample

Table 4: Mass of concrete beam

Specimens	POFA (%)	EPS (%)	Sample 1 (kg)	Sample 2 (kg)	Sample 3 (kg)	Average Mass of Samples (kg)	Difference to specimen 1 (kg)
1	0	0	57.30	57.80	57.55	57.55	-
2		10	55.70	55.40	54.30	55.41	-2.14
3	10	0	57.10	57.25	57.10	57.15	-0.40
4		10	55.65	54.80	53.05	54.50	-2.81
5	20	0	56.70	56.90	56.75	56.78	-0.77
6		10	54.50	53.05	54.30	53.95	-3.60

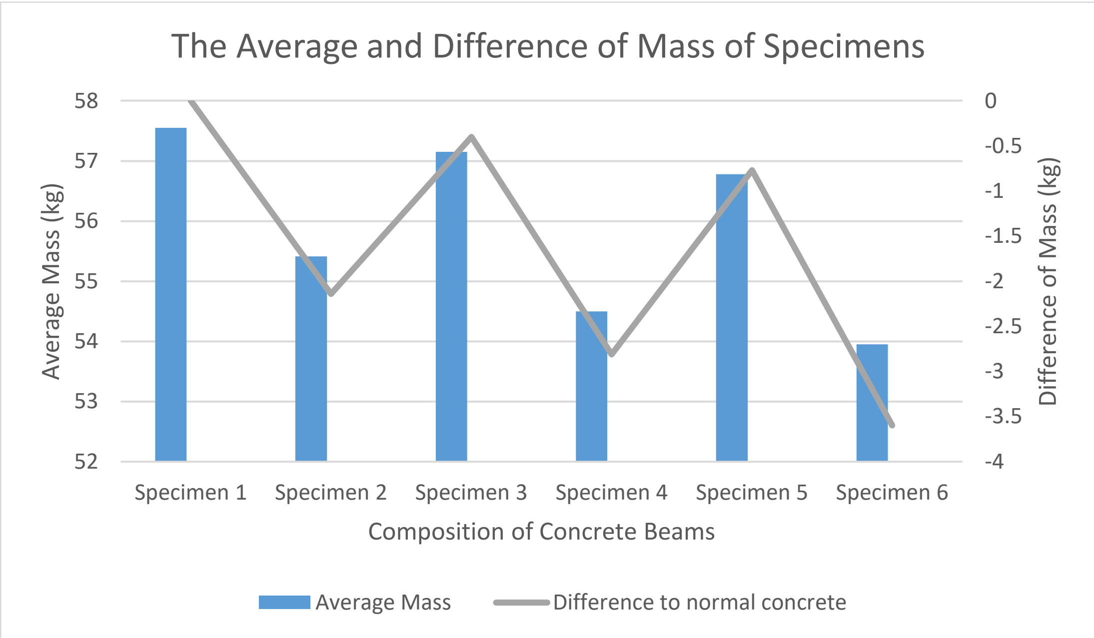

Figure 7: Comparison of mass of sample mass

Based on Table 4 and Figure 7, the average of normal concrete beam was 57.55 kg, and was used as reference of comparison to the modified beams. The addition of 10.00 % EPS to the concrete beams were observed to be averagely 55.41 kg, which is 2.14 kg lighter than normal beams. The beams which contain 10.00 % POFA and no EPS was recorded at 57.15 kg, which is only 0.40 kg lighter than he normal beam, while the beams which were replaced by 10.00 % of POFA and EPS had averagely 54.50 kg, which was 2.81 kg lighter than normal concrete. Next, the concrete beams sample with only 20.00 % POFA modification was weighted to be averagely 56.78 kg, which is 0.77 kg lighter than normal beam, and again, the additional replacement of 10.00 % EPS had decreased weight, averagely 53.95 kg, which is 3.60 kg lighter than normal beams. According to the observation, it can be concluded that the negativity of difference of weight of all specimens compared to normal concrete indicate that the usage of POFA and EPS in concrete can reduce the mass. It can be observed there is a trend of decrease in mass when POFA was used as replacement, and the specimens with EPS replacement were lighter than the beam with only POFA replacement. Both POFA and EPS replacement reduce mass, while POFA reduces only a little, EPS which has very low density reduces the mass significantly because of its natural lightweight property which is much lighter than fine aggregates. Density of EPS is 19.00 kg/m3 which is much lower than 1420 kg/m^3 of fine aggregate. The POFA and EPS with lower densities than their substitution naturally obtain concrete with lower density and lighter mass. It can be concluded that replacement of POFA and EPS as cement and fine aggregates respectively can produce lightweight concrete, and EPS has better performance in reduction of mass.

3.3 Workability

Table 5: Slump value of specimens

Specimens	Percentage of POFA (%)	Percentage of EPS (%)	Slump Value (mm)
1	0	0	47
2		10	44
3	10	0	38
4		10	36
5	20	0	33
6		10	30

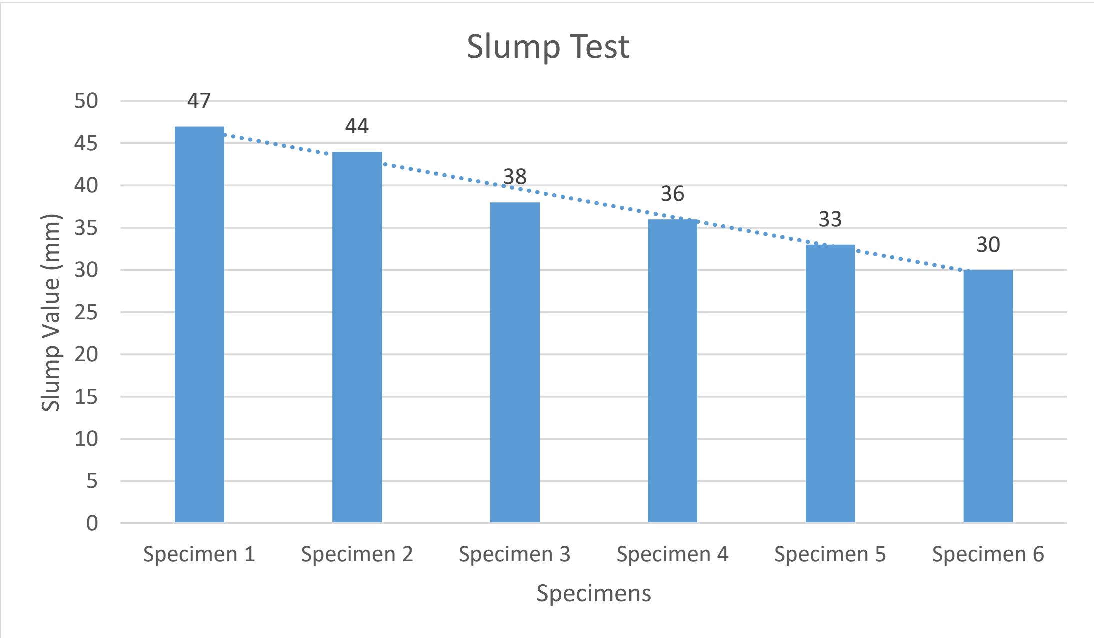

Figure 8: Slump value of concrete

Table 5 and Figure 8 showed that replacing cement and fine aggregates with POFA and EPS reduced the workability of the concrete. The slump value of normal concrete was 47 mm, which recorded the highest slump value among all samples. By replacing with 10.00 % EPS, the slump value decreased to 44 mm, which is acceptable for its minor reduction. For specimen 3 and specimen 4 which were replaced with 10.00 % POFA, and also replaced with 0.00 % and 10.00 % EPS respectively, their slump values were 38 mm and 36 mm, which was significant lose of slump values. Specimen 5 was replaced with 20.00 % POFA only, and specimen 6 was replaced with 20.00 % POFA and 10.00 % EPS, their slump value were reduced again to 33 mm and 30 mm respectively. In short, both replacement of POFA and EPS in concrete beam reduced the slump value, and the reduction is directly proportional to the percentage of replacement. This is because of the high porosity and low density of POFA and EPS, increase the requirement of water to the mix and also reduce the volume, hence the workability decreases. The reason is because the high porosity requires much water to fill the voids but the addition of water was not done, hence the concrete was drier in presence. The drier concrete had lower slurry properties and hard to be shaped, hence the workability of the concrete with POFA is not as high as normal concrete as the water is not sufficient and the concrete drop less in slump test. For EPS, the extremely low density caused EPS to be harder to be compacted in concrete hence the workability decreased. Although the workability of the concrete replaced with POFA and EPS were not as high as normal concrete, they were still acceptable as the allowable slump value for the design was between 30 mm to 60 mm.

3.4 Compressive strength

Table 6: Compressive strength of specimens

Specimens	POFA (%)	EPS (%)	Compressive Strength (MPa)	
			7 days	28 days
1	0	0	23.03	27.87
2		10	17.15	27.10
3	10	0	24.14	29.49
4		10	10.54	27.17
5	20	0	13.63	17.42
6		10	6.34	16.48

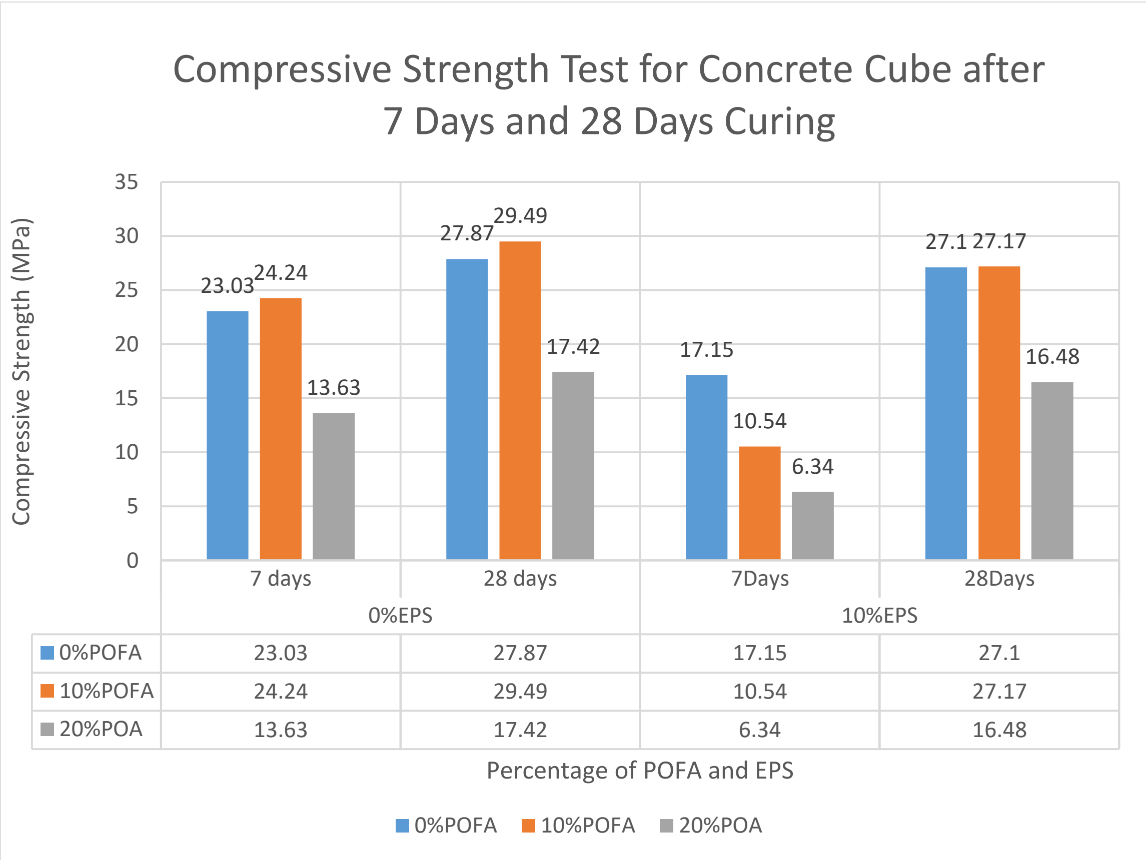

Figure 9: Compressive strength of concrete cubes

Based on the Table 6 and Figure 9, the average compressive strength of normal concrete cubes for 7 days after curing was 23.03 MPa and while 28 days after curing recorded 27.87 MPa. The concrete cubes with only 10.00 % POFA replacement recorded 24.24MPa for 7 days after curing and 29.49 MPa for 28 days after curing, which is the only composition to have increased compressive strength in the experiment. The specimen and specimen 3, both with 10% EPS replacement but with 0.00 % and 10.00 % POFA replacement respectively, had significantly dropped compressive strength after 7 days of curing, which recorded 17.15 MPa and 10.54 MPa. However, after 28 days, specimen 2 and specimen 3 achieved similar compressive strength as normal concrete, which were 27.10 MPa and 27.17 MPa. For cube samples with 20.00 % POFA replacement, the compressive strength had significant reduction to 13.63MPa after 7 days curing and 17.42 MPa after 28 days curing. On top of that, another 10.00 % of EPS replacement with 20.00 % POFA replacement samples had the drastically least compressive strength, which were 6.34 MPa after 7 days curing and 16.48 MPa after 28 days curing. By the data collected, it can be said that concrete with 10.00 % POFA replacement was the ideal composition in performance of compressive strength as it had higher compressive strength compared to the normal concrete after 7 days and 28 days after curing. However, the pozzolanic characteristic of POFA can affect compressive strength when much POFA was used. The powerful proof to the pozzolanic of POFA was shown as specimen 5 and specimen 6 both having 20.00 % of POFA with either absence or presence of EPS, the compressive strength reduced much. The reason of 10.00 % POFA had better compressive strength was because the little pozzolans can improve the resistance to attack, and reduce the heat of hydration, providing concrete with better strength. However, too much pozzolanic reaction reduce the rate of development of strength, and the setting time increased and require improved environment, hence the 20.00 % POFA experienced lower compressive strength as the pozzolans increased. The presence of EPS also reduced the compressive strength, as EPS was hard to be compacted and low density, it had literally no strength support to the composition. However, the replacement of 10.00 % of EPS can still be used after proper treatment as the results of them achieve ideal compressive strength after 28 days of curing. In conclusion, concrete with 10.00 % POFA replacement was a good modification, whilst the increase of percentage of POFA and EPS reduced the compressive strength.

3.4 Strain and stress

Table 7: Maximum stress, maximum strains of concrete beams

Specimens	POFA (%)	EPS (%)	Max Load (kN)	Max Stress (MPa)	Maximum Bottom Strain (ε)	Maximum Top Strain (ε)
1	0	0	152.60	67.822	0.00026	-0.00045
2		10	134.73	59.880	0.00043	-0.00058
3	10	0	153.23	68.102	0.00020	-0.00027
4		10	152.43	67.747	0.00026	-0.00043
5	20	0	128.97	57.320	0.00069	-0.00090
6		10	108.03	48.013	0.00089	-0.00125

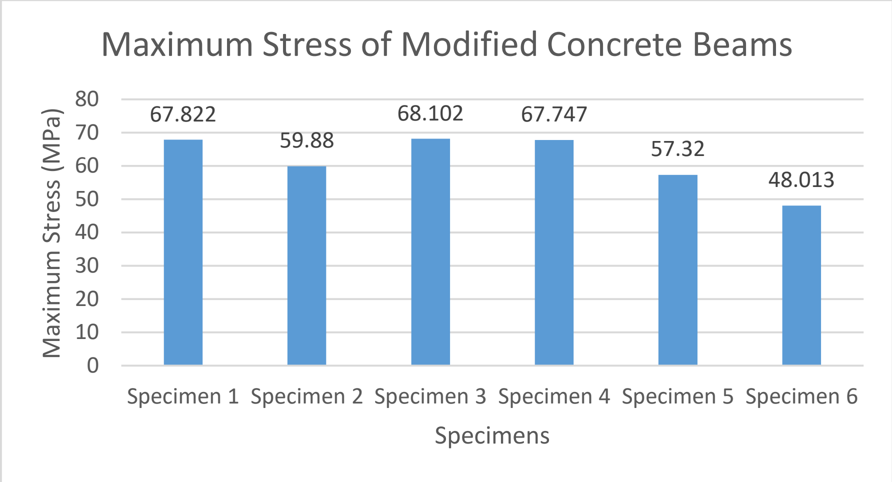

Figure 10: Maximum stress of concrete beams

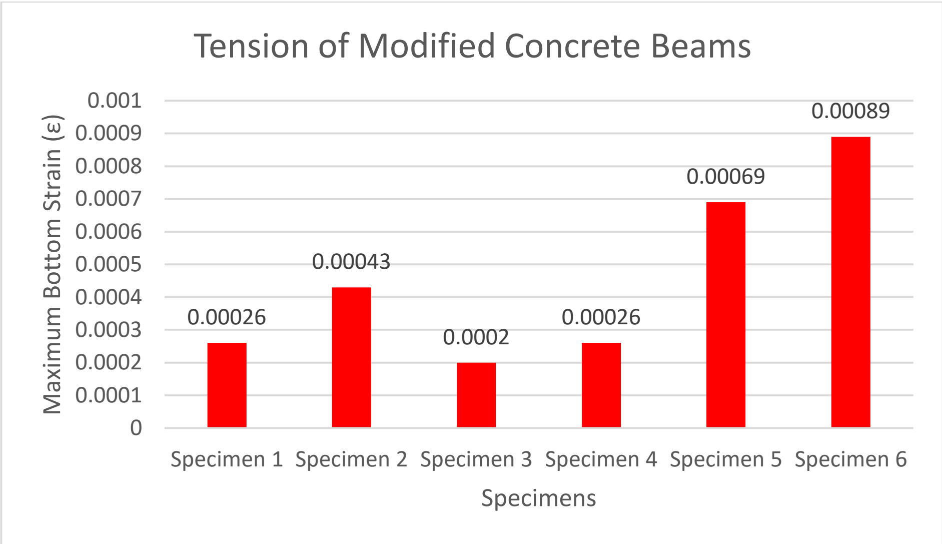

Figure 11: Maximum bottom strains of concrete beams

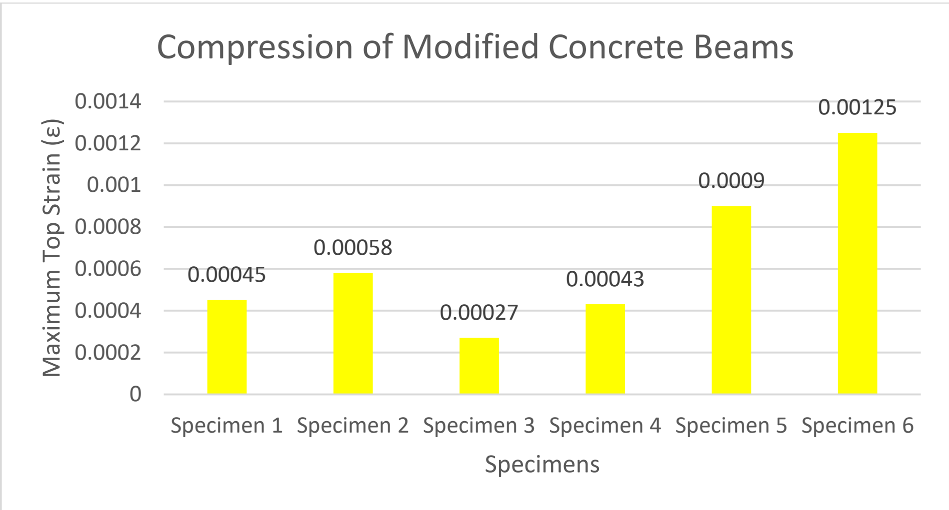

Figure 12: Maximum top strains of concrete beams

Table 7 showed that the forces applied on the beams were recorded in kilo Newton (kN). To study the stress and strain action on the beams, the loads were converted to stress, and the maximum stress for the beams to fail were recorded along with the strains. The upper part experienced compression, hence the values of the strain is in negative, while the lower part experienced tension, hence the values of the strain were in positive. According to Table 7, Figure 10, Figure 11 and Figure 12, the normal concrete beam without modification recorded 67.82 MPa of maximum stress, with 0.00026 ε maximum bottom strain and -0.00045 ε maximum top strain respectively. The maximum stress sustained by the 10.00 % EPS modified concrete beam decreases a little to 59.88 MPa, recorded 0.00043 ε bottom strain and 67.822 ε top strain. The specimen 3 which was 10.00 % POFA modification beam recorded the highest maximum stress which was 68.10 MPa, and the minimum tension and compression which were 0.00020 ε and -0.00027 ε. The concrete beam replaced with 10 % EPS and 10.00 % POFA withstood 67.747MPa of maximum stress, and maximum top strain of 0.00026 ε and maximum bottom strain of -0.00043ε. For specimen 5 and specimen 6 which were replaced with 20.00 % POFA, the beams withstood less maximum stress. The beams modified with 20.00 % POFA only recorded maximum stress of 57.32 MPa, and maximum bottom strain and maximum stress of 0.00069 ε and -0.00090 ε respectively. For specimen 6 replaced with 20.00 % POFA and 10.00 % EPS, it only recorded 48.01 Mpa maximum stress, and 0.00089ε and -0.00125 ε of maximum bottom strain and maximum top strain. From the result, it was shown that 10.00 % POFA increased the maximum stress beams can withstand and experienced the least compression and tension. The result of specimen 3 was better than normal concrete, this proved that it is the best composition to withstand larger stress, but had the least change of shape hence the least internal compression and tension. The normal concrete, however recorded a decent result as its maximum stress was high and maximum strains were low. The addition of EPS decreased the performance of strain and stress a little, keeping the specimen 4 recorded similar results to normal concrete, they had the same maximum top strain, and smaller maximum bottom strain compared to normal concrete beam. The concrete beam replaced with 10% EPS had slightly lower performance. However, addition of 20.00 % POFA decreased the performance of the beams, which gave lowest maximum stress withstood and highest compression and tension for the both specimen 5 and specimen 6 which were replaced with 20.00 % POFA and with presence and absence of EPS. Replacing 10.00 % POFA improved the strength of the concrete beam because of the pozzolans gave better resistance and reduce the heat required in hydration, hence the pozzolanic activity gave positive change to the hardness of concrete and less change in shape occurred. However, 20.00 % POFA exceeded the suitable pozzolans amount and the disadvantages of pozzolans displayed as it also reduced the strength development of concrete. Low density of EPS became the cause of concrete experienced poorer performance to withstand higher stress and bend easily because it did not have sufficient strength to support the concrete beams. In short, 10.00 % POFA improved the stress and strain performance and EPS decreased a little, while 2.00 0% POFA replacement decreased the performance significantly.

4. Conclusion

This study proved that concrete can be replaced with POFA or EPS with optimal amount. Concrete modified with POFA and EPS is more cost and environment friendly, which will be recommended to be popularised to the construction industry. However, the over adding of POFA in concrete reduced the performance of the concrete. In conclusion, the results prove that:

i. Different percentage of POFA and EPS used in concrete directly or inversely change the performance of the concrete.
ii. The workability of concrete decreased when percentage of POFA and EPS increased.
iii. The mass of concrete beams decreased when percentage of POFA and EPS increased.
iv. The compressive strength of concrete decreased when percentage of POFA exceeded 10% and EPS increased.
v. The maximum stress and maximum stress for concrete beam containing 10% POFA had the best result and the performance decreased when the percentage of POFA and EPS increased.

According to the conclusion, POFA and EPS cannot be full replacement for materials of concrete but can be partially used to replace to balance the benefits. Results concluded that concrete with 10.00 % POFA replacement increased the performance significantly. While concrete with 10.00 % POFA and 10.00 % EPS replacement did not have improvement in performance, but the performance is similar to normal concrete, which proved that it can maintain the performance while promoting waste products as materials to save cost and reduce environmental problems.

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