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Strength Development of Geopolymer Concrete Containing Palm Oil Clinker Powder

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Abstract: Cement manufacturing is responsible for the high carbon dioxide (CO_2) emission and leads to global warming. Therefore, geopolymer is introduced as an alternative binder to reduce CO_2 emissions and utilize industrial by-products as primary materials. It is synthesis by activating the aluminosilicate materials with alkaline solutions. Meanwhile, palm oil clinker powder (POCP) is a good source of alumina and silica. It is categorized as pozzolanic material but often overlooked due to its less reactivity trait. However, the reactivity of POCP can be enhanced by increasing its finesse. Therefore, this study utilizes POCP as blending binder materials in fly ash-based geopolymer concrete with different percentages of 0.00, 2.00, 4.00, 6.00, 8.00 and 10.00 % (by the weight of fly ash). A slump test was conducted to determine the workability of freshly mixed geopolymer concrete. The strength performance of fly ash-based geopolymer concrete was evaluated on 7 and 28 days of curing. Based on the findings, the slump of fly ash-based geopolymer concrete with no blended POCP recorded a higher value than with POCP. 6.00 % of POCP in geopolymer showed the highest compressive strength result with 54.97 MPa at 28 days of curing. Increasing POCP finesse significantly impacted the geopolymerisation process due to the rapid dissolution of aluminosilicates materials and producing polymerization products. Therefore, POCP is an excellent blending binder for fly ash-based geopolymer and sustainable source material for a greener product.

Keywords: Geopolymer, Palm Oil Clinker Powder, Compressive Strength

1. Introduction

In recent years, concrete has been the essential construction material due to the rapid development of infrastructure and construction projects. The high demand for concrete has drawn great attention to cement manufacturing since it was used as a binder material in concrete [1]. However, cement manufacturing is not environmentally friendly since it leads to toxic emissions such as carbon dioxide (CO_2) being released into the surrounding area during the manufacturing process. In addition, each ton of cement emits approximately one ton of CO_2, contributing roughly 7.00 % of CO_2 emissions into the

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atmosphere [2]. Therefore, geopolymer was introduced to replace cement which is more environmentally friendly.

Geopolymer is a mineral binder synthesis by activating aluminosilicate materials with an alkaline solution, potentially replacing cement as the main material in concrete due to its characteristics. Geopolymer is also one of the sustainable construction products because it uses agricultural and industrial waste. The source materials usually used in geopolymer are fly ash, slag, and rice husk ash with high silica and alumina content. Geopolymerization is the process that takes place with the dissolution, which occurs when the solid alumino-silicates substance dissolves in water and alkali activator [3]. From that process, it will result in a three-dimensional polymer chain and a Si-O-Al-O bond structure [4]. Fly ash is commonly preferred for synthesizing geopolymer concrete due to its availability.

Fly ash is a by-product of burning pulverized coal in electric generation coal-fired plants that have high contents of calcium oxide (CaO), silicon dioxides (SiO_2), aluminium oxide (Al_2O_3), and iron oxide (Fe_2O_3), which can be used as a precursor in geopolymer [3]. Most studies agreed that fly ash-based geopolymer possesses superior characteristics to conventional concrete [5]. Nevertheless, using fly ash as the sole binder for geopolymer concrete might result in rapid hardening of the concrete and limit its application. In addition, the regulations on fly ash disposal and storage are lacking since most nations worldwide do not consider fly ash a hazardous waste [6]. Thus, the additional source material is needed to fill the gaps and help reduce the lack of fly ash-based geopolymer blended with other pozzolanic materials to achieve and improve some specifications of geopolymer concrete.

Malaysia is a country with prominent exporters of palm oil products. It has generated a massive amount of solid waste around, 6.1 million tons, every year [7]. Moreover, palm oil clinker is produced when oil palm shell and palm kernel fibre are burned in certain amounts at high temperatures. Thus, this causes environmental pollution [8]. Palm oil clinker (POC) is a pozzolanic material that has not been extensively used in geopolymer application. The origins of POCP was generated from biomass of empty fruit bunches (EFB), mesocarp fibre (MF), palm shell (PS), oil palm fronds (OPF), and oil palm trunks (OPT) [9]. Utilizing POCP as filler material to produce lightweight concrete with excellent mechanical properties [10]. The study also mentioned the positive effect of POC in self-compacting concrete, leading to cost reduction, energy consumption, and carbon footprint. Therefore, this study aims to evaluate the compressive strength performance of geopolymer concrete containing various proportions of POCP to replace fly ash as source material at 2.00, 4.00, 6.00, 8.00 and 10.00 % (by weight of fly ash) and obtain its optimum mix proportion of geopolymer concrete.

2. Materials and Methods

2.1 Materials

Fly ash was used as the main binder for this research. It is collected from Manjung Coal-Based Thermal Power Plant, Malaysia, classified as Class F fly ash. Meanwhile, palm oil clinker was collected from Felda Lepar Hilir 3, Kuantan, Malaysia. It has a large particle size in a raw state due to the collection from the burning process [11]. Palm oil clinker was ground in a ball mill to increase its surface area and pozzolanic properties. Then, it was sieved through 300 μm to get powder foam referred to as POCP.

POCP was introduced in the mixture to replace a certain proportion of fly ash as a blending material in geopolymer concrete. It was intended to increase the strength of geopolymer with the presence of high silica and alumina source that would reactively react during the polymerization process. This study used different proportions of POCP from 2.00, 4.00, 6.00, 8.00 and 10.00 % (by weight of fly ash). The mixed proportion used in this research was adopted from the previous study [12]. Table 1 shows the complete mixture proportions of POCP in geopolymer concrete.

A combination of alkali activators, sodium hydroxide (NaOH), and sodium silicate (Na_2SiO_3) solution, was used to activate the source material during the geopolymerization process. The NaOH solution was prepared by diluting 480 g of NaOH pellets in 1000 g of water to get one kg of 12 M NaOH solution. Meanwhile, the Na_2SiO_3 solid used in this study had Ms of 2.0 with the chemical composition of Na_2O: 14.70 %, SiO_2: 29.80 %, and H_2O: 55.50 %. A few hours before the mixing process, NaOH solution was prepared to prevent excess heat from NaOH dissolution.

Table 1: Details of mix proportion

% of POCP	% of Fly ash	Proportion in kg/m^3						
		Fly ash	POCP	Coarse aggregate	Fine aggregate	NaOH solution	Na_2SiO_3 solution	Extra water
0	100	350	0	1200	645	41	103	35
2	98	343	7	1200	645	41	103	35
4	96	336	14	1200	645	41	103	35
6	94	329	21	1200	645	41	103	35
8	92	322	28	1200	645	41	103	35
10	90	315	35	1200	645	41	103	35

2.2 Methods

This study used a similar method to prepare the geopolymer concrete with the mixing procedure of conventional concrete. The aggregates (fine and coarse) mixed with the fly ash and POCP in the dry state. The alkali activator solution was gradually added into the dry mix with extra water to reach the specified water-to-geopolymer binder ratio. It was continuously mixed for 1 to 2 minutes to get a homogeneous mixture. Since the mixture hardened too fast, the mixing must be done quickly after adding the alkali activator. A workability test was conducted to ensure the design mixture passed in this study. The fresh mixtures then were cast into 100 mm x 100 mm x 100 mm moulds.

A combination of oven and room temperature was used to cure the geopolymer concrete specimen. The specimens were placed in the oven with a temperature of 65 °C for 24 hours. All geopolymer concrete cube specimens took 24 hours before inducting into the oven. The geopolymer concrete is covered with plastic before being placed in the oven for thermal heating. After taking it out from the oven, the specimens were cured at room temperature until 7 and 28 days curing days. The compressive strength and statistical analysis of the geopolymer specimens were determined after 7 and 28 days.

3. Results and Discussion

3.1 X-Ray Fluorescence

X-ray fluorescence (XRF) analysis is carried out to determine the chemical oxide composition used as binders in the geopolymer concrete. Table 2 depicts the chemical oxide composition of fly ash and POCP used in this research. Based on the findings, SiO_2 is the primary oxide in fly ash and POCP with 51.70 % and 55.39 %, respectively. In comparison, the proportion of Al_2O_3 in fly ash is significantly higher than POCP, indicating fly ash becomes the primary source of alumina in the geopolymerisation process. Meanwhile, the content of SiO_2 and Fe_2O_3 in POCP is higher than fly ash.

However, the summation of SiO_2 +Fe_2O_3 + Al_2O_3 in POCP does not meet the defined specification in ASTM C618 Class F pozzolan, which is less than 70.00 %. Nevertheless, POCP fits the description for Class C pozzolan with some cementitious properties due to the summation of SiO_2 +Fe_2O_3 +Al_2O_3 being more than 50.00 %. Furthermore, POCP contains high amorphous silica proportion will increase the silicate precursors for the condensation process. Rapid oligomeric silicate or aluminate formation resulted in polymeric Si-O-Al bonds during the polymerization process [13]. Thus, leading to the formation of the three-dimensional structure of amorphous or crystalline structures.

Table 2: Oxide Composition Percentage of Fly Ash and POCP

Oxide	Percentage (%)	
	Fly ash	POCP
SiO_2	51.70	55.39
K_2O	1.60	17.70
Fe_2O_3	4.76	10.81
CaO	8.84	7.05
P_2O_5	1.70	3.97
Al_2O_3	29.10	2.18
MgO	-	2.00
SO_3	1.50	0.19
TiO_2	0.702	-
SrO	0.109	-
Others	-	0.28

Meanwhile, Table 3 compares the particle size distribution and BET surface area of fly ash and POCP. The result presents that POCP specimens that pass 300 µm have a large gap in particle size and surface area with fly ash. On the other hand, the BET surface area results showed that fly ash has a larger surface area than POCP, with 0.5004 m^2/g and 4.26 m^2/g, respectively. As a result, the difference in particle size and a large gap in the surface area may affect the strength of geopolymer concrete when the inclusion of POCP increases.

Table 3: Physical Properties Fly Ash and POCP

Properties	Fly Ash	POCP
d_{10}	2.970 µm	37.163 µm
d_{50}	16.540 µm	136.362 µm
d_{90}	99.210 µm	279.213 µm
BET surface area	4.260 m^2/g	0.500 m^2/g

3.2 Workability

Table 4 shows the workability of geopolymer concrete containing POCP based on the slump test result. The control specimens indicate that 212 mm of slump value has the highest workability. In contrast, when replacing the specific value of fly ash with POCP, the workability of geopolymer increased from 2.00 % to 6.00 %, which is from 163 mm to 195 mm of slump value. Furthermore, the workability of geopolymer concrete decreased as the inclusion of POCP increased. It has shown that the workability of geopolymer concrete decreased by 8.00 % and 10.00 % of POCP, which is 167 mm and 155 mm of slump value. The inclusion of POCP has high water absorption and has a porous structure since it was the waste product from the burning process. As a result, the workability for all the mix designs of geopolymer concrete was acceptable because the slump test result was more than 150 mm. Accordingly of its high workability, the concrete mix is very wet. However, the geopolymer concrete mix procedure is still easy to perform and utilize on the site.

Table 4: Result of Slump Test

Percentage of POCP (%)	Slump (mm)
0	212
2	163
4	187
6	195
8	167
10	155

3.3 Compressive Strength

Figure 1 shows the compressive strength of POCP at different curing ages of 7 and 28 days. 0.00 % of POCP act as a control geopolymer concrete, recorded compressive strength results of 41.67 MPa and 44.07 MPa for 7 and 28 days, respectively. The graph displays similar trends for both curing ages, where the inclusion of POCP increased from 0.00 % to 4.00 %, causing the strength of geopolymer concrete to decrease. This trend happened because of a weaker bond between the geopolymerization reaction of fly ash with POCP causing the geopolymer concrete to have lower strength. As a result, less POCP to replace the role of fly ash could not improve the strength development of geopolymer concrete.

Moreover, the geopolymer strength concrete escalated from 6.00 % to 10.00 % of POCP on 7 and 28 days. Figure 1 shows that 6.00 % of POCP is the highest compressive strength with 47.93 MPa and 54.97 MPa for 7 and 28 days, respectively. As a comparison, the strength of 6.00 % of POCP is significantly different from the control specimen for both curing ages. It may happen due to the strength of 6.00 % of POCP influenced by the bonding between fly ash surfaces being disturbed due to the inclusion of POCP. In addition, the high content of silica in 6.00 % of POCP has increased the geopolymerization reaction and polymerization product which produced higher strength of concrete. Therefore, it proved that geopolymer's strength might increase the strength of geopolymer concrete due to the ability of POCP as a replacement of fly ash to fill the microcracks [14].

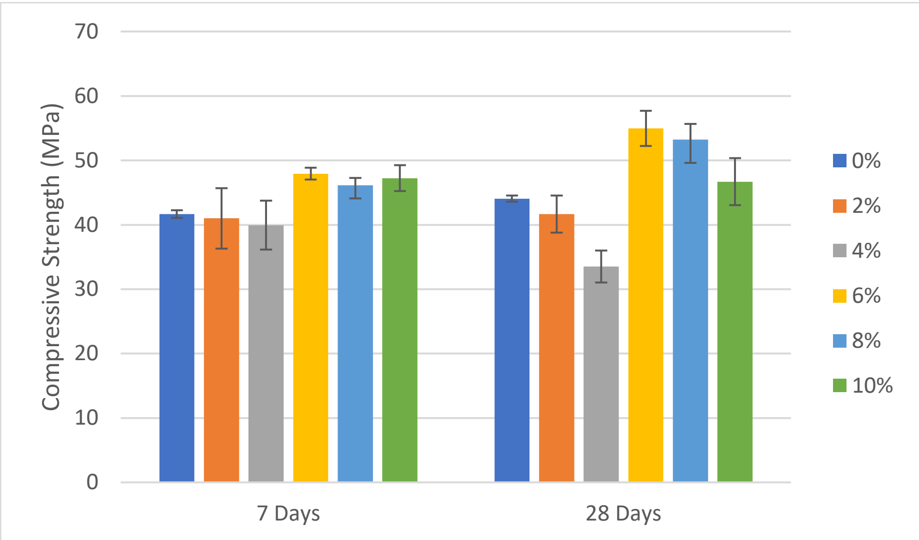

Figure 1: Compressive strength of POCP for 7 and 28 days

The t-test analysis also confirmed the result obtained from Figure 1. The statistical analysis failed to reject the null hypothesis since there is no significant difference between control and specimen containing POCP for 7 and 28 days. Moreover, 8.00 % inclusion of POCP has been chosen as the optimum mixture for geopolymer concrete. This result was obtained by comparing t-test analysis between 6.00 % and 8.00 % of POCP for both curing ages, as shown in Table 5. The null hypothesis stated no statistically significant difference between 6.00 % and 8.00 % of POCP for 7 and 28 days as indicated by $t_{stat} < t_{crit}$ (1.22 < 2.77) and $P > \alpha$ (0.14 > 0.05), $t_{stat} < t_{crit}$ (0.47 < 2.78) and $P > \alpha$ (0.33 > 0.05), respectively. As a result, at a 95.0 % confidence level, there were no significant differences between the strength of 6.00 % and 8.00 % POCP in geopolymer for both curing ages. This analysis supports the study by replacing 8.00 % of POCP can use more waste instead of 6.00 %. Therefore, the statistical study proved the inclusion of 8.00 % POCP as a fly ash substitute in geopolymer since it can minimize waste and increase its strength.

Table 5: The result of t-test analysis for 6.0 % and 8.0 % for 7 and 28 days

	7 Days		28 Days	
	0.06	0.08	0.06	0.08
Mean	47.93	46.12	54.97	53.26
Variance	2.51	4.02	55.63	17.64
Observation	3	3	3	3
Hypothesized Mean Difference	0		0	
df	4		4	
t Stat	1.22		0.47	
P(T<=t) one-tail	0.14		0.33	
t Critical one-tail	2.13		2.13	
P(T<=t) two-tail	0.29		0.67	
t Critical two-tail	2.77		2.78	

3.4 Correlation Strength with Proportion of POCP

Figure 2 shows the correlation between the compressive strength of geopolymer with the proportion of POCP (%) for 7 and 28 days. The graph displayed that 2.00 % of POCP is the lowest strength of geopolymer concrete, while 8.00 % of POCP is the highest strength of geopolymer concrete for 7 and 28 days. It shows that the small proportion of POCP indicates low strength compared to the control geopolymer. On the other hand, the strength of POCP was significantly increased when the proportion of POCP increased. Furthermore, the result of strength geopolymer at 2.00 % of POCP for 28 days indicate the lowest strength compared to the strength for 7 days. It may happen due to the reaction of chemical composition at 2.00 % of POCP for 28 days cannot support the geopolymerization reaction, which causes the low strength of geopolymer concrete.

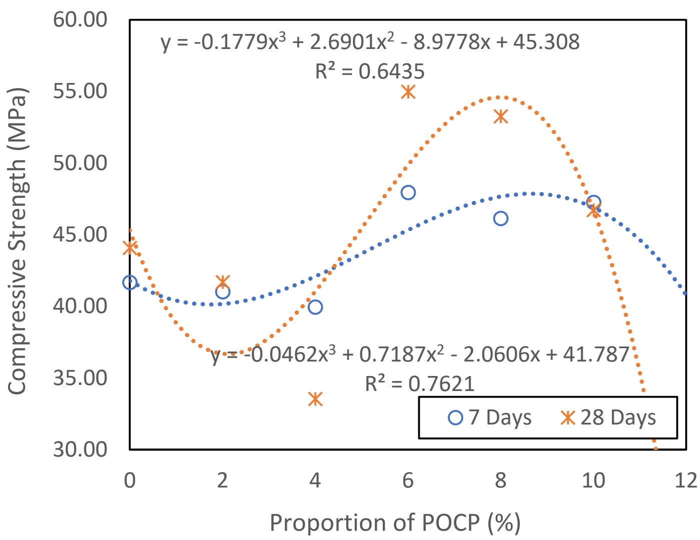

Figure 2: Correlation Strength with Proportion of POCP (%)

Moreover, the graph displayed that the strength was dropped at 10.00 % of POCP at 28 days due to the excess amount of POCP, which prevents the geopolymerization reaction process and weakens the geopolymer concrete bond [15]. Therefore, the decrease in compressive strength showed at 10.00 % for 28 days has less geopolymerization reaction. However, the strength of 10.00 % of POCP still meets the optimum standard of strength concrete, which is more than 20MPa. In addition, the graph demonstrates that the proportion of POCP has generated a polynomial trendline for 7 and 28 days with the R2 value is 0.6435 for 7 days is lower than 28 days with the R2 value is 0.7621. As a result, it has proved that there has been strength development between 7 and 28 days.

4. Conclusion

Based on this study's experimental result and data analysis, it can be concluded that POCP significantly contributes to geopolymer concrete strength development. The inclusion of POCP in geopolymer concrete has increased the geopolymerization reaction and polymerization product. The result can see this of the specimen producing a higher concrete strength. Furthermore, compressive strength results show an increment at 6.00 % of POCP. This aid in the replacement of fly ash content in geopolymer concrete. The statistical analysis selected the value of 8.00 % of POCP as the optimum mixture of geopolymer concrete. The strength is not significantly different between 6.00 % and 8.00 % of POCP. It shows that a large amount of waste material can be used while producing the same high strength. This value may be less than existing commercial pozzolan [11], but it would be a first step toward producing sustainable concrete material besides reducing waste from the palm oil mill industry.

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