

# Bonding Performance on Steel Bar in Concrete Containing Expanded Polystyrene (EPS) and Palm Oil Fuel Ash (POFA) by Pull Out Test with 0.6% of Water to Cement Ratio

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## Abstract

This study explored the bond performance between Palm Oil Fuel Ash (POFA), Expanded Polystyrene Styrofoam (EPS), and steel reinforcement in concrete. This research aimed to solve concrete bonding issues with POFA and EPS and to reduce the environmental footprint of the construction industry, promote alternative materials and improve the performance of concrete structures. Concrete samples were tested with compression tests, tension tests and pull-out tests to achieve the objective of the study. Testing 20 MPa grade concrete containing POFA replacing cement at 0%, 10%, and 20%, and partial fine aggregate replacement with EPS at 0% and 10%, showed a decrease in compressive strength with higher POFA and EPS replacement. The result of pull out test data showed that the highest pull out strength was normal concrete which is 54.233kN for 28 days. While the lowest pull out strength was the 10% POFA 0% EPS replacement ratio. Respectively, 22.823kN for 28 days. The overall results show that there is no gradual decrease or gradual increase. Treatment of POFA (T-POFA) was carried out to test whether the strength of concrete could be improved from Untreated POFA (U-POFA). Treated POFA (T-POFA) shows improved chemical properties, especially improving the bond between EPS and cement, increasing the pull-out strength. Recommendations suggest limiting POFA replacement to 10% while the EPS should not replace more than 10% and exploring treatment methods to optimize concrete strength.

## 1. Introduction

Material selection in construction went beyond bonding performance with steel. Sustainability was a major concern, aligning with SDG 12 (Responsible Consumption and Production). Engineers focused on materials compatible with steel that were also easily recyclable or reusable to cut down on waste. This approach aimed to lessen the environmental impact of construction. Other than that, cost also was crucial need to concern. While prioritizing sustainability, engineers looked at the long-term costs of materials, including procurement, installation, maintenance, and lifespan. Opting for durable, low maintenance, and energy efficient materials aimed at saving costs while ensuring a strong bond between concrete and steel.

Addressing industrial and consumer waste remains a significant concern, aligning with SDG 12. Innovative methods have been explored to incorporate waste materials into concrete production without compromising bonding performance with steel. This approach not only reduces environmental pollution but also offers a sustainable solution to manage waste. For example, Palm Oil Fuel Ash (POFA), a biodegradable waste material, and Expanded Polystyrene Styrofoam (EPS), a non-biodegradable waste, are commonly disposed of through burning or landfilling, causing environmental harm. However, these materials can be effectively utilized in concrete by replacing coarse or fine aggregates [1]. Incorporating POFA and EPS into concrete presents an opportunity for the construction industry to minimize environmental pollution while finding sustainable uses for these waste materials.

Incorporating POFA and EPS into concrete presents an opportunity for the construction industry to minimize environmental pollution while finding sustainable uses for these waste materials, aligning with SDG 13 (Climate Action). Palm Oil Fuel Ash (POFA) is a by-product from burning palm oil fuel in power plants or palm oil mills. It is considered an agricultural waste and is abundantly available in regions with active palm oil production, notably Southeast Asia, especially in Malaysia and Indonesia [1]. POFA has attracted attention across industries, especially in construction, as a potential sustainable material. Expanded Polystyrene Styrofoam (EPS) is a lightweight, sturdy plastic foam used widely in various industries [2]. It is created by expanding polystyrene beads containing a blowing agent, resulting in a cellular structure known for its excellent insulation properties. Introduced by the German company BASF in 1951 as "Styropor," EPS was developed through research aiming to create a lightweight material with great thermal insulation. Its popularity soared due to its unique features like low density, high strength, thermal and moisture resistance, as well as its cushioning abilities.

The purpose of this study was to investigate the bonding performance between alternative materials, such as Palm Oil Fuel Ash (POFA) and Expanded Polystyrene Styrofoam (EPS), and steel reinforcement in concrete. The aim was to address challenges concerning concrete strength, density, and bonding performance while prioritizing environmental sustainability. By examining how these materials interacted with steel reinforcement, the study aimed to create effective solutions and guidelines for designing and constructing sustainable concrete structures. The study's findings were intended to contribute to reducing the environmental impact of the construction industry and advocating for the use of alternative materials. The goal was to ensure the structural integrity and long-term durability of reinforced concrete structures while minimizing the industry's environmental footprint.

In summary, material selection in building design and construction demands a thorough assessment of multiple factors, notably the bonding performance between concrete and steel. Engineers prioritize evaluating material compatibility with steel reinforcement to uphold structural integrity [3]. Moreover, sustainability, cost efficiency, and waste management play pivotal roles in crafting environmentally conscious and economically feasible solutions. By emphasizing bonding performance alongside these considerations, the construction industry can create lasting structures while mitigating environmental impact. By emphasizing bonding performance alongside these considerations, the construction industry can create lasting structures while mitigating environmental impact and contributing to SDGs 12 and 13.

## 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

The identification of suitable materials is critical for ensuring that the test is carried out smoothly and in accordance with the specified objectives. This study requires the use of Palm Oil Fuel Ash (POFA), Expanded Polystyrene (EPS), and concrete components.

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

### 2.2 Methods

Several tests are carried out to determine the chemical and mechanical properties of concrete when POFA and EPS are used as substitutes. This study investigated the bond performance of POFA, EPS, and steel reinforcement in concrete, as well as the mechanical properties of the concrete's compressive strength, tensile strength, and pull out strength. While XRD test conducted to determine chemical properties. The water cement ratio for this study is 0.60 for POFA replacing cement at 0%, 10%, and 20%, and for partial fine aggregate replacement with

EPS at 0% and 10%. The concrete samples are tested after 7 and 28 days of curing. This concrete's performance is compared to that of standard concrete. T-POFA treatment was performed to see if the strength of concrete could be improved over untreated POFA (U-POFA).



**Fig. 2.1** Compressive Strength Test (a) Cube has been compressed (b) Collecting Data



**Fig 2.2** Tensile Strength Test (a) Sample being compressed for Tensile Strength (b) Retrieved sample.



**Fig 2.3** Pull Out Test (a) Preparation sample for testing (b) Sample being tested



**Fig 2.4** POFA Treatment Process (a) Burning the POFA (b) Open Burning

### 2.2.1 Compressive Test

The compression test is commonly used to determine the strength of concrete in order to achieve the required concrete grade. The results of the test will vary depending on the maturity of the concrete. The compressive strength test involved smashing a concrete cube sample to failure. After the samples have been cured for 7 and 28 days, respectively, this test will be performed [4]. The maximum force applied to the sample was recorded. Divide the maximum load by the cross-sectional area of the concrete cube sample to determine its compressive strength.

### 2.2.2 Tensile Test

The tensile strength test assessed the splitting tensile strength of cylindrical concrete specimens according to BS EN 12390-6 [5]. This test method involved subjecting a cylindrical concrete sample to diametrical compression until it fractured, typically using a specialized testing machine. The test measured the maximum tensile stress that the specimen could withstand before failure occurred. The standard outlined the dimensions, preparation, and testing procedures of the test specimens to ensure consistency and accuracy in determining the concrete's splitting tensile strength. This parameter was crucial in understanding the material's behavior under tensile loading conditions and was essential for evaluating its quality and suitability for various construction applications.

### 2.2.3 Pull Out Test

Effective bonding between reinforcing bars and concrete is critical for the full development of composite action in reinforced concrete. As a result, the bond of reinforcing bars is critical in the structural behavior of reinforced concrete. Crack control during serviceability and durability design is also influenced by the bond of reinforcing bar. Rebar is embedded within a concrete prism during a pull-out test. During the test, rebar is extracted by applying a tension force at a static loading rate in a confined test setup (reaction applied directly to the sample itself). The applied force and corresponding relative displacement between rebar and concrete are measured and recorded on a continuous basis.

### 2.2.4 Treatment of POFA

Treatment of POFA (T-POFA) has been conducted to try whether the strength of the concrete could be improved than Untreated POFA (U-POFA). This treatment of POFA has been conducted through heat by previous study [6]. The findings that have been found are the improvement of the chemical properties of POFA through heat treatment, eliminating unburnt carbon, and increasing the mineral composition without additional crystallization. T-POFA shows superior performance in HSC compared to U-POFA due to its lower specific gravity, allowing for increased paste volume. Conversely, excess unburned carbon in GPOFA limits consistency and inhibits hydration and pozzolanic reactions. So, the treatment of POFA has been conducted through open burning.

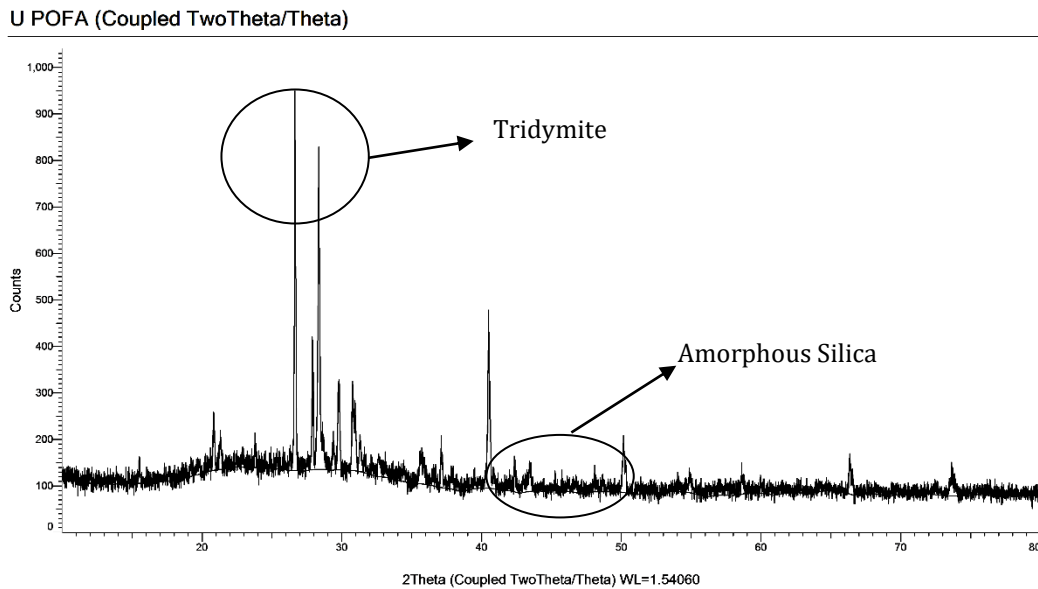
## 3. Results and Discussion

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 84 samples were mixed with difference volume of POFA and EPS. 36 samples were mixed for samples cube while another 36 samples were mixed for cylinder sample (36 sample for tensile test and 12 for pull out test). The result is determined by every test that has been conducted.

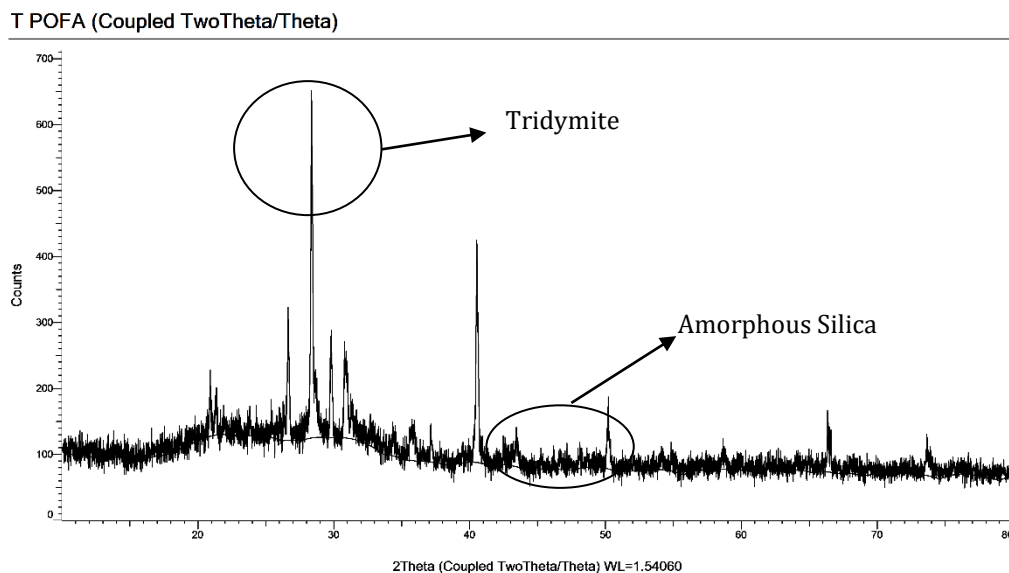
### 3.1 Results

This study included a compressive test, tensile test and pull-out test using Universal Test Machine to determine the test result to be applied to each sample. For cube sample comes with size 100mm x 100mm x 100mm while for cylinder 100mm x 200mm.

### 3.1.1 XRD Test



**Fig 3.1** XRD Pattern for Untreated POFA



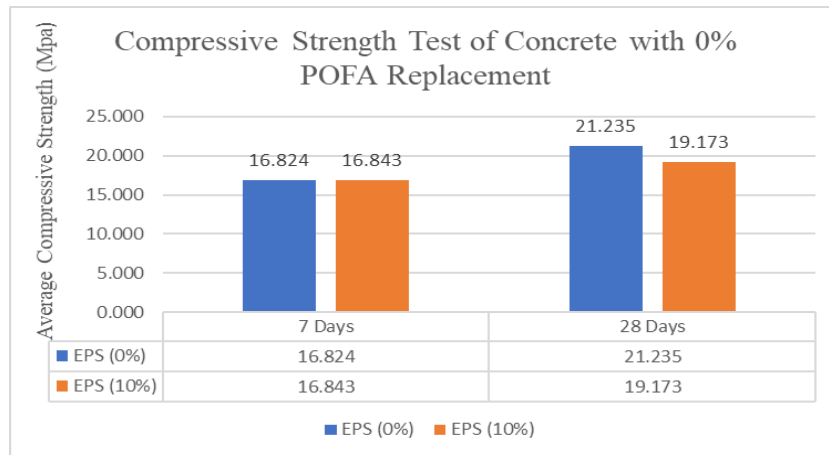
**Fig 3.2** XRD Pattern for Treated POFA

This form of amorphous silica is important in promoting the pozzolanic reaction, a major factor contributing to the strength of concrete. Initially, the XRD pattern displayed several small peaks identified as crystalline silica, which may indicate crystalline phases such as Tridymite (classified as silica dioxide) and aluminum compounds. This crystalline phase coexists with amorphous silica in POFA. The XRD pattern of Untreated POFA shows a broad peak, indicating the presence of an amorphous phase, especially a wide hump between 20° to 40° in Figure 3.1, suggesting the presence of amorphous silica (SiO<sub>2</sub>) in the material. Meanwhile, in Figure 3.2 the presence of amorphous phase on Treated POFA is increasing compared to Untreated POFA. This process has a positive effect on the microstructure of concrete, increasing its compressive strength. In summary, XRD analysis of POFA revealed the presence of silica phases and amorphous crystals. Amorphous silica is important in increasing pozzolanic activity, contributing to increased concrete strength.

### 3.1.2 Compressive Test

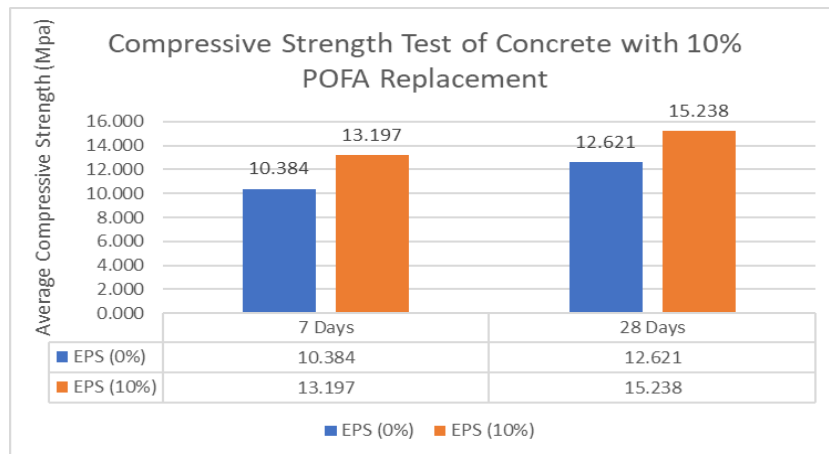
**Table 3.4** Results of Compressive Test for 28 days

POFA (%)	EPS (%)	28 Days (Mpa)
0	0	21.235
	10	19.173
10	0	12.621
	10	15.238
20	0	17.667
	10	15.734



**Fig 3.4** Average of Compressive Strength with 0% POFA Replacement

In Figure 3.4. the compressive strength of concrete cubes with 0% POFA replacement was displayed. The compressive strength of the normal concrete after 7 days and 28 days was recorded as 16.824 MPa and 21.235 MPa, respectively. With an increase in the replacement ratio of EPS, a corresponding decrease was observed in the compressive strength of concrete cubes same as previous study by [2]. After 28 days, the compressive strength of concrete cubes with 10% EPS replacement measured 16.843 MPa and 19.173 MPa, respectively.



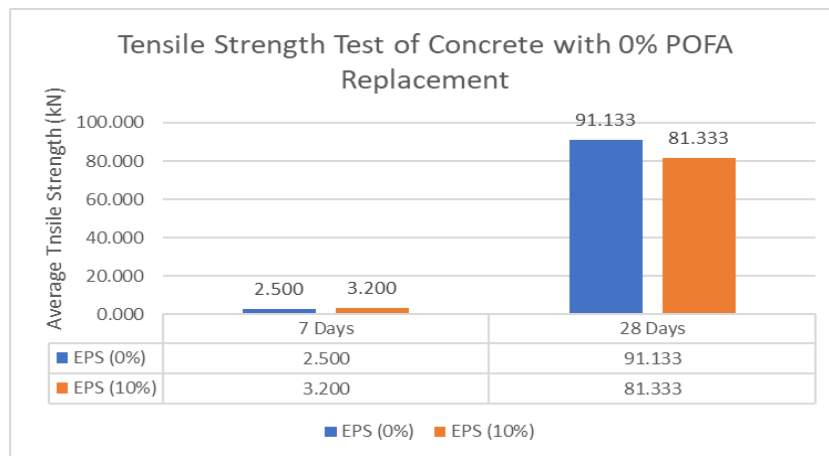
**Fig 3.5** Average of Compressive Strength with 10% POFA Replacement

Figure 3.5 shows the compressive strength of concrete cubes with 10% POFA replacement. The compressive strength of concrete with 10% POFA replacement after 7 days and 28 days were 10.384MPa and 12.621MPa respectively, which were slightly lower than the normal concrete. As the EPS replacement ratio increased, the compressive strength of concrete with 10% POFA replacement slightly increased [2]. The compressive strength of concrete with 0% and 10% EPS replacement were 13.197MPa and 15.238MPa.

### 3.1.3 Tensile Test

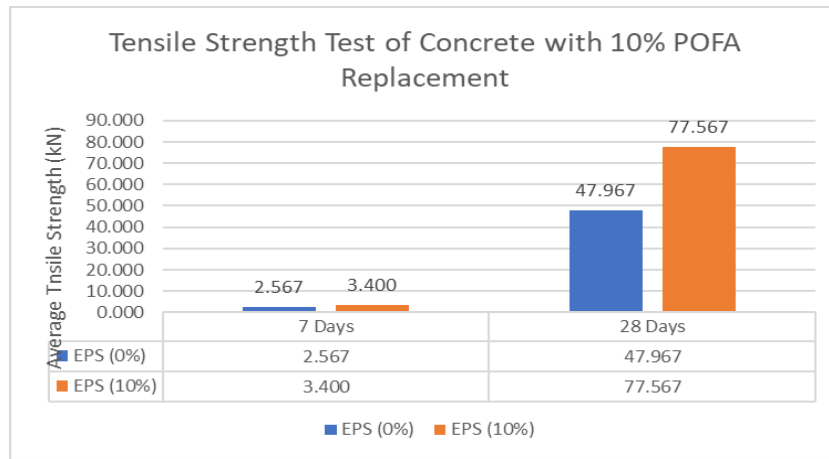
**Table 3.5** Results of Tensile Test for 28 days

POFA (%)	EPS (%)	28 Days (kN)
0	0	91.133
	10	81.333
10	0	47.967
	10	77.567
20	0	78.567
	10	75.667



**Fig 3.6** Average of Tensile Strength with 0% POFA Replacement

Based on Figure 3.6, the average of tensile strength with % replacement. The results show that there are huge differences between curing for 7 days and 28 days for normal concrete, which are 2.5kN and 91.133kN respectively. In fact, not only the normal concrete showed huge difference, but other ratio replacement also has a huge difference. As the EPS replacement ratio increased, the tensile strength of concrete with 0% POFA replacement slightly increased. The tensile strength for 10% EPS, 7 days were 3.2kN, but for 10% EPS, 28 days decreased than normal concrete to 81.33kN.



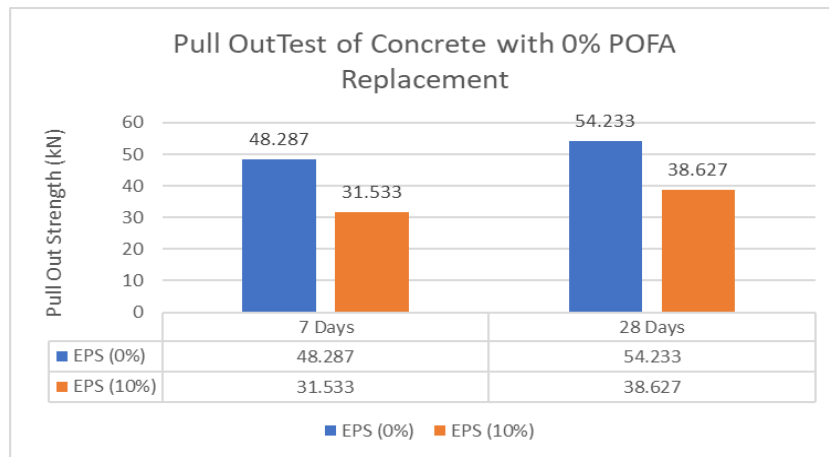
**Fig 3.7** Average of Tensile Strength with 10% POFA Replacement

Average tensile strength with 10% POFA replacement as shown in Figure 3.7. Can be seen that, as the EPS replacement ratio increased, the tensile strength also increased. After curing for 28 days, the tensile strength with 10% POFA replacement decreased to 47.967kN and 77.567kN for 0% and 10% EPS replacement ratio. The results are lower than the normal concrete or control ratio.

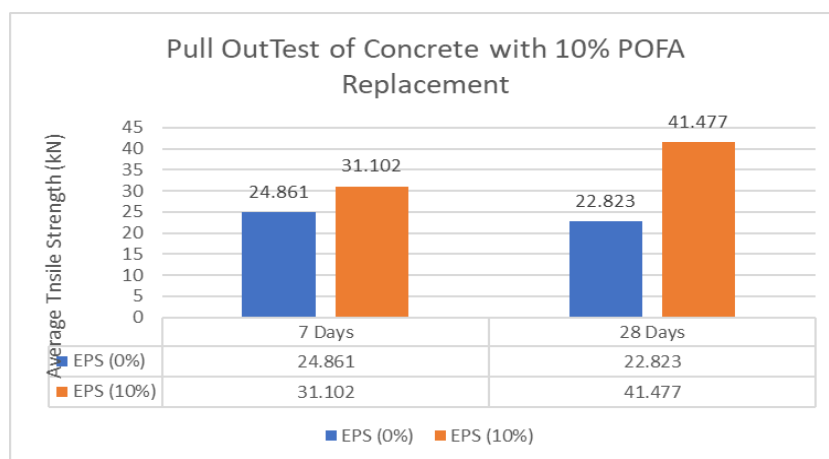
### 3.1.4 Pull Out Test

**Table 3.6** Results of Pull-Out Test for 28 days

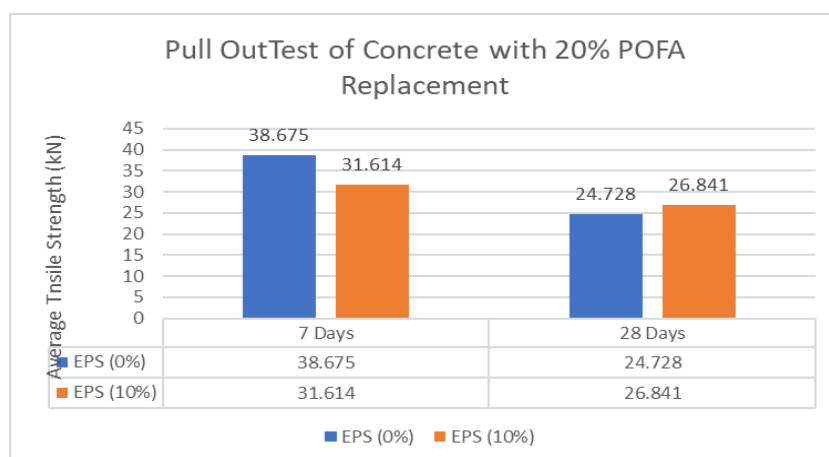
POFA (%)	EPS (%)	28 Days (kN)
0	0	54.233
	10	38.627
10	0	22.823
	10	41.477
20	0	24.728
	10	26.841



**Fig 3.8** Average of Pull Out with 0% POFA Replacement



**Fig 3.9** Average of Pull Out with 10% POFA Replacement



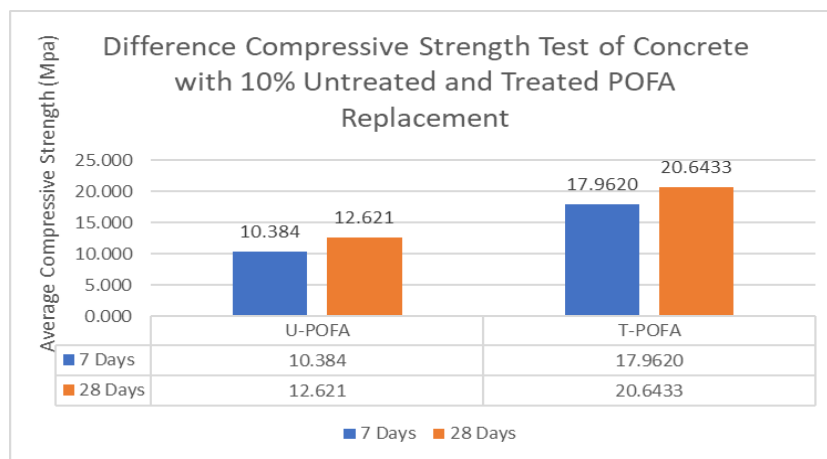
**Fig 3.10** Average of Pull Out with 20% POFA Replacement

The pull-out test was conducted on concrete cylinder containing 12 diameters of rebar that had undergone 7- and 28-days curing period. Based on Table 3.6, the results of pull-out test at 7 days and 28 days. The data showed that the highest pull-out strength was normal concrete which is 48.287kN for 7 days and 54.233kN for 28 days. While the lowest pull-out strength was the 10% POFA 0% EPS replacement ratio. Respectively, 24.861kN and 22.823kN for both 7 and 28 days. The overall results show the same as the previous study that there is no gradual decrease or gradual increase [7]. For detailed records of pull out for each concrete specimen were illustrated in graph in Figures 3.8 until Figures 3.10.

### 3.1.5 Pull Out and Compressive Test After Treated POFA

**Table 3.7** The Different Results of Compressive Test at 7 Days and 28 Days with Untreated POFA And Treated POFA

	POFA (%)	EPS (%)	Sample	Compressive Strength (Mpa)	Average (Mpa)
U-POFA	10	0	A	13.072	12.621
			B	12.538	
			C	12.254	
T-POFA	10	0	A	21.195	20.643
			B	21.092	
			C	19.643	

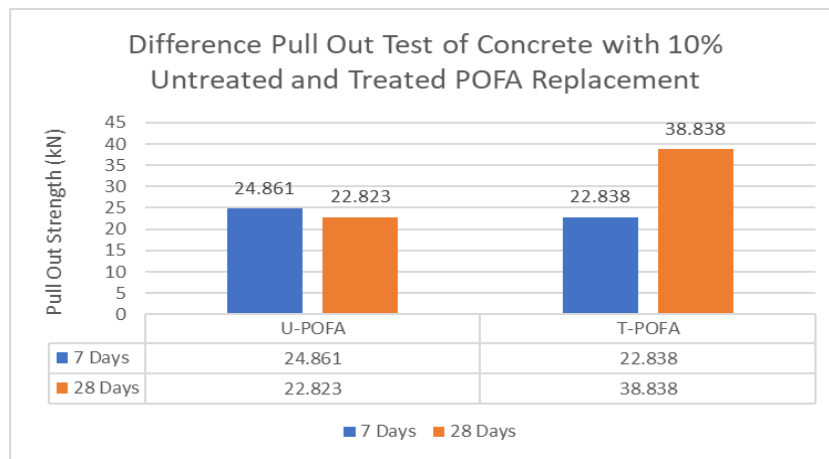


**Fig 3.11** Difference Compressive Strength Test of Concrete with 10% Untreated and Treated POFA Replacement

Table 3.7 and Figure 3.11 illustrate the differences observed in the compressive strength test results between 10% Untreated POFA (U-POFA) and 10% Treated POFA (T-POFA). The data show a significant increase in compressive strength from U-POFA to T-POFA, showing values of 12.621 MPa and 20.643 MPa, respectively. This significant increase from U-POFA to T-POFA shows a significant increase in the compressive strength of the material, amounting to an impressive 63.46% increase. Such a surge in strength following the treatment process underlines the effectiveness of the treatment applied to Palm Oil Fuel Ash (POFA). This remarkable increase in compressive strength stands as proof of the effectiveness of the treatment methodology used on POFA, confirming its positive influence on the structural integrity of the material. This remarkable increase in compressive strength stands as proof of the effectiveness of the treatment methodology used on POFA, confirming its positive influence on the structural integrity of the material. This statement was also proved by [6]. The observed improvement from U-POFA to T-POFA shows the potential for optimal performance and durability in building materials through careful treatment processes.

**Table 3.8** The Different Results of Pull Out at 7 Days and 28 Days with Untreated POFA And Treated POFA

	POFA (%)	EPS (%)	7 Days (kN)	28 Days (kN)
U-POFA	10	0	24.861	22.823
T-POFA			22.838	38.838



**Fig 3.12** Difference Pull Out Test of Concrete with 10% Untreated and Treated POFA Replacement

Upon careful inspection of the data presented in Table 3.8 and Figure 3.12, a significant improvement in the Pull Out Test. The Pull-Out test, denoted by a value of 22.823 kN for U-POFA and 38.838 kN for T-POFA, showed a significant improvement following the treatment process. This significant increase from 22.823 kN (U-POFA) to 38.838 kN (T-POFA) reflects an impressive 70.10% increase in Pull Out. Such a significant increase underlines the effectiveness of the treatment used on Palm Oil Fuel Ash (POFA) in increasing its Pull-Out Strength. The significant increase in Pull-out Strength from U-POFA to T-POFA proves the positive effect of the treatment method on the structural strength of the material [6]. This increase in load-bearing capacity emphasizes the potential advantages of using treated POFA as a beneficial additive in building materials.

### 3.2 Discussion

Analysis of fine and coarse aggregates reveals different characteristics that affect the performance of concrete. Fine aggregates show a well-graded distribution, suggesting favourable conditions for optimal concrete workability. On the other hand, coarse aggregates exhibit poor grade distribution, potentially affecting workability and structural strength. Subsequent evaluations involving degradation values and density analysis showed decreasing degradation values with increasing substitution of Palm Oil Fuel Ash (POFA) and Expanded Polystyrene (EPS). This decrease exceeds the acceptable range of concrete, thus leading to a reduced average density, failing to meet the standards of lightweight concrete. Water absorption tests show that water absorption is reduced in POFA and EPS-replaced concrete, affecting the void content and distribution in the material. In particular, the compressive strength shows variability with different POFA and EPS substitutions, sometimes deviating from the established standards. However, a significant increase in apparent compressive strength was evident in treated POFA compared to untreated POFA. Tensile strength analysis echoes fluctuations with varying replacement ratios, exhibiting deviations from normal concrete strength. Furthermore, pull-out tests showed a significant increase in pull-out strength for treated POFA compared to untreated POFA, indicating a potential improvement in structural integrity.

### 4. Conclusion

After the completion of the laboratory test, the objectives mentioned above were achieved. The chemical and mechanical properties of concrete containing POFA and EPS were determined in terms of Density Test, Water Absorption Test, Workability Test, Compressive Strength Test, Tensile Strength Test and Pull Out Test. Lastly, the optimum percentage of POFA and EPS as the replacement materials in concrete will be stated in the recommendation. Based on the objective of this study, the purpose of this research was to investigate the bonding performance of steel bars in concrete containing EPS and POFA in terms of the Pull-Out Test and to determine the ideal proportion of EPS and POFA in concrete that may maximize the bonding performance between steel and concrete. POFA consists of a high percentage of silica, making it a good pozzolanic material to replace cement in concrete mixture. The compressive strength of concrete decreased as the replacement ratio of EPS and POFA increased regardless of curing age. This was due to pozzolanic materials such as fly ash causing a delay in the hydration process. 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. Lastly, there is significant improvement in Pull-Out strength observed in Treated POFA compared to Untreated POFA.

## Acknowledgement

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## Appendix A: Concrete Mix Design

**Table 1:** Concrete Mix Design

Ingredients	Content (kg/m <sup>3</sup> )
Water cement ratio	0.6
Cement	290
Water	160
Fine Aggregate	695
Coarse Aggregate	1135

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