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Bonding Strength Between Steel and Concrete Through Incorporation of 20% Palm Oil Fuel Ash (POFA) and Expanded Polystyrene (EPS)

Arief Firdaus Bakhary[1], **Mohamad Hairi Osman**[2]*

[1]Department of Civil Engineering Technology,Faculty of Engineering Technology, University Tun Hussein Onn Malaysia, Pagoh Education Hub, 84600, Johor, MALAYSIA

[2]Intelligent Construction Centre,
University Tun Hussein Onn Malaysia, Pagoh Education Hub, 84600, Johor, MALAYSIA

*Corresponding Author Designation

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Abstract: In general, palm oil fuel ash (POFA) was a by-product of the production of cooking oil. POFA comprising pozzolanic material that has little or no cementitious value but, in finely divided form and in the presence of moisture, will chemically react with calcium hydroxide at ordinary temperatures to generate cementitious compounds. With these features, the concrete binder will be increased indirectly. Using POFA as a replacement is one way to make cement more environmentally friendly, given that POFA is derived from an organic substance. This study's primary objective was to discover if POFA and EPS are suitable for use in concrete. It focused on the bonding strength between straight steel bars and concrete, as well as the usage of expanded polystyrene (EPS) and palm oil fuel ash (POFA) as concrete alternatives. This experiment substituted 10% to 30% of the fine aggregate volume in the concrete mixture with expanded polystyrene (EPS). In contrast, 20% of the cement mass in the concrete mixture was replaced with POFA. The binding strength of EPS-POFA concrete and steel bar was measured using a pull-out test. The mechanical properties of POFA were examined using the compressive test and compared to cement. The performance of the EPS and POFA-containing concrete was then compared to that of standard concrete. Thus, the ideal replacement percentage for EPS and POFA was determined. Based on research finding, the bonding performance will increase when the POFA is present.

Keywords: Palm Oil Fuel Ash (POFA), Expanded Polystyrene (EPS), Pozzolanic, Concrete Binder, Bonding Strength

**Corresponding Author: mhairi@uthm.edu.my*

1. Introduction

Concreting is known as an exceptional structural construction material or a composite material used in construction. " Buildings will continue to be constructed with the rise of civilisation and development, according to Brunauer and Copeland. Since natural aggregates account for 70% of the total volume of concrete, this means that 8 to 12 million tonnes of natural aggregates are consumed annually. Environmental harm has been catastrophic and natural aggregate resources have been drastically diminished as a result of the excessive demand. As a result, new approaches to sustainable development are needed to reduce the overall use of natural resources, degradation of the environment, and the vast amount of industrial waste generated by various industries [1].

Thermoplastic, lightweight, and rigid, EPS is a foam plastic. Packaging is a common use for EPS. Polystyrene wastes, on the other hand, are becoming a major environmental issue because the substance is non-degradable. Researcher started to integrate EPS beads into concrete as substitution of natural aggregates since 1970s [2]. EPS beads may be easily blended into concrete to generate lightweight concrete (LWC). EPS lightweight concrete has a wide applicability in construction activity. Natural aggregate use and polystyrene waste can both be reduced by the use of lightweight EPS concrete. [3]

An additional waste product that may be utilised to make concrete is palm oil fuel ash (POFA). POFA is an excellent pozzolanic material for concrete mixing because of its high SiO2 content. It is believed that 5-6 percent of all carbon dioxide greenhouse gases emitted by human activities originates from 2 cement manufacture [4]. Hence, utilising POFA to partly replace the cement in building concrete is positive to the environment [5].

Pull-out tests are the only way to gain a deeper understanding of the bond-slip characteristics of reinforced structures and composites. Examples include FRP or Steel Bar Pull-Out Tests in Concrete, which were commonly conducted to determine how to better reinforce concrete structures by utilising Steel Bars to strengthen their mechanical resistance. These studies were conducted to determine ways to increase the mechanical resistance of reinforced concrete structures. The description above leads to the aims of this work to explore the strength of concrete that utilising EPS and POFA as substitute materials between steel bar [6]. Less cement would be needed to make concrete with POFA, lowering production costs, and the disposal problem would be reduced. When used as a cement replacement, POFA's high fineness allows for the production of strong concrete while also decreasing the material's permeability to water and exhibiting less expansion and loss of compressive strength than concrete manufactured with ordinary Portland cement [7]. Using POFA as pozzolans allows for the production of mortar that is both strong and resistant to chloride penetration.

2. Materials and Methods

This section provides a comprehensive summary of the methods and materials used for this project. The information will cover all aspects of the testing procedure, and diagrams for completing this study.

2.1 Materials

Cement, fine aggregate, coarse aggregate, expanded polystyrene foam, and water were the primary constituents in the concrete-making process that was the subject of this article. In the percent set, EPS and POFA are substituted for fine aggregate and cement, respectively. For pull out test specimen, the dimensions are 1300mm x 1400mm x 2800mm, and each side of the sample concrete cube is 100mm. In order to ensure that there were no discernible differences between the numerous specimens, the experiment's raw materials were standardized. Table 1 displays the specimens and their constituent materials.

Table 1: Details Materials Used

Material	**Details**
Cement	OPC
EPS	Size: 2mm
POFA	Size: 300 µm
Fine Aggregate	Size: <5mm
Coarse Aggregate	Size: 5mm-20mm
Steel Bar	Type: Y12

2.2 Methods

During the course of this inquiry, concrete specimens with EPS and POFA replacement ratios were made for testing in a laboratory. Each replacement ratio resulted in the creation of three 100-millimeter-sided concrete cubes and two rig samples with the following dimensions. It was discovered that EPS could replace fine aggregates in concrete at a volumetric equivalent of to 30 percent, whereas POFA could replace cement at a weight equivalent of 20 percent in concrete. A typical concrete sample was produced with 0 percent EPS and POFA replacement so that it could be used as a point of reference. Table 2 provides the details measurement of mould.

Table 2: Details Measurement of Moulds

Shape	Dimension	Quantity
Cube	100x100x100mm	6
Rig	1300x1400x2800mm	6

The mixing of concrete was performed manually with a shovel in a mixing tray. The procedure for producing concrete cubes was as follows:

1) The ingredients for concrete mixing, including sand, gravel, cement, EPS, POFA, and water, were weighed according to the design's calculations.
2) The components were placed in a mixing tray and stirred with a shovel.
3) This is done to facilitate the removal of concrete cubes from the mould once the concrete has hardened and to guarantee the quality of the concrete cubes.
4) Three layers of fresh concrete were poured into the moulds. Using a steel rod, each layer was used to eliminate voids in the fresh concrete. This can prevent honeycomb formation within the concrete.
5) The surplus concrete was then removed to create a smooth surface.

Figure 1: Process of Pull Out Test

3. Results and Discussion

This chapter will provide both a tabulation of the laboratory test findings as well as a discussion of those results. Each and every laboratory test was carried out under the guidance of assistant engineers in order to prevent improper handling of the apparatus. This research includes a tensile test using Universal Testing Machine to determine the pull-out load able to be applied to each designed sample. Compression test also carried out to the cube sample to determine the concrete strength. Four separate experiments: slump test, density test, pull-out test, and compressive test were carried out in order to get information regarding the qualities of the concrete cubes and the pull-out sample. The result will be compared to the performance of normal concrete.

3.1 Result

The first test was to find the bonding strength between steel bar and the concrete mixture by using universal tensile machine. The maximum pull-out load value for each sample were recorded. The pull-out test was performed on concrete after they were cured for 7 days and 28 days. Table 3 showed the results of compressive strength test of 7 days and 28 days respectively.

Table 3: Data of Pull Out Test

POFA (%)	EPS (%)	Average Sample	Bond Stress (N/mm^2)	Pull Out Load (kN)
0	0	7 days	398	44.97
		28 days	415	46.90
	10	7 days	430	48.59
		28 days	410	46.33
	20	7 days	497	56.16
		28 days	473	53.45
	30	7 days	393	44.41
		28 days	402	45.43
20	0	7 days	402	45.43
		28 days	410	46.33
	10	7 days	318	35.93

	28 days	435	49.16
20	7 days	444	50.17
	28 days	513	57.97
30	7 days	351	39.66
	28 days	319	36.05

Firstly, for sample contains 0% POFA replacement, pull-out load of the normal concrete after 7 days and 28 days were 44.97kN and 46.90kN respectively. As the replacement ratio of EPS increased, the pull-out load of concrete sample increase except on 30% of EPS. After 28 days, the pull-out load of concrete sample with 10%, 20%, and 30% EPS replacement were 46.33kN, 53.45kN and 45.43kN respectively. Therefore, the highest value for 0% POFA was when the replacement of EPS is 20% with 53.45kN. Figure 1 show the graphical view for 0% POFA replacement.

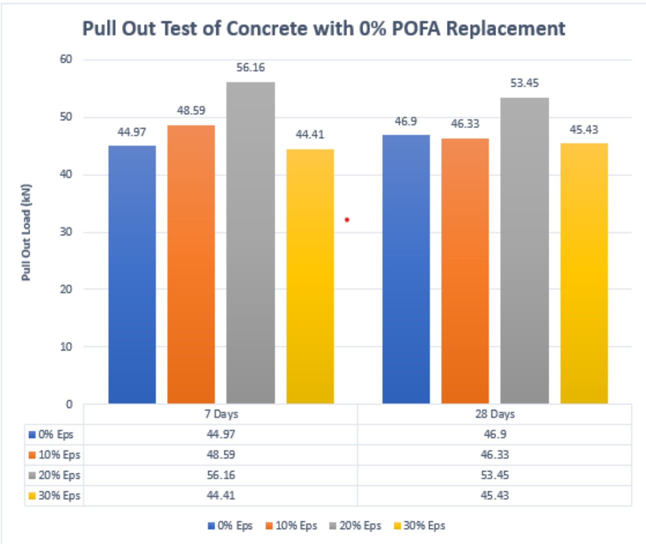

Figure 2: Pull Out Test Data for 0% POFA Replacement

After 7 days and 28 days of curing, the pull-out load value of the sample containing 20% POFA replacement was 45.43kN and 46.33kN, respectively, which was somewhat greater than the strength of conventional concrete. When the EPS is 10%, the force after seven days is 35.93kN, which is somewhat lower than when the EPS is 0%. Except for 30% of EPS, the pull-out load of concrete samples increased as the replacement ratio of EPS increased. The highest value for the pull-out load of the concrete sample at 20% after 28 days is 57.97kN. Figure 2 showed the graphical view for 20% POFA replacement.

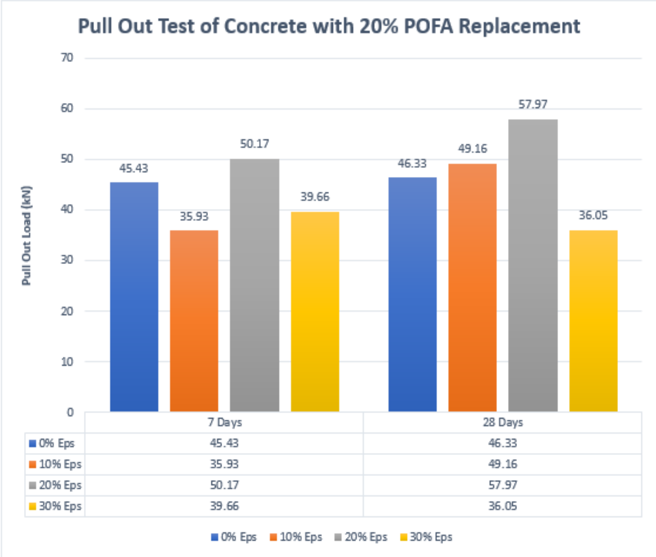

Figure 3: Pull Out Test Data for 20% POFA Replacement

Next is compressive test for cube sample. Since all concrete used in building must pass a compression test, this property stands as the most important one for the material. Compression stress determines the maximum load that can be sustained before failure. When optimum compression stress achieved, the concrete failure occurred and lost its shape or destructed. Figure 3 showed the compressive strength of concrete cubes with 0% POFA replacement. The compressive strength of the normal concrete after 7 days and 28 days were 27.20MPa and 30.69MPa respectively. As the replacement ratio of EPS increased, the compressive strength of concrete cubes decreased. After 28 days, the compressive strength of concrete cubes with 10%, 20%, and 30% EPS replacement were 43.48MPa, 28.60MPa and 14.64MPa respectively.

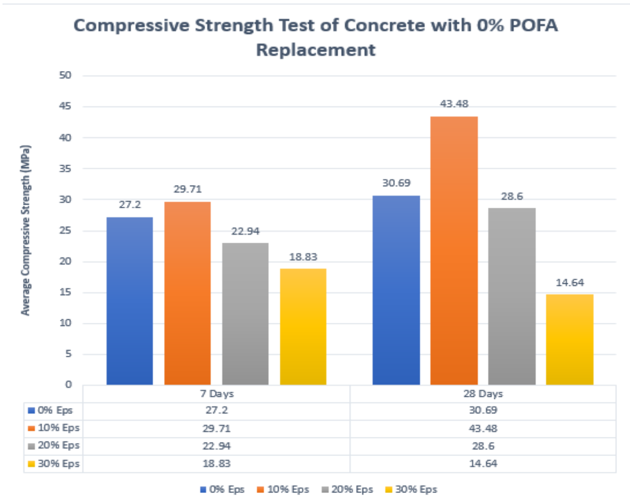

Figure 4: Compressive Strength of Concrete Cube with 0% POFA

The compressive strength of concrete cubes with 20% POFA replacement was depicted in Figure 4. After 7 days and 28 days, the compressive strength of concrete with 20% POFA substitution was 27.16MPa and 33.14MPa, respectively, which was somewhat more than the strength of normal concrete. When the EPS is 10%, the strength is 24.91MPa after 7 days and 30.84MPa after 28 days, which is somewhat lower than 0% EPS. However, when 20% EPS is added to the concrete, the strength increases to 27.84MPa and 36.45MPa after 7 and 28 days, respectively.

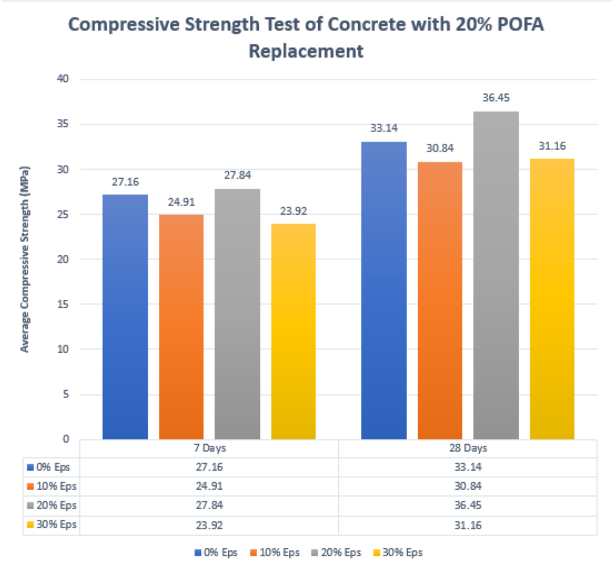

Figure 5: Compressive Strength of Concrete Cube with 20% POFA

3.2 Discussion

In a nutshell, the overall pull-out test and compressive strength of the concrete specimens increased with the age of the concrete, which corresponds to the findings of a previous study. Based on the results of all tests, the optimal composition is 20% POFA and 20% EPS. This result occurs, in my opinion, because POFA acts as a binder and reacts chemically with calcium hydroxide at room temperature to form compounds with cementitious properties [8]. However, EPS acts to reduce the density of concrete. My opinion is that EPS had a very positive value at 20% because EPS does not absorb water and maintains the strength of the concrete by maintaining a good temperature during the curing period. At 30% of EPS, the value is a little bit lower than it was previously due to the properties of EPS, which have almost no aggregate strength. In term of workability, the concrete will slightly decrease as the POFA increases. This is because POFA characteristic absorb more water than normal concrete and will affect the water cement ration of the design concrete. All EPS concretes without special bonding agents exhibit good workability and are easily compactable and finish able [9]. The flow values increased as the POFA increased.

4. Conclusion

After completing the laboratory test, the previous mentioned objectives were finally achieved. Using a pull-out test, the bonding strength between a concrete mixture containing POFA and EPS and a steel bar was successfully determined. The slump value, density, and compressive strength of concrete containing EPS and POFA were measured to determine its mechanical properties. In the recommendations, the optimal percentage of EPS and POFA as replacement materials in concrete will be stated. Based on the objectives of this study, the objective of this research was to reduce the consumption of natural resources by substituting EPS and POFA for sand and cement in concrete. In addition, the purpose of this research was to develop concrete that is sustainable, eco-friendly, and as effective as conventional concrete.

In this study, the conclusions were summarized that POFA contains a high proportion of silica. Making it a suitable substitute for cement in concrete mixtures. As the replacement ratio of EPS and POFA grew, the slump value of fresh concrete decreased. However, the slump values of freshly-mixed concrete including EPS and POFA as replacement components remained within the DOE's permitted ranges. The density of concrete decreased as EPS and POFA replacement percentages increased. This is because EPS and POFA have a lower density than fine aggregates and cement. The density of concrete containing EPS and POFA as replacement materials was not classified as lightweight concrete, but it was still significantly less dense than standard concrete. Depending on the proportion of replacement material, the bonding strength of the steel bar and concrete produced by various mixtures can be strong or slightly weak. With 28 days of curing, the ratio of the strongest sample is 20% POFA and 20% EPS. due to the binding capabilities of POFA and the chemical reaction with calcium hydroxide at room temperature that produces compounds with cementitious properties. The compressive strength of concrete increase as the replacement ratio of EPS and POFA increased except for 30% of EPS regardless of curing age. This was due to its characteristic that EPS has almost no aggregates strength compare with normal fine aggregates.

Although all three objectives of this project were achieved, there are a number of limitations and recommendations that can be improved on to enhance the performance of concrete containing EPS and POFA as substitute materials. Firstly, POFA could be used as a supplementary cementitious material in concrete mixtures, even for steel bar bonding strength. Increase the volume of concrete casting should encourage the bonding strength between steel bar and concrete. In order to partially replace cement, POFA should be properly ground into fine particles to enhance the pozzolanic reaction, thereby aiding in the boost of the binding strength of concrete. The recommended replacement percentage of POFA is no more than 20%, while the recommended replacement percentage of EPS for fine aggregates is also 20%.

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