© Universiti Tun Hussein Onn Malaysia Publisher's Office

JSMBE

http://publisher.uthm.edu.my/ojs/index.php/jsmbe

e-ISSN : 2821-3432

Journal of Structural Monitoring and Built Environment

Performance of High Strength Concrete Containing Treated Fine Metakaolin, Palm Oil Fuel Ash, and Coal Bottom Ash as Substitute Materials Toward Compressive Strength and Flexural Strength Test

Mohammad Amirul Mohd Nizam[1], Mohd Hanif Ismail[1*], Nur Anis Natasha Che Rahim[1], Muhammad Nur Rasyid Abu Bakar[1]

[1]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/jsmbe.2023.03.01.006
Received 10 December 2023; Accepted 11 December 2023; Available online 19 December 2023

Abstract: The annual increase in cement use has a detrimental effect on the environment. To lessen the harmful effects on the environment, concrete production now incorporates industrial waste from power plants such as coal bottom ash and palm oil fuel ash (POFA). In order to create more environmentally friendly concrete, this study used metakaolin (MK), palm oil fuel ash (POFA), and coal bottom ash (CBA). The purpose of this study is to determine how these substitute materials affect the compressive and tensile strengths of concrete. MK and POFA are partial cement replacements, whereas CBA is a partial sand replacement. The compressive and flexural strengths of the concrete were assessed to determine the impact of these materials on its strength. The trials used 20% MK and 10% CBA as the constants and 5%, 10%, 15%, and 20% POFA as cement substitutions for the variables. The concrete with a 10% POFA replacement had the highest compressive strength (78 MPa) and flexural strength (7.5 MPa) among the other concrete mixes while having the best workability.

Keywords: Metakaolin, palm oil fuel ash, coal bottom ash, concrete strength

1. Introduction

The demand for construction materials increases every year due to the increasing construction projects [1]. Two commonly used construction materials are concrete and steel. Both materials were commonly used simultaneously due to their weaknesses and benefits that complement each other. In some cases, the project specifically demands the use of a single material or alternative materials due to the restriction. Concrete, which is made up of cement, fine aggregate, coarse aggregate, and water, is the most important component of building. The manufacture of cement is a major source of carbon dioxide (CO2) emissions, accounting for approximately 8% of global CO2 emissions. The current surge in concrete usage will have a long-term negative impact on the environment. Cement production must be reduced in order to reduce the environmental impact. There is no denying there are other materials produced that are damaging to the environment and humans, such as POFA from palm oil factories and CBA from coal combustion processes. To achieve sustainability, these materials should be used in the manufacturing of concrete to reduce the consumption of cement while also reducing factory waste.

Metakaolin is unique in that it is not an industrial by-product and does not come entirely from natural sources. Metakaolin was produced by high-temperature calcining kaolinite-rich clay. The need for electricity is rapidly

*Corresponding author: mohdhanif@uthm.edu.my

increasing, and one method of supplying electricity is through a thermal power plant. However, coal-fired thermal power plants produce vast quantities of bottom ash and fly ash [2]. Coal bottom ash (CBA) is a type of industrial waste that is increasing in volume every year in our country, contributing to solid waste pollution. Palm oil fuel ash was a by-product of agricultural waste combustion of waste palm oil fiber, palm kernel shell, and empty palm fruit bunches. While in 2019, Malaysia produced about 20 million tons of palm oil and has maintained its position as the world's second-largest producer.

The main objective of this research is to determine the compressive strength and flexural strength for concrete containing treated fine metakaolin, palm oil fuel ash and coal bottom ash. This research was limited to determining the workability following BS: EN 12350-2: 2019, the compressive strength in accordance with EN 12390-3: 2019, and the flexural strength by BS: EN 12390-5: 2019 of concrete containing MK and POFA as cement replacements and CBA as sand replacements. The average results were derived from compressive and flexural strength tests conducted on 30 concrete cube samples and 15 concrete prism samples.

2. Materials and methods

The materials that will be used for this research consist of Ordinary Portland Cement (OPC), Water, Aggregates, MK, POFA, and CBA, and superplasticizer. MK and POFA will be substituted for cement, while CBA will be partially substituted for sand.

2.1 Binding Materials

The type of metakaolin that is used for this research is treated fine metakaolin, where the metakaolin has the size of 2µm. The amount of MK used as cement replacement is 20% MK for this research. In this study, POFA was being used with 5%, 10%, 15%, and 20% replacement of the cement. Before POFA can be utilized as a cement replacement, POFA must be oven-dried for 24 hours and ground several times until it achieves a sieve size of less than 75µm.

2.2 Aggregate

The bottom ash from coal was used to replace some of the fine aggregates. CBA that fit through a 5-mm sieve was used to make sure that the replacement material was the same size as the fine aggregate. The fine aggregates used in this research were natural sand with the particle size passing the 5 mm sieve. The coarse aggregates used in this research were gravel or crushed stones with the particle size stayed on a 5 mm sieve and went through a 14 mm sieve.

2.3 Concrete Design Mixture

The concrete design mix utilized in this study is detailed in Table 2 by referring to design mix by Zeyad [3] for high-strength concrete with a water-cement ratio of 0.27. Constant constituents included MK, CBA, fine aggregates, coarse aggregates, water, and superplasticizer. In this study, the variable POFA content was 5%, 10%, 15%, and 20% as cement replacement. In order to improve the workability, a superplasticizer was used with 2% of the cement mass. The desired compressive strength of this design mixture at 28 days of age is 50 N/mm^2. The designation of replacement materialsis shortened for easier reading. “M” refers to MK, “P” refers to POFA, and “C” refers to CBA.

Table 1 - Design mix proportion with POFA as a variable

Mix(m^3)	OPC (kg)	MK (kg)	POFA (kg)	CBA (kg)	Sand (kg)	Coarse Aggregate(kg)	Water (kg)	SP (kg)
Control	550	0	0	0	742	1034	148.5	11
20M 5P 10C	412.5	110	27.5	74.2	742	1034	148.5	11
20M 10P 10C	385	110	55	74.2	742	1034	148.5	11
20M 15P 10C	357.5	110	82.5	74.2	742	1034	148.5	11
20M 20P 10C	330	110	110	74.2	742	1034	148.5	11

2.4 Sample Preparation

In this study, there are 5 different mix designs. Table 3.2 shows that 30 cube specimens and 15 prism specimens were needed for each mix design to test hardened concrete. All the tests on hardened concrete were done after it had been cured for 7, and 28 days. For the compressive strength test, cube-shaped samples were used. For the flexural strength test, on the other hand, prism specimens were used. The cube specimen measured 100mm x 100mm x 100mm, while the prism specimen measured 500mm x 100mm x 100mm.

3. Result and Discussion

The slump test, compressive strength test, and flexural strength test are the findings from this research.

3.1 Slump Test

The slump test was done once the concrete mixture was completely mixed. The freshly mixed concrete is poured into the cone and compressed before the cone is removed. In this study, slump tests are conducted to identify which design mixture has the appropriate workability for usage in construction. Fig. 1 below shows the slump of the concrete mixed with MK, POFA and CBA.

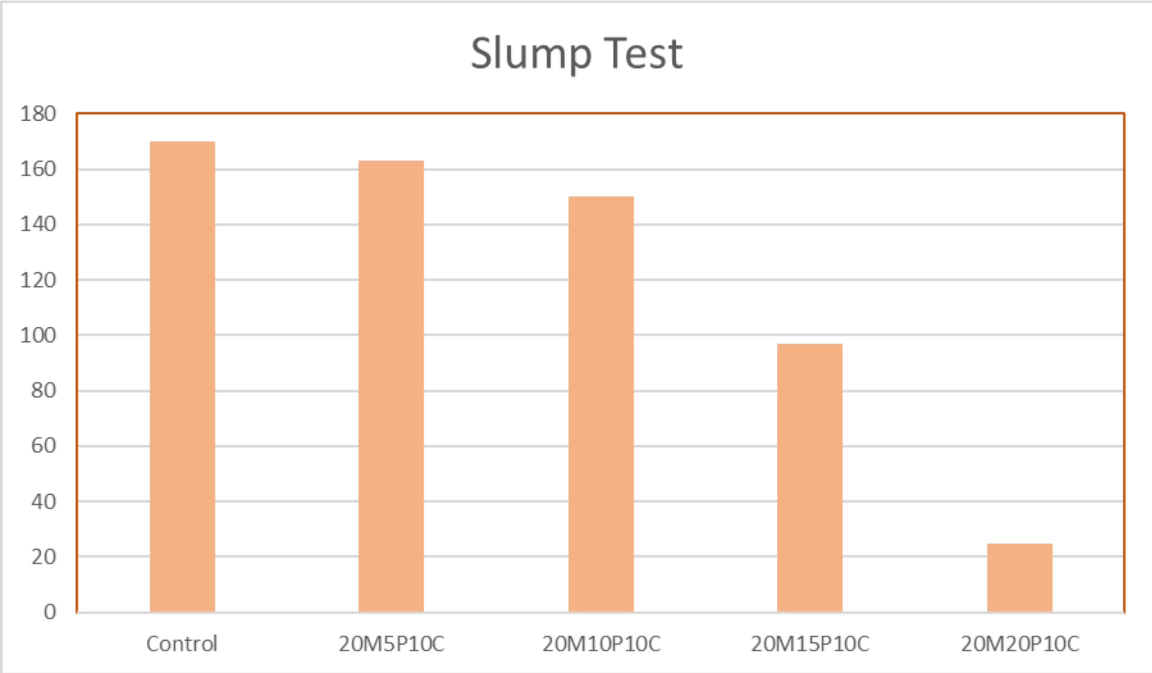

Fig. 1 - Slump of concrete with POFA, MK and CBA

Based on the results from Fig. 1, it is clear that all of the concrete mixes including replacement ingredients had less workability than the control mix. One of the reasons for the reduced workability is that the POFA particles have a high porosity, which causes them to absorb more water [4]. [5] also mentioned that utilizing CBA instead of natural aggregate reduces concrete slump [5]. Aside from that, the size of MK affects the workability of the concrete. In this study, MK was employed with a particle size of 2 μm, which is a fine particle with a greater surface area that requires more water to cover the surface of the MK particle. However, because POFA is the variable in this study, the graph pattern of diminishing concrete workability as the amount of POFA as cement substitution grows makes sense. The highlighted area depicts the best slump outcome for workability, which is the control mix, (5% POFA 20% MK 10% CBA) mix and (10% POFA 20% MK 10% CBA) mix. The other two mixes, on the other hand, are inefficient for use in construction.

3.2 Compressive Strength of Concrete

After 7 and 28 days of curing in a water tank, the concrete cube sample underwent a compressive strength test. The compressive strength test was conducted three times for each design mix, and the average compressive value was calculated. Fig. 2 display the concrete's compressive strength test results at 7 and 28 days:

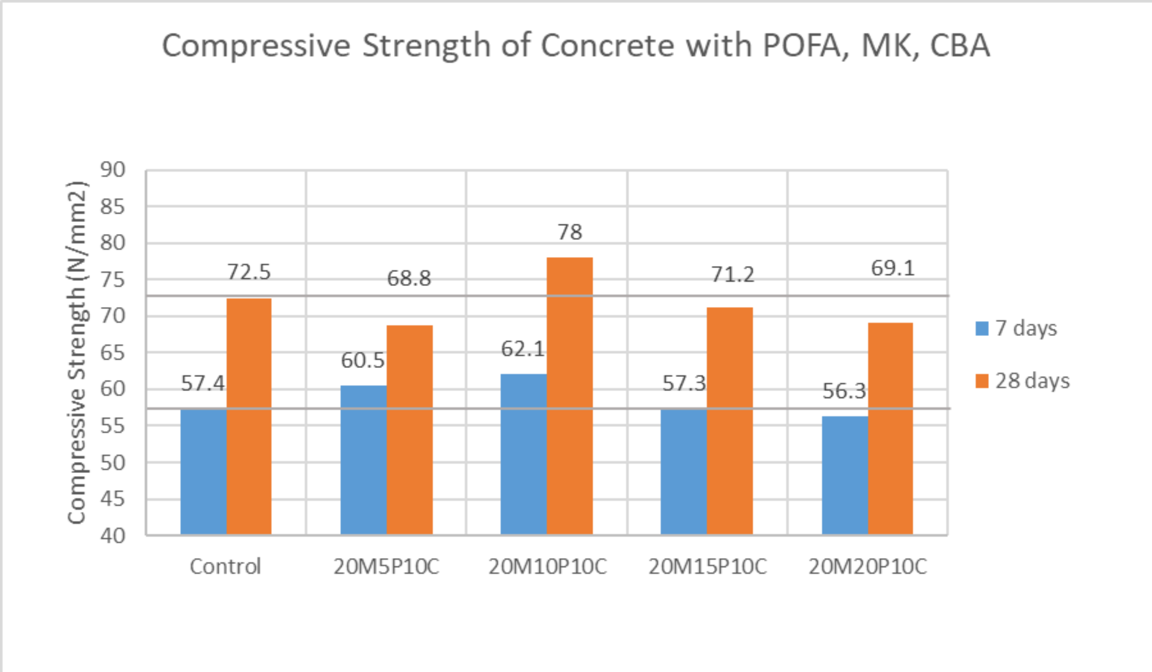

Fig. 2 - Compressive strength of concrete with POFA, MK and CBA

Based on the findings in Fig. 2, it is evident that the concrete's compressive strength rises as POFA replacement increases until it reaches 10% replacement on 7 days before starting to fall. The 10% POFA, 20% MK, and 10% CBA concrete provided the highest compressive strengths of 62.1 N/mm2 for 7 days and 78 N/mm2 for 28 days, respectively. All other concrete mixes were measured against the control mix in terms of compressive strength. For 7-day cured concrete compressive strength, two mixtures perform better than the control mix: (5% POFA 20% MK 10% CBA) mix and (10% POFA 20% MK 10% CBA) mix. One mix alone surpasses the control mix in terms of compressive strength of 28-day cured concrete: 10% POFA 20% MK 10% CBA. According to the study that was done by Chen et al., 2020, The 20% MK yields the highest result for compressive strength. This is because, although this pozzolanic action is constrained by the MK/cement content ratio, the MK reacted with the calcium hydroxide generated by cement hydration to form secondary C-S-H gel. According to Aiswarya V et al., 2017, the optimal amount of POFA to get the greatest compressive strength value is 10% [7].

3.3 Flexural Strength of Concrete

After being cured for 28 days in a water tank, concrete prism samples underwent a flexural strength test. For each design mix, the flexural strength test was conducted three times, and the average compressive value was recorded. The results of the concrete's flexural strength test at 28 days are shown in Fig. 3 below:

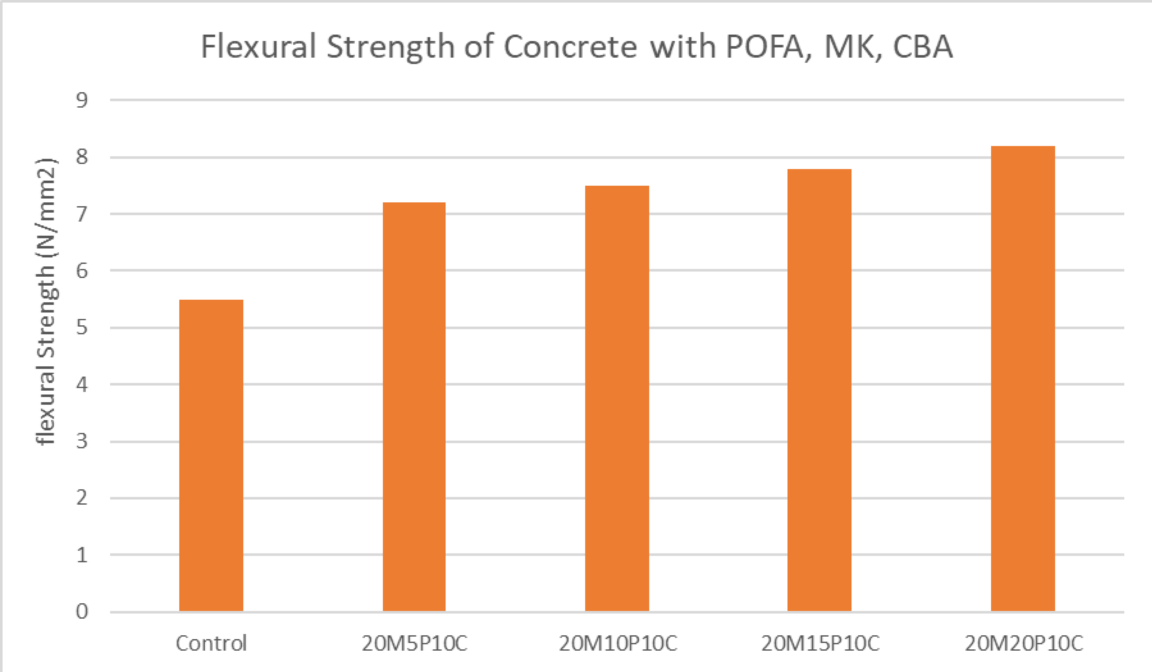

Fig. 3 - Flexural strength of concrete with POFA, MK and CBA

Based on result from Fig. 3 above it can be seen that the amount of POFA as partial cement replacement, the flexural strength increases gradually. In Fig. 3, it describes that all of the concrete mixes which incorporated replacement material obtained higher flexural strength than the control mix. The highest flexural strength was obtained when the concrete was mixed with 20% POFA as cement replacement, which is 8.2 N/mm2. However, the flexural strength of mix containing 20% and 15% POFA is not suitable been used due to the low workability. Thus concluded, the most optimum POFA replacement for the flexural strength is 10% with a flexural strength of 7.5 N/mm2. To provide support for this result, the research by Aiswarya V et al., 2017 stated that the optimum POFA replacement for maximum flexural strength is at 10% [7].

4. Conclusion

The initial purpose of this study is to measure the compressive strength and workability of concrete using MK, CBA, and POFA. The compressive strength for 5% POFA, and 10% POFA considerably increased and was higher than the control on the 7th while on the 28th day only the 10% POFA achieved strength higher than the control. However, at 15% and 20% POFA, the compressive strength fell. This is since the cement replacement content must be balanced against the OPC value. If the cement replacement content is too low, the strength composition of the concrete will change. The best value for this experiment was 10% POFA as a cement substitute. Aside from that, the second goal of this study is to investigate the flexural strength performance of concrete with MK, CBA, and POFA. iv. In terms of concrete flexural strength, greater POFA utilization in concrete mix enhances flexural strength up to 20% POFA substitution. The concrete mix containing 20% POFA and 20% MK as cement replacements and 10% CBA as sand replacements had the highest flexural strength of any of the concrete mixes tested. With workability in mind, the best POFA substitute for flexural strength is 10%. By referring to the first and second objectives, it is possible to conclude that the ideal mix for use in the building is concrete with 10% POFA and 20% MK as cement replacement, and 10% CBA as sand replacement since it has the maximum compressive strength among all other concrete mixes. While having the greatest flexural strength in terms of workability. This concrete mix's workability is also regarded as having a very high workability.

Acknowledgement

The Fundamental Research Grant Scheme (FRGS/1/2021/STG05/UTHM/03/2), managed by the Ministry of Higher Education (MOHE), provided funding for this study. The researchers would like to thank Bandung Palm Oil Mill Sdn. Bhd. for providing POFA and Malakoff Power Berhad for providing CBA in this research, as well as the staff at Universiti Tun Hussein Onn Malaysia's Faculty of Civil Engineering and Built Environment laboratory, where the research was conducted.

References

[1] Bonnet, C., Hache, E., Jabberi, A., Seck, G. S., Simoen, M., & Carcanague, S. (2019). The impact of future generation on cement demand: An Assessment based on Climate Scenarios. Working Paper 2019-2. https://inis.iaea.org/search/50020591
[2] Yang, I. H., Park, J., Dinh Le, N., & Jung, S. (2020). Strength properties of high-strength concrete containing coal bottom ash as a replacement of aggregates. Advances in Materials Science and Engineering, 2020, 1-12. https://doi.org/10.1155/2020/4246396
[3] Zeyad, A. M., Johari, M. M., Tayeh, B. A., & Yusuf, M. O. (2016). Efficiency of treated and untreated palm oil fuel ash as a supplementary binder on engineering and fluid transport properties of high-strength concrete. Construction and building materials, 125, 1066-1079. https://doi.org/10.1016/j.conbuildmat.2016.08.065
[4] Saffuan, W. A., Muthusamy, K., Salleh, N. M., & Nordin, N. (2017, November). Properties of concrete containing ground palm oil fuel ash as fine aggregate replacement. IOP Conference Series: Materials Science and Engineering, 264(1), 012008. IOP Publishing. https://doi.org/10.1088/1757-899X/264/1/012008
[5] Kim, H. K., & Lee, H. K. (2015). Coal bottom ash in field of civil engineering: A review of advanced applications and environmental considerations. KSCE Journal of Civil Engineering, 19, 1802-1818. https://link.springer.com/article/10.1007/s12205-015-0282-7
[6] Chen, J. J., Li, Q. H., Ng, P. L., Li, L. G., & Kwan, A. K. H. (2020). Cement equivalence of metakaolin for workability, cohesiveness, strength and sorptivity of concrete. Materials, 13(7), 1646. https://doi.org/10.3390/ma13071646
[7] Aiswarya, V. S., Beyoola, W., Harsha, V. N., & Preethi, M. (2017). Palm oil fuel ash as partial replacement of cement in concrete. International Journal of Engineering Research & Technology, 6(3), 544-546. https://www.ijert.org/palm-oil-fuel-ash-as-partial-replacement-of-cement-in-concrete