

# Early Strength Characteristics of Palm Oil Fuel Ash and Metakaolin blended Geopolymer Mortar

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**Abstract.** In this paper, the early strength behavior of Metakaolin and Palm Oil Fuel Ash (POFA) based geopolymer mortar was investigated for the purpose of exploring the utilization of POFA which is a waste material generated from production of palm oil. Geopolymer mortar was prepared by activating metakaolin combined with POFA at 0%, 30%, 40%, 50%, 60%, 70% and 80% replacement levels in NaOH and Na<sub>2</sub>SiO<sub>3</sub> medium. The mortar specimens were tested for compressive strength at 3 and 7 days. The maximum compressive strength at 3 and 7 days are 65.264MPa and 68.863MPa respectively corresponding to a POFA replacement of 40%. A replacement of 80% POFA to 20% Metakaolin gave compressive strength as high as 26.174MPa and 30.791MPa for 3 and 7 days. It was also discovered that water demand of the system reduced with increase in POFA replacement. It is concluded that POFA addition to metakaolin can improve behavior of Metakaolin and POFA geopolymer system.

## Introduction

Much research works have reported the viability of geopolymer as an alternative to Portland cement mainly reputed for its substantial contribution to carbon dioxide emission during production [1]. Geopolymer on the other hand is known to present a comparable lower carbon dioxide emission and energy consumption requirement [2]. The profound interest in geopolymer is further supported by its excellent performance with regards to high and rapid strength development, low permeability, thermal conductivity, shrinkage and heat of hydration; fire, chemical and heat resistance and comparable low processing energy consumption [3].

Materials containing adequate proportions of aluminosilicates are suitable precursors for synthesis of geopolymers. This include natural mineral based material such as metakaolin sourced from calcined kaolin, industrial waste materials mainly of Fly ash and ground granulated blast furnace slag and a mixture of both [4].

This paper presents the results of study of early strength characteristics of geopolymer mortar made from a blend of Metakaolin and Palm Oil Fuel ash (POFA) with a view to explore the useful application of POFA. The knowledge of the utilization of POFA with Metakaolin will be beneficial to proper understanding and future application of the material in construction. The replacement of Metakaolin with POFA provides means of adjusting the SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> ratio and stands to improve the property of the geopolymer. It will also provide avenue for useful employment of vast wastes being generated from production of vegetable oil which promises to increase as the global demand increases and thereby contribute to environmental sustainability.

## Materials and Method

Geopolymer mortar was prepared using metakaolin mixed with palm oil fuel ash and activated with sodium hydroxide and sodium silicate. Metakaolin was prepared by calcination

of kaolin obtained from Kaolin (Malaysia) Sdn in furnace at 750°C for 6 hours. Palm oil fuel ash (POFA) was obtained from palm oil mill in Kahang Malaysia. The POFA containing charred particles was beneficiated by sieving to collect particles passing through 150micrometer sieve and was further ground in Los Angeles abrasion machine to obtain fine particles with BET specific surface area of 23.751m<sup>2</sup>/g. The chemical composition of Metakaolin and POFA as determined by XRF are indicated in Table 1. The sand used was sieved to obtain particles passing through 2.32mm sieve and was then washed to remove silt contents and any possible contaminants and oven dried for 24hrs.

Table 1 Chemical Composition of Meatakaoli and POFA (%wt)

Material	CO2	SiO2	K <sub>2</sub> O	Fe <sub>2</sub> O <sub>3</sub>	CaO	P2O5	MgO	Al2O3	SO3	Cl	TiO
Metakaolin	0.1	54.7	2.58	1.43	-	-	0.7	39.9	-	-	-
POFA	0.1	63.70	9.15	6.27	5.97	4.26	4.11	3.68	1.59	1.59	0.30

Table 2 Mix of Geopolymer Mortar from blending of POFA and Metakaolin

Mix	Agg. [kg/m <sup>3</sup> ]	MK [kg/m <sup>3</sup> ]	POFA [kg/m <sup>3</sup> ]	Na <sub>2</sub> SiO <sub>3</sub> [kg/m <sup>3</sup> ]	NaOH [kg/m <sup>3</sup> ]	Add. water [kg/m <sup>3</sup> ]	Total water content	Water/Binder ratio	Flow [mm]
100MK	1680.0	560.00	-	443.20	155.20	2.67	349.59	0.48	113
70MK	1680.0	392.00	168.00	408.80	142.80	-	319.60	0.4	112
60MK	1680.0	336.00	224.00	380.00	132.00	56.46	308.06	0.4	125
50MK	1680.0	280.00	280.00	308.30	108.00	53.00	294.24	0.4	121
40MK	1680.0	224.00	336.00	260.00	92.00	79.2	283.34	0.4	123
30MK	1680.0	168.00	392.00	205.48	72.00	110.00	270.89	0.4	125
20MK	1680.0	112.00	448.00	162.56	56.00	133.64	264.31	0.4	127

Metakaolin was replaced with POFA at 0%, 30%, 40%, 50%, 60%, 70% and 80% by weight. Sodium hydroxide pellets were used to prepare 12M solution and mixed with sodium silicate as received to give ratio of Na<sub>2</sub>O contribution as 1 to 1.5 respectively with quantity used determined from Na<sub>2</sub>O/Al<sub>2</sub>O<sub>3</sub> ratio of 1.0 based literature which reported a fully reacted metakaolin based geopolymer at ratios between 0.8 and 1.2 [9]. The fine aggregate to binder ratio was 3.0 and the materials were mixed for 10min to obtain a thorough mixed mortar cast into 50mm cube moulds. The flow of the fresh geopolymer mortar was controlled between 110 to 127mm to achieve a workable mix. The casting was done in two layers with each layer compacted with vibration table for 30s. The samples were left to precure for 24 hours after which they were remolded and cured in the oven at temperature of 60°C for 48hours. The samples were tested for 3 and 7 days compressive strength. The mix design is shown in Table 2.

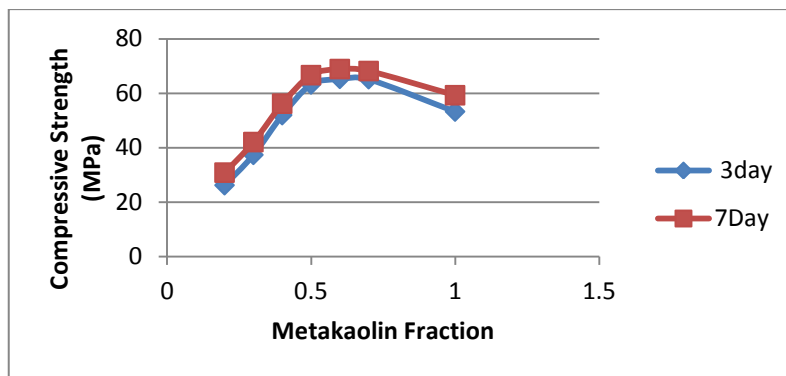
In another phase of the experiment, the influence of POFA replacement on water demand was also studied by preparing samples with various replacements and adjusting the water/binder ratio to obtain a near constant mortar flow of 110mm. The results of this study are represented in Fig. 2.

## Results

**Effect of Metakaolin/POFA ratio on strength.** The early strength of the system of Metakaolin and POFA is depicted in Fig. 1for 3 and 7 days. There was a general increase in compressive strength as the fraction of Metakaolin in the mixture of Metakaolin and POFA increased from 20% up to 60% with the highest strength of 65.264 and 68.863 MPa for 3 and 7 days. Geopolymer mortar sample with 80% POFA and 20% Metakaolin has the least

compressive strength of 26.174 and 30.791 MPa at 3 and 7 days respectively. The experiment was designed to have a common water/Binder ratio of 0.4 for all the mixes by addition of extra water and 1% weight of binder as superplasticiser for purpose of providing common basis for observation of their strength characteristics under same water/binder ratio. However, it was observed that the 100% Metakaolin mix was not workable and additional water had to be added to improve flow which increased the water/binder ratio to 0.48 to achieve a flow of 113mm. The increase in water/binder ratio may be responsible for the lower compressive strength of the mix [5] even though it has highest alumina content which could have been a source of higher polymerization reaction to give a stronger aluminosilicate framework [6]. The additional water could have effect of lowering the pH and subsequently the strength [7]. It should be noted that water is not actually used up in the geopolymeric reaction rather it is expelled and as such is mainly essential for workability [8]

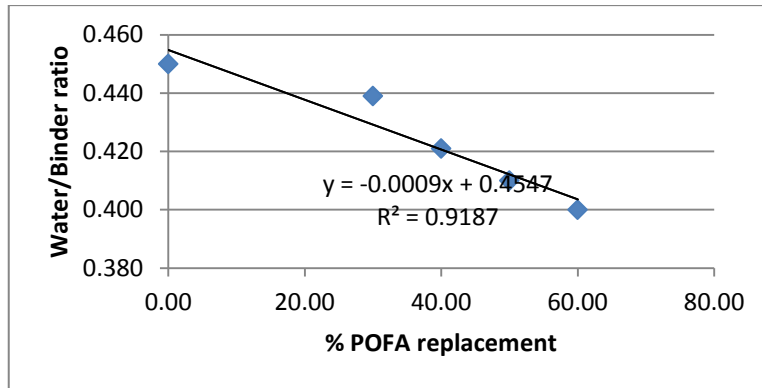
It is interesting to note from Fig 1 and Table 2 that while mixes with 50% and 60% metakaolin content had highest strength of 66.616 MPa and 68.863 MPa respectively, their alkali consumption was relatively lower than that of 100% metakaolin because less alumina is involved in the reaction requiring less Na ion for charge balancing in the aluminosilicate framework making the replacement to be more efficient in terms of alkali consumption.



**Fig. 1. Compressive strength of Geopolymer mortar with varying Metakaolin**

### **Effect of POFA replacement on water demand**

Targeting a flow of 110mm, the relationship between Metakaolin replacement with POFA and water/Binder was studied as represented in Fig 2. It can be seen that the required water/binder ratio to meet a flow of about 110mm decreases with increase in replacement level of POFA. The implication is that addition of POFA is able to reduce water demand of mixture which is the problem with mono system of metakaolin based geopolymer.  $R^2$  of 0.9187 means that water/Binder ratio is strongly influenced by POFA replacement. This may be due spherical shaped of POFA particles intermingling with platy shaped Metakaolin and reduces its hydrophilic nature.



**Fig. 2. Effect of POFA replacement on Water/Binder ratio**

### Conclusion

In this study, the effect of replacing Metakaolin with 0%, 30%, 40%, 50%, 60%, 70% and 80% POFA was studied using NaOH and Na<sub>2</sub>SiO<sub>3</sub> as the activating alkali. Early strength of geopolymer prepared from mixture of metakaolin and POFA shows that the system is capable of providing efficient route for geopolymer application. The compressive strength increased with decrease in Metakaolin addition up to 50% replacement and starts to decrease up to a measured POFA replacement value of 80% and the compressive strengths corresponding to this value of 80% are 26.17 and 30.791MPa for 3 and 7 days respectively. These strength values are notable at least for low strength mortar. Replacement of POFA with metakaolin also improves workability and reduces demand for water in the geopolymer mortar.

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### References

- [1] F. Winnefeld, A. Leemann, M. Lucuk, P. Svoboda, M. Neuroth: Submitted to Journal of Construction and Building Materials (2010)
- [2] M. C. G. Juenger, F. Winnerfeld, J. L. Provis, and J.H Ideker: Submitted to Journal of Cement and Concrete Research (2011).
- [3] M. Schneider, M. Romer, M. Tschudin and H. Bolio: Submitted to Journal of Cement and Concrete Research (2011)
- [4] D. L. Y. Kong, J. G. Sanjayan and K. Sagoe-Crentsil: Sumitted to Journal of Cement and Concrete research (2007)
- [5] M. Olivia and H. R. Nikraz: Submitted to ARPN Journal of Engineering and Applied Sciences (2012)
- [6] K. Komnitsas, and D. Zaharaki: Submitted to Journal of Minerals Engineering (2007)
- [7] M. C. Bignozzi, S. Manzi, I. Lancellotti, E. Kamseu, L. Barbieri and C. Leonelli: Submitted to Journal Cement and Concrete (In press)
- [8] A. K. Konstantinos: Submitted to Procedia Engineering (2011)
- [9] Z. Yunsheng, S. Wei and L. Zongjin: Submitted to Journal of Colloids Surfaces (2007)

