# EFFECT OF ULTRAFINE PALM OIL FUEL ASH AND PALM OIL CLINKER ON LIGHTWEIGHT AGGREGATE CONCRETE

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# ABSTRAK

Pengurusan sisa pertanian merupakan salah satu cabaran alam sekitar dunia kerana pengumpulan sampah dalam jumlah yang banyak di tapak pembuangan sampah mengakibatkan pelepasan karbon oksida. Ia amat penting untuk mengurangkan kesan negatif pengumpulan sisa-sisa ini. Banyak kajian telah dilakukan oleh teknologis simen dan konkrit untuk menyelesaikan isu ini termasuklah menghasilkan konkrit agregat ringan (LWAC) yang memerlukan penggunaan kandungan simen yang tinggi. Selain itu, model statistik dan matematik dihasilkan untuk menilai prestasi bahan buangan tempatan yang digunakan dalam pengeluaran LWAC. Oleh itu, kajian ini bertujuaan untuk menyiasat kesan abu bahan bakar kelapa sawit ultrahalus (UPOFA) sebagai penggantian separa simen dan batu hangus kelapa sawit (POC) sebagai penggantian separa/penuh agregat kasar terhadap sifat-sifat mekanikal LWAC. POFA telah digunakan sebagai pengganti separa simen dari 0% hingga 30% dan POC sebagai agregat kasar dari 0% hingga 100%. Disamping itu, jumlah bahan-bahan campuran konkrit lain (air, aggregat halus, dan super memplastik) disamatarakan dalam semua campuran konkrit. Peringkat permulaan, sifat-sifat fizikal dan komposisi kimia UPOFA dan POC diuji untuk melihat kesesuaian penggunaannya sebagai simen dan agregat. Selepas itu, kekuatan mampatan, UPV, kekuatan lenturan, dan tegangan pemisahan dibuat pada 7, 28, 90, 180, dan 365 hari pengawetan. Selain itu, ujian SEM / EDX diuji untuk menunjukkan kesan UPOFA dan POC pada LWAC. Kaedah tindak balas permukaan (RSM), satu pakej teknik statistik dan matematik telah digunakan untuk memproses 13 campuran eksperimen untuk mengoptimumkan parameter pembolehubah yang digunakan. Tahap penggantian optimum UPOFA dan POC yang diperolehi dari eksperimen dalam reka bentuk komposit pusat (CCD) telah diuji dengan kaedah analisis varians (ANOVA). Pembaharuan kajian ini ialah mengunakan dua jenis sisa kelapa sawit dengan peratus berbeza sebagai bahan konkrit dengan menggunakan RSM iaitu kaedah statistik yang baharu untuk rekabentuk eksperimen. Keputusan yang diperolehi menunjukkan bahawa penambahan UPOFA yang bersifat pozzolan dengan kandungan silika yang tinggi telah meningkatkan kekuatan konkrit terutama untuk usia pengawetan yang lebih lama. Sementara itu, POC mempunyai sifat yang sangat berpori dan graviti tentu yang lebih rendah daripada agregat kasar biasa cenderung menghasilkan konkrit dengan kepadatan dan kekukuhan yang lebih rendah. Penggabungan UPOFA dalam Campuran 4 menghasilkan ketumpatan terendah dengan 1945 $kg/m^3$ disebabkan graviti tentu UPOFA dan POC lebih rendah daripada simen dan agregat kasar. Nilai runtuhan tertinggi dengan 120 mm kerana menggunakan 30% UPOFA sebagai pengganti simen. Kekuatan tertinggi LWAC diperolehi pada 365 hari iaitu 85 MPa. Ini menghasilkan bacaan UPV, kekuatan lenturan dan tegangan pemisahan dengan 4375 m/s, 8.53 MPa, dan 5.38 MPa. Keputusan analisis oleh ANOVA menunjukkan bahawa POC lebih berkesan dari segi mengurangkan ketumpatan, kebolehkerjaan, kekuatan mampatan, UPV, kekuatan lenturan dan tegangan, dan meningkatkan penyerapan air. Sementara UPOFA menyumbang kepada peningkatan semua tindakbalas, hasil nilai pengoptimuman adalah 12.42 % UPOFA sebagai pengganti simen dan 11.27% POC sebagai agregat kasar untuk mencapai nilai kehendak 0.619. Nilai ini sesuai dengan nilai optimum bagi ketumpatan, kebolehkerjaan, kekuatan mampatan, UPV, kekuatan lenturan, kekuatan tegangan, dan penyerapan air dengan 2300.36 $kg/m^3$ , 97.98 mm, 78.87 MPa, 4079.34 m/s, 7.34 MPa, 5.36 MPa, dan 1.72%.

# ABSTRACT

The management of agricultural waste is one of the world's environmental challenges due to accumulating large amounts of wastes in landfills causing the emission of carbon oxide. It is imperative to minimize the negative effect of the accumulation of these wastes. Numerous options have been tried by the cement and concrete technologists to solve such issues including the production of lightweight aggregate concrete (LWAC) which required high cement content. Additionally, the statistical and mathematical models were generated to evaluate the performance of local wastes used in the LWAC production. Therefore, this study aims to investigate the effect of ultrafine palm oil fuel ash (UPOFA) as partial cement replacement and palm oil clinker (POC) as partial/full coarse aggregate replacement on the properties of lightweight aggregate concrete (LWAC). The UPOFA was used as partial replacement of cement from 0 to 30% and POC was used as coarse aggregate replacement from 0 to 100%. While, other concrete materials (water, fine aggregate, and super-plasticizer content) were kept constant in all concrete mixes. First, physical properties and chemical composition analysis were conducted on the UPOFA and POC to find out the suitability of using it as cement and coarse aggregate, respectively. Thereafter, the compressive strength, ultrasonic pulse velocity (UPV), flexural and tensile strength were conducted after 7, 28, 90, 180, and 365 days of curing. In addition to that, the test of SEM/EDX was investigated to show the effect of UPOFA and POC on the LWAC. In the response surface methodology (RSM), a set of statistical and mathematical techniques, was employed in 13 experimental runs to optimize the variable parameters. The optimum percentage of replacement levels of UPOFA and POC obtained from the experimental runs in central composite design (CCD) were analyzed using the analysis of variance (ANOVA). The novelty of this study is that it uses two palm oil wastes as the concrete materials in different percentages using RSM as a new statistical method for experimental design.The results obtained showed that the addition of UPOFA enhances the properties of the concrete specimens owing to the pozzolanic effect of siliceous nature of UPOFA especially at later curing age. On the other hand, POC has a highly porous nature and lower specific gravity than normal coarse aggregate which tended to lower the density and stiffness of the concrete. Incorporation of the UPOFA and POC achieved the lowest density of 1945 kg/m$^3$ attributed to the lowerspecific gravity of UPOFA and POC than that of the cement and coarse aggregate. The highest slump value of 120 mm was achieved due to the usage of 30% UPOFA as cement replacement. The highest strength of LWAC was achieved at 365-days i.e. 85 MPa. This resulted in UPV, flexural, and splitting tensile strength values of 4375 m/s, 8.53 MPa, and 5.38 MPa, respectively. Analysis of the results by ANOVA indicated that the POC is more effective in terms of reducing the density, workability, compressive strength, UPV, flexural and tensile strengths, and enhancing the water absorption. While the UPOFA contributed to improving all the responses, the optimization results revealed that 12.42 % UPOFA as cement replacement and 11.27 % POC as coarse aggregate are optimum dosages to achieve the desirability' value of 0.619. These levels correspond to the optimum values of density, workability, compressive strength, UPV, flexural strength, tensile strength, and water absorption as 2300.36 kg/m$^3$, 97.98 mm, 78.87 MPa, 4079.34 m/s, 7.34 MPa, 5.36 MPa, and 1.72 %, respectively.

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# LIST OF SYMBOLS

| | |
|---|---|
| µm | Micro-meter |
| $Kg/m^3$ | Kilogram per cubic meter |
| m/s | Meter per second |
| Km/s | Kilometer per second |
| MPa | Mega Pascal |
| GPa | Giga Pascal |
| mm | Millimeter |
| $Cm^2/g$ | Square centimeter per gram |
| ± | Plus minus |
| $^{o}$ C | Degree Celcius |
| α | Alpha |
| 2θ | Two-theta |
| V | Volume |
| M | Mass |
| $R^2$ | Regression coefficient |
| p-value | Probability of obtaining results |
| F-value | To determine whether the test is statistically significant or not. |
| df | Degree of freedom |
| 2D | Two-dimensional |
| 3D | Three-dimensional |
| fc | Compressive strength |
| P | Maximum applied load |
| Ac | Cross-sectional area |

## LIST OF ABBREVIATIONS

| | |
|---|---|
| ACV | Aggregate crushing value |
| AIV | Aggregate impact value |
| $Al_2O_3$ | Aluminium oxide |
| ANOVA | Analysis of variance |
| ASTM | American Society for Testing and Materials |
| BS | British standards |
| BS EN | British Standard European Norm |
| CaO | Calcium oxide |
| Ca(OH) | Calcium hydroxide |
| CARIFF | Center of Excellence for Advanced Research in Fluid Flow |
| CCD | Central composite design |
| $CO_2$ | Carbon dioxide |
| C-S-H | Calcium silicate hydrate |
| DOE | Design of experiment |
| EDX | Energy Dispersive X-ray spectroscopy |
| FA | Fly ash |
| $Fe_2O_3$ | Iron oxide |
| GC | Geopolymer concrete |
| GGBFS | Ground granulated blast-furnace slag |
| GGBS | Ground granulated blast slag |
| GPOFA | Ground POFA |
| HPGC | High-performance green concrete |
| $K_2O$ | Potassium oxide |
| LAMM | Los Angeles abrasion machine |
| LOI | Loss on ignition |
| LWA | Lightweight aggregate |
| LWAC | Lightweight aggregate concrete |
| LWC | Lightweight concrete |

| | |
|---|---|
| LWFC | Lightweight foamed concrete |
| MgO | Magnesium oxide |
| MK | Metakoline |
| MPOB | Malaysia Palm Oil Board |
| NAT | Nitrogen adsorption technique |
| $Na_2O$ | Sodium oxide |
| NWC | Normal weight concrete |
| OPC | Ordinary Portland Cement |
| OPS | Oil palm shell |
| OPSFGC | Oil pal shell foamed geopolymer concrete |
| POC | Palm oil clinker |
| POFA | Palm oil fuel ash |
| RHA | Rice husk ash |
| RCB | Reinforced concrete beams |
| RPOFA | Raw POFA |
| RSM | Response surface method |
| SCC | Self-compacting concrete |
| SEM | Scanning electron microscopy |
| $SiO_2$ | Silica oxide |
| SLWAC | Structural lightweight aggregate concrete |
| $SO_3$ | Sulphur trioxide |
| SP | Super plasticizer |
| SSD | Surface saturated dry |
| TEM | Transmission electron microscopy |
| TPOFA | Treated POFA |
| UPOFA | Ultrafine palm oil fuel ash |
| UPV | Ultrasonic pulse velocity |
| XRD | X-ray diffraction |
| XRF | X-Ray Fluorescence |

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## Publication of papers

1. Hamada, H. M., Jokhio, G. A., Yahaya, F. M., Humada, A. M., & Gul, Y. (2018). The present state of the use of palm oil fuel ash (POFA) in concrete. *Construction and Building Materials*, *175*, 26-40. Q1 (Impact factor = 4.419)

2. Hamada, H. M., Yahaya, F. M., Muthusamy, K., Jokhio, G. A., & Humada, A. M. (2019). Fresh and hardened properties of palm oil clinker lightweight aggregate concrete incorporating Nano-palm oil fuel ash. *Construction and Building Materials*, *214*, 344-354. Q1 (Impact factor = 4.419)

3. Hamada, H. M., Jokhio, G. A., Al-Attar, A. A., Yahaya, F. M., Muthusamy, K., Humada, A. M., & Gul, Y. (2020). The use of palm oil clinker as a sustainable construction material: A review. *Cement and Concrete Composites*, *106*, 103447. Q1 (Impact factor = 6.257)

4. Hamada, H. M., Alya'a, A., Yahaya, F. M., Muthusamy, K., Tayeh, B. A., & Humada, A. M. (2020). Effect of high-volume ultrafine palm oil fuel ash on the engineering and transport properties of concrete. *Case Studies in Construction Materials*, *12*, e00318.

5. Hamada, H., Tayeh, B., Yahaya, F., Muthusamy, K., & Al-Attar, A. (2020). Effects of nano-palm oil fuel ash and nano-eggshell powder on concrete. *Construction and Building Materials*, *261*, 119790. Q1 (Impact factor = 4.419)

6. Hamada, H. M., Tayeh, B. A., Al-Attar, A., Yahaya, F. M., Muthusamy, K., & Humada, A. M. (2020). The present state of the use of eggshell powder in concrete: A review. *Journal of Building Engineering*, 101583. Q1 (Impact factor= 3.379)

7. Hamada, H. M., Thomas, B. S., Tayeh, B., Yahaya, F. M., Muthusamy, K., & Yang, J. (2020). Use of oil palm shell as an aggregate in cement concrete: A review. *Construction and Building Materials*, *265*, 120357. Q1 (Impact factor = 4.419)

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1. Hamada, H. M., Jokhio, G. A., Yahaya, F. M., & Humada, A. M. (2018, April). Properties of fresh and hardened sustainable concrete due to the use of palm oil fuel ash as cement replacement. In *IOP Conference Series: Materials Science and Engineering* (Vol. 342, No. 1, p. 012035). IOP Publishing. (SCOPUS)

2. Hamada, H. M., Jokhio, G. A., Yahaya, F. M., & Humada, A. M. (2018, April). Applications of Nano palm oil fuel ash and Nano fly ash in concrete. In *IOP*

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3. Jokhio, G. A., Hamada, H. M., Humada, A. M., Gul, Y., & Abu-Tair, A. (2020). Environmental benefits of incorporating palm oil fuel ash in cement concrete and cement mortar. In *E3S Web of Conferences* (Vol. 158, p. 03005). EDP Sciences. (SCOPUS)

4. Hamada, H. M., Yahaya, F., Muthusamy, K., & Humada, A. (2019, October). Comparison study between POFA and POCP in terms of chemical composition and physical properties-Review paper. In *IOP Conference Series: Earth and Environmental Science* (Vol. 365, No. 1, p. 012004). IOP Publishing. (SCOPUS)

5. Hamada, H. M., Yahaya, F., Muthusamy, K., & Humada, A. (2019, October). Effect of incorporation POFA in cement mortar and desired benefits: a review. In *IOP Conference Series: Earth and Environmental Science* (Vol. 365, No. 1, p. 012060). IOP Publishing. (SCOPUS).