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Bonding Behaviour of Steel and Concrete Containing 10% Palm Oil Fuel Ash (POFA) and Expanded Polystyrene (EPS)

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Abstract: This study focusses on the application of using Palm Oil Fuel Ash (POFA) and Expanded Polystyrene (EPS) as the replacement materials in concrete. POFA was replaced the cement up to 10% of its mass in the concrete mixture and the fine aggregate was replaced by EPS up to 30% of its volume in the concrete mixture. The mechanical properties of concrete containing EPS and POFA as replacement materials were determined in terms of workability, compressive strength, and bonding performance between steel and concrete. The bonding steel and concrete was then compared with the normal concrete with pull-out testing. Expanded polystyrene granules can be included into a concrete mix to make lightweight polystyrene aggregate concrete with varying densities, compressive strengths, and tensile strengths. As the results, the optimum percentage of replacement of EPS and POFA were determined. The optimum percentage was 10% POFA and 20% EPS for compressive cube test and 10% POFA with 30% EPS for pull-out concrete test as the result were nearly to normal concrete value. In conclusion, POFA consists high percentage of silica that make it a good pozzolanic material to replace cement in concrete mixture.

Keywords: Concrete, Palm Oil Fuel Ash (POFA), Expanded Polystyrene (EPS).

1. Introduction

Materials selection cannot be overlooked or take with negligence in the design and construction of any engineering structures. Engineers are daily involved with materials or substances in manufacturing, selection, usage, and analyses. A number of significant decisions are made when choosing materials to be combined into a design, which include whether the materials can be formed into the precise and desired shape, dimensional tolerance and maintain the desired shape during usage, whether the essential properties can be attained and maintained during usage.

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Palm oil fuel ash (POFA) is one of the waste materials that can be utilized as replacement material for concrete production. Rich in SiO2, thus POFA acts as a good pozzolanic material to replace cement in concrete mixing [1]. In terms of compressive strength, the concrete samples made from cement and the POFA with original size have less compressive strength than conventional concrete samples, but the concrete samples made from cement and POFA with fine particles have compressive strength higher than traditional concrete samples. POFA has not only been utilised in standard concrete, but also in specialised concretes such as high strength, high performance, and aerated concretes [2]. Various research has reported that ground POFA can be used to build concretes with great strength and performance [3].

Most of lightweight aggregates are mineral raw materials, with the remainder being manufactured [4]. Expanded Polystyrene (EPS) is a stable, low-density foam composed of discrete air spaces in a polymer matrix. The polystyrene beads can be easily mixed into mortar or concrete to create lightweight concrete with a variety of densities. Now, EPS lightweight concrete may be utilised in a variety of structural components, including cladding panels, curtain walls, composite flooring systems, load bearing concrete blocks, the subbase material for a pavement, and floating marine constructions. Due to its excellent energy-absorbing properties, it can be used specifically within the protective layer of a structure for impact protection.

2. Materials and Methods

This section provides a thorough overview of the methods and materials used in this project. The information will include all aspects related to the work procedures.

2.1 Materials

Important for ensuring that the test will be conducted smoothly and in accordance with the specified objectives is the identification of suitable materials. Palm Oil Fuel Ash (POFA), Expanded Polystyrene (EPS), and concrete components are required for this study.

- Cement (Ordinary Portland Cement)
- Fine Aggregate and Coarse Aggregate
- Water
- Palm Oil Fuel Ash (POFA)
- Expanded Polystyrene (EPS)

2.2 Methods

Several tests are conducted to determine the mechanical properties of concrete using EPS and POFA as replacements. This study investigates the mechanical qualities of the compressive strength and tensile strength of the concrete. The water cement ratio for this study is 0.50 for 0% POFA and 0.55 for 10% POFA samples. After 7 and 28 days of curing, the concrete samples are subject to testing. The performance of this concrete is compared to that of standard concrete.

2.2.1 Slump Test

Slump test was used to determine the workability of fresh concrete. This test was carried out before the concrete was placed into the cube mould. The slump test was carried out by following the procedures 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 200mm, top diameter of 100mm and height of 300mm. Other apparatus used were 600mm long tamping rod with 16mm in diameter, scoop, sampling tray and ruler.

The concrete then subsided. This subsidence was termed as slump and was measured with records. The slumped concrete takes various shapes. According to the profile of slumped concrete, the slump was defined as true slump, shear slump or collapse slump. A collapse slump indicates the mix is too wet. Figure 1 show the type of slump.

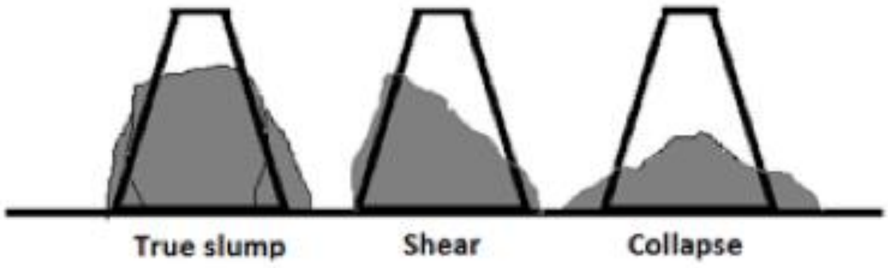


Figure 1: Type of Slump

2.2.2 Compression Cube Test

Commonly, the compression test is used to determine the concrete's strength in order to reach the required concrete grade. The test will yield varied findings based on the maturity of the concrete. The test for compressive strength consisted of smashing concrete cube sample to failure. This test will be undertaken after the sample have been cured for seven and twenty-eight days, respectively. This test is conduct in accordance with BS 1881: Part 116: Method for determining the compressive strength of concrete cubes. The highest force exerted on the sample was noted. The compressive strength of the concrete cube sample is determined by dividing its maximum load by its cross-sectional area.

2.2.3 Pull Out Testing

In reinforced concrete, effective bond between reinforcing bars and concrete is vital for full development of composite action. Hence the bond of reinforcing bars plays an important role in the structural behaviour of reinforced concrete. The bond of reinforcing bar is also important in crack control during serviceability and durability design. In a pull-out test, rebar is embedded within a concrete prism. During the test, rebar is pulled out by applying a tension force in a static loading rate and with a confined test setup (reaction applied directly to the sample itself). The values of the applied force and corresponding relative displacement between rebar and concrete are continuously measured and recorded.

3. Results and Discussion

After the results have been carried out, every data was recorded for analysis. The analysis is based on the percentage of Palm Oil Fuel Ash (POFA) and expanded polystyrene (EPS). Those 64 samples were mixed with difference volume of POFA and EPS. 32 samples were mix by 0% of Palm Oil Fuel Ash (POFA) and 0%, 10%, 20%, and 30% of Expanded Polystyrene (EPS) while another 32 samples were mix by 10% of POFA and 0%, 10%, 20%, and 30% of EPS. The result is divided to two parts which are compressive strength and tensile performance.

3.1 Result

This study included a tensile test using Universal Test Machine to determine the tensile load able to be applied to each sample. Compression Test also carried out to the cube samples with the size of 100mm to determine the concrete strength.

3.1.1 Slump Test

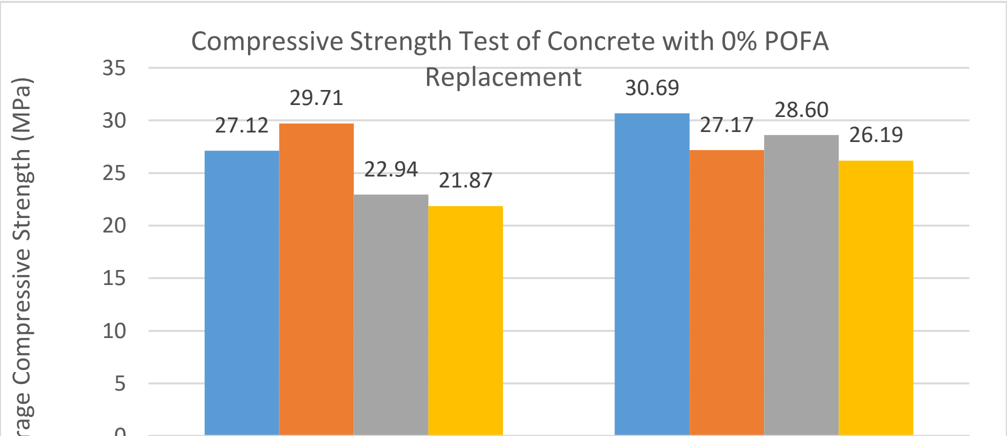
Table 1: Slump Test Result

Samples		Slump(mm)	Slump Type
POFA (%)	EPS (%)		
0	0	45	True Slump
0	10	42	True Slump
0	20	35	True Slump
0	30	32	True Slump
10	0	42	True Slump
10	10	40	True Slump
10	20	35	True Slump
10	30	30	True Slump

According to the Table 1, the slump value for the normal concrete was 45mm. As the percentage of EPS and POFA increased, the slump value of the fresh concrete decrease. Concrete with replacement of 10% POFA and 30% EPS showed the minimum slump value which is 30mm. The presence of POFA causing more water to be absorbed than normal concrete as it interferes water cement ratio and causing decreases of workability. Since the all the concrete mix was designed to have an allowable slump between 30mm-60mm, hence the result were acceptable.

3.1.2 Compression Cube Test

The compression calculated by dividing the maximum load which is failure load by area of the sample in the compression test. Concrete cube test held on the concrete with dimension of 100mmx100mmx100mm. Compression strength is according to the mature period. The result of compression test is shown in Figure 2 and Figure 3.



	7 DAYS	28 DAYS
0% EPS	27.12	30.69
10% EPS	29.71	27.17
20% EPS	22.94	28.60
30% EPS	21.87	26.19

Figure 2: Compressive Strength Test of Concrete with 0% POFA Replacement

Figure 2 showed the compressive strength of concrete cubes with 0% POFA replacement. The compressive strength of the normal concrete which is 0% POFA with 0% EPS after 7 days and 28 days were 27.12MPa and 30.69MPa respectively. As the replacement ratio of EPS increase, the compressive strength of concrete cubes decreased. After 28 days, the compressive strength of concrete cubes with 10% EPS and 20% EPS were 27.17MPa and 28.60MPa respectively.

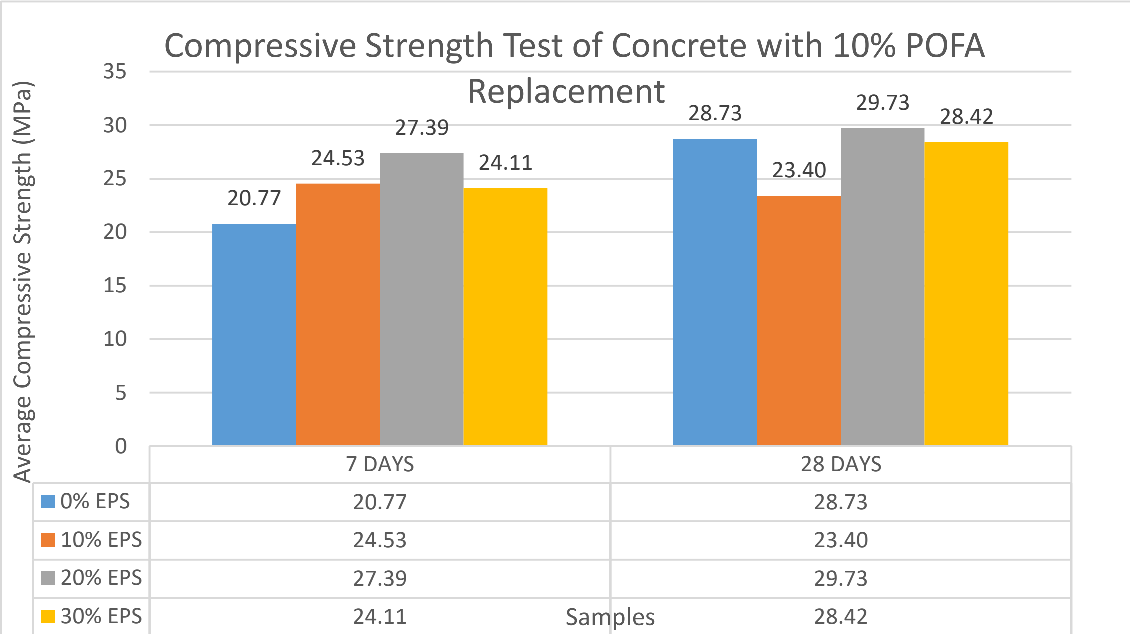


Figure 3: Compressive Strength Test of Concrete with 10% POFA Replacement

Figure 3 showed the compressive strength test of concrete cubes with 10% POFA replacement. Compressive strength of concrete with 10% POFA and 0% EPS replacement after 7 days and 28 days were 20.77MPa and 28.73MPa respectively, which were slightly lower than the normal concrete. As the percent of EPS increased, the compressive strength of concrete with 10% POFA decreased. After curing for 7 and 28 days, the compressive strength of concrete cube with 20% EPS were 27.39MPa and 29.73MPa respectively, which listed as the higher compressive strength for 10% POFA replacement.

3.1.3 Pull Out Test

Pull out tests were conducted for each sample to obtain maximum load before failure occur to the concrete mix. It is carried to each sample by applied tensile load to the to the samples which inserted in the rig mould in the Universal Tensile Machine (UTM). The load is gradually increased until failure occurred in each sample.

Figure 4: Concrete Sample and Rig

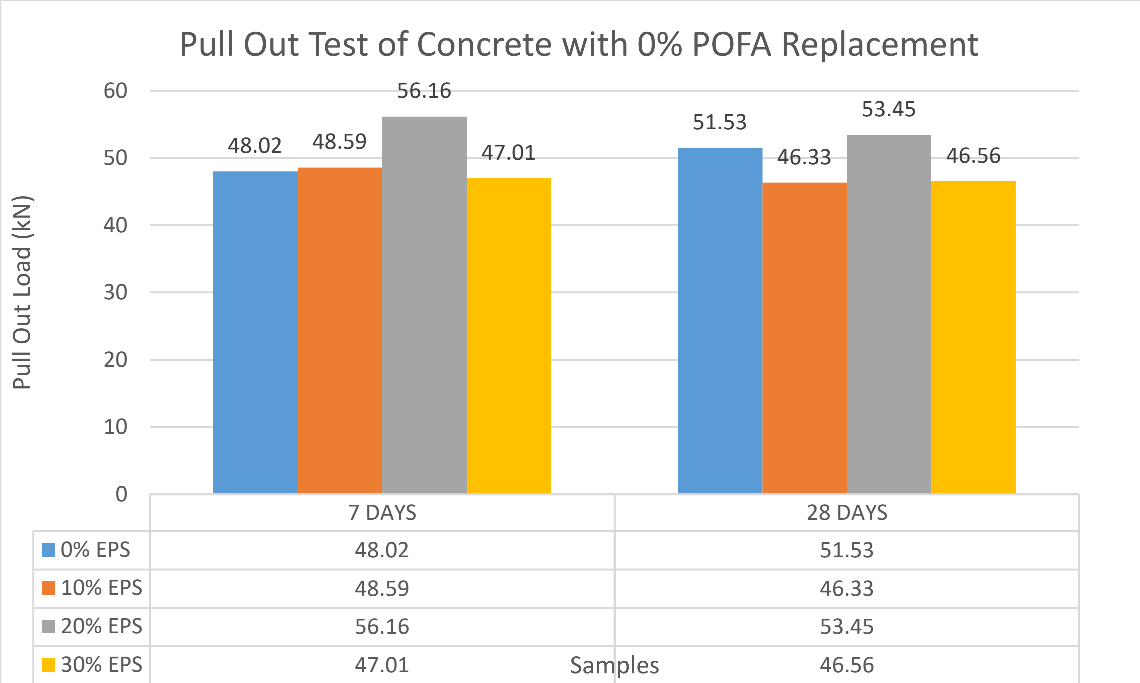


Figure 5: Pull Out Test of Concrete with 0% POFA Replacement

Figure 5 showed the pull-out load of the concrete samples with 0% POFA replacement. The pull out load of the normal concrete after 7 days and 28 days were 48.02kN and 51.53kN respectively. As the replacement ratio of EPS increased, the pullout load decreased. The pull out load with 0% POFA and 20% EPS were the highest at 7 days and 28 days with 56.16kN and 53.45kN respectively. As the replacement ratio of EPS was 30%, The pull out load were decreased for both 7 days and 28 days.

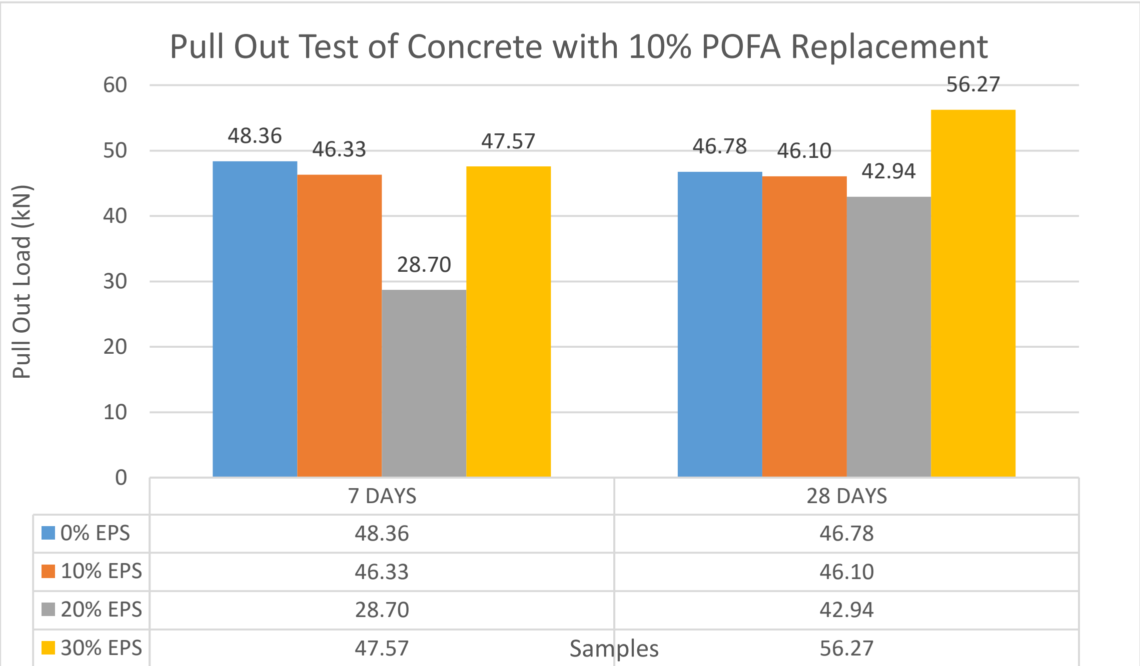


Figure 6: Pull Out Test of Concrete with 10% POFA Replacement

Figure 6 showed the pull-out load of concrete with 10% POFA replacement. The pull out load with 10% POFA replacement after 7 days was 48.36kN and 46.78kN after 28 days. This were slightly lower than the normal concrete. As the percentage of EPS increase, the pull out load with 10% POFA replacement were decreased. After 28 days, the pull-out load of the sample with 10% POFA and 30% EPS the highest which was 56.27kN while after 7 days the pull-put load was 47.57kN.

3.2 Discussions

The overall compressive strength of the concrete samples increased as the age of concrete increased, which correspond with result of previous study. The compressive strength decreased as the Extended Polystyrene (EPS) content increased, this is maybe the replacement of volume concrete mixture with EPS increased the surface area of fine particles, which can lead to weakening of interfacial transition zones between the fine aggregate and the cement paste [5]. Besides, the compressive strength of concrete samples decreased as the POFA replacement increased. This could be due to the high porosity particle, which can cause more water absorption thus increasing void content and decreasing the compressive strength of pervious concrete [6].

The pull out load of the concrete samples increased as the age of concrete increased, which correspond with result of previous study. The pull out load of the concrete decreased as the EPS content increased, which probably due to the increment of EPS replacement ratio. As a result, the surface area of fine particle increase, which can weaken interfacial transition zones between the fine aggregate and cement paste [5]. Besides, the pull out load of the concrete decreased as the POFA replacement increased. This may be due to the high porosity of POFA particle, which leads to more water absorption thus increased void content and decreased the pull out load of previous concrete.

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4. Conclusion

The conclusion is POFA consists high percentage of silica, making it a good pozzolanic material to replace cement in concrete mixture. POFA used in this study was found to improve the bond between EPS and cement as well as increased the pull-out load close to the normal concrete pull out load but in low density. Slump value of the fresh concrete decreased as the replacement ratio of EPS and POFA increased. However, the slump values of fresh concrete containing EPS and POFA as replacement materials were still acceptable as it was within the designed ranged based on the DOE concrete mix design. The compressive strength of concrete decreased as the replacement ratio of EPS and POFA increased regardless of curing age. This was due to the pozzolanic materials such as fly ash will cause a delay in hydration process. Lastly, 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.

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Appendix A

Table 2: Details of Concrete Cube Samples

Percentage of POFA	Percentage of EPS (%)	Density of Material (kg/m³)						Number of Cube	
		Cement	POFA	Fine Aggregate	EPS	Coarse Aggregate	Water	7 Days	28 days
0%	0	320	0	405.0	0.00	1440	160	3	3
	10	320	0	364.5	0.54	1440	160	3	3
	20	320	0	324.0	1.08	1440	160	3	3
	30	320	0	283.5	1.63	1440	160	3	3
10%	0	288	32	405.0	0.00	1440	160	3	3
	10	288	32	364.5	0.54	1440	160	3	3
	20	288	32	324.0	1.08	1440	160	3	3
	30	288	32	283.5	1.63	1440	160	3	3
							Total Cube	48	

Table 3: Concrete Mix Design Grade 25

Ingredients	Ratio	Content (kg/m³)
Water Cement Ratio	0.5	
Cement	1	320
Water	0.5	160
Fine Aggregate	1.265	405
Coarse Aggregate	4.5	1440

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