Ain Shams Engineering Journal 14 (2023) 102150

Contents lists available at ScienceDirect

Ain Shams Engineering Journal

journal homepage: www.sciencedirect.com

Optimising concrete containing palm oil clinker and palm oil fuel ash using response surface method

Hussein M. Hamada [a,*], Alyaa A. Al-Attar [b], Bassam Tayeh [c], Fadzil Bin Mat Yahaya [a], Yazan I. Abu Aisheh [d]

[a] Faculty of Engineering Technology, University Malaysia Pahang, 26300, Pahang, Malaysia
[b] Northern technical university, Mosul, Iraq
[c] Civil Engineering Department, Faculty of Engineering, Islamic University of Gaza, P.O. Box 108, Gaza Strip, Palestine
[d] Department of Civil Engineering, Middle East University, Amman 11831, Jordan

ARTICLE INFO

Article history:
Received 6 February 2022
Revised 25 May 2022
Accepted 8 January 2023
Available online 16 January 2023

Keywords:
Palm oil clinker
Ultrafine palm oil fuel ash
Response surface method
Cement
Aggregate
Concrete

ABSTRACT

Cement production led to the consumption of high energy and generated harmful gases, such as CO_2. Therefore, the use of alternative materials becomes necessary. The research attempts to use palm oil clinker (POC) and ultrafine palm oil fuel ash (UPOFA) as a full replacement of coarse aggregate and partial cement replacement, respectively. This study aims to use the response surface method (RSM) to optimise the properties of concrete, namely, density and water absorption. The study investigated the density and water absorption of concrete using RSM. Results showed that the density reduced sharply owing to the full replacement coarse aggregate by POC aggregate. Meanwhile, water absorption increased significantly due to the rise in the POC aggregate replacement. However, water absorption decreased because of the use of UPOFA as cement replacement. The study recommended the use of more UPOFA as cement replacement because of its high pozzolanic property.

1. Introduction

Malaysia and Indonesia are the largest exporters of palm oil products all over the world. In 2011 alone, around 5 million hectares was planted with oil palm trees [1]. As reported by the United States Department of Agriculture, the global production of palm oil in 2016–2017 was approximately 64.5 million tons [2]. Therefore, solid waste increased dramatically because of the expansion of about 6.1 million tons of empty fruit bunches, fibres and kernels in the plantation [3]. These waste materials are frequently dumped into landfills and open areas after the extraction of palm oil. This inappropriate and indiscriminate dumping results in air, water and land pollution, which have adverse effects on human health [4]. Conversely, the increasing need for lightweight aggregate (LWA) concrete (LWAC) leads to the reuse of wastes generated from palm oil products either as pozzolanic partial supplementary material or LWA [5,6].

The manufacturing of one ton of ordinary Portland cement (OPC) results in the emission of approximately-one ton ofiCO_2 gas [7]. Nearly 7 % of the greenhouse gases released into the atmosphere resulted from the production of cement [8]. To solve these problems, palm oil fuel ash (POFA) and fly ash (FA) can be used as supplementary cementitious material (SCM) with cement in various proportions [9–11]. In addition, these SCMs are used to enhance the durability and strength of concrete because of their ability to undergo pozzolanic reactions [12–14]. The reduction of environmental wastes and their utilisation give room for sustainability [15–17]. POFA is a by-product that resulted from the burning of oil palm shell, fibres and empty fruit bunches that are used as fuel for electricity generation in oil palm factories at high temperatures between 800 ℃ and 1000 ℃ [3,18–22]. In 2007, approximately 3 million tons of POFA was produced in Malaysia [23]. Huge amounts of POFA were disposed as waste into open areas and landfills without any appropriate handling, thereby causing problems in health and the environment [8,24]. Therefore, the use of POFA as cementitious material by the researchers increased gradually since the 1990 s [25,26]. Treatments of POFA, such as increasing the fineness and removal of carbon content, have improved its quantity and quality when used as SCMs [11,27–

* Corresponding author.
E-mail address: enghu76@gmail.com (H.M. Hamada).

Peer review under responsibility of Ain Shams University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.asej.2023.102150
2090-4479/

30]. Hence, ground POFA resulted in low particle size and improved the silica content, microstructural performance and its pozzolanicity [19,20,28,31,32]. Previous studies stated that up to 20 % of cement replacement by POFA is a suitable matter for producing sustainable concrete [33–36]. Hamada et al. [3,22,37] showed the positive influence of POFA in different particle sizes on the compressive strength of concrete. Hussin et al. [38] reported that the nano particle size of 80 % POFA improved the concrete properties [39]. Other studies reported that the nano-POFA can be obtained from extra grinding, and 60 % of it could be used as a cement replacement to enhance the compressive strength and durability of concrete [23,30,40].

Since 2010, the construction industry has consumed up to 12 billion tonnes of normal aggregates annually [41]. Owing to the decrease in normal aggregates and the need to preserve the natural resources, many researchers have used oil palm shell (OPS) and palm oil clinker (POC) as substitutes for LWA to produce sustainable LWAC [30,42–46]. Malaysia produces large amounts of OPS and POC as waste materials [47]. POC has been used as LWA to produce structural LWAC with suitable mechanical properties [45,47]. The use of POC to replace coarse aggregate would reduce the cost of construction and environmental problems that accompany the accumulation of palm oil waste. LWAC has many advantages, such as the decrease in dead load, minimised micro cracks in concrete and uniform stress distribution at the micro level [48,49]. Many studies have been conducted to show the effects of POC as coarse aggregate. For instance, Kabir et al. [50] studied the properties of geopolymer concrete that contained POC as coarse aggregate together with the utilisation of ground granulated blast furnace slag (GGBS) in ternary with POFA and OPC. POC aggregate has a good pozzolanic reaction and bonding with cement matrix because of the presence of alumina-siliceous compounds [51] in the LWAC.

Response surface methodology (RSM) is an accumulation of numerical and statistical methods used for experimental design and data analyses for adequate optimisation and prediction. In 1951, Box and Wilson proposed the RSM technique to optimise the experimental works, and it has been widely used for many applications since then. RSM is a group of useful mathematical and statistical techniques to optimise the selected responses from the variables' interaction [52]. The set of effected variables is called the design of expert (DOE) [53]. The main objective of using RSM is to obtain appropriate approximation for the practical relationships between the independent variables and the selected responses. These responses can be represented by any shape surface available in the RSM software [53]. Overall, the RSM has many advantages, such as the use of least square method to build the RSM functions. Therefore, the probabilistic prediction, as well as analyse the stochastic probability of occurrence, can be analysed to select certain input variables to build the functions [54]. In this paper, the central composite design (CCD) has been adopted; it is one of the most frequently used approach in finding the functional relationship between the available and responses using RSM [55]. It is the most used design approach within the RSM software [56], and it is used to determine the functional relationships amongst the responses (density and water absorption) and factors ([POC] content and ultrafine POFA (UPOFA) content) using RSM.

Design of experiments (DoE) is a famous method that contains a set of mathematical equations and statistical analyses of results from minimum resources, time and effort. Aldahdooh et al. [57] replaced the cement partially by UPOFA from 0 % to 50 % and replaced the DSF by UPOFA from 0 % to 100 % using the RSM. They concluded that the tensile and flexural strengths intensified when the replacement levels of cement by UPOFA increased. This current study will adopt the CCD as one of the RSM that contains a set of mathematical equations and statistical analyses to investigate the combined effect of the total content of UPOFA and POC on the density and water absorption of concrete. Evidently, such study and the optimization of the responses, including density and water absorption, are not yet available in the literature. This study is aimed at developing a model that will minimise the cost of experiments required to optimise the benefits that can be obtained from UPOFA and POC as sustainable construction materials.

2. Experimental programme

2.1. Materials used in the concrete

Ordinary Portland cement (OPC) was tested for Blaine specific surface area of (3310 cm^2/g), specific gravity (3.15), initial (62 min) and final setting time (138 min). The chemical composition and physical properties of the cementitious materials are listed in Table 1. The raw POFA was collected from a palm oil mill located near Gambang, Pahang, Malaysia, as illustrated in Fig. 1. The final UPOFA was made to pass through many steps to obtain the UPOFA required, as explained by Hamada et al. [30].

The Palm oil clinker (POC) was used as a coarse aggregate in various proportions to produce LWAC. It is one of the wastes that is collected from a palm oil mill located in Gambang, Pahang, Malaysia (Fig. 2). Table 2 illustrates the physical properties of POC and natural coarse aggregates. The POC used as coarse aggregate was also prepared through many treatments, as reported by Hamada et al. [30]. Fig. 3 shows the sieve analysis of aggregates (coarse aggregates (POC and natural) and fine aggregate used in this study.

Tap water was used for concrete production. Also, Sika ViscoCrete superplasticizer was used (1 wt% of cement) to improve the mixture consistency in accordance with BS 5075 [58]. The mining sand was used as fine aggregate with specific gravity, water absorption and fineness modulus of 2.75, 0.78 % and 2.79, respectively.

2.2. Experiment design using RSM

The total test numbers for the factors mentioned were 13, resulting from ($2k + 2^k + 5 = 13$), where ($k = 2$), and k is the number of factors. Eight tests plus five repetitions tests were improved to evaluate the pure error, as shown in Tables 3 and 4.

POC and UPOFA are the factors, whilst density and water absorption indicate the responses. Choosing the ranges of the parameters (factors), POC content 0 %–100 % [58–60] and UPOFA 0 %–30 % [61–63], is based on the primary experimental runs and the previous studies. It was anticipated that these ranges would offer different outcomes, producing a design to explain the effects

Table 1
Chemical composition and physical properties of OPC and UPOFA.

Properties	OPC	UPOFA
CaO	54.8	3.97
SiO_2	26.1	67.3
Fe_2O_3	4.09	8.12
Al_2O_3	8.54	4.12
MgO	0.358	2.72
Na_2O	0.186	0.115
TiO_2	0.427	0.229
K_2O	0.97	8.45
MnO	0.137	0.07
SO_3	2.77	0.535
P_2O_5	0.177	2.47
LOI	2.2	1.4
Mean particle size (μm)	6.8	0.982
Specific gravity	3.15	2.52
Specific surface area (m^2/g)	0.337	1.962
Blaine Fineness (cm^2/g)	3310	4830

Fig. 1. Raw UPOFA.

Fig. 2. Raw POC.

Table 2
Physical properties of natural coarse aggregates and POC.

Properties	Natural coarse aggregate	POC coarse aggregate
Aggregate size (mm)	4.75 to 10	4.75 to 10
Bulk density (kg/m3)	1452	732
Fineness		6.23
Specific gravity (SSD)	2.65	1.78
Water absorption (24 h) %	0.74	5.7
Moisture content %	0.29	0.38
Los Angeles abrasion value (%)	23.9	49.7
Aggregate impact value (AIV) %		31.57
Aggregate crushing value (ACV)%	16.8	46.5

of POC and UPOFA. The use of more than 40 % UPOFA is not recommended owing to its negative impact on the concrete performance [35,64]. Using POC aggregates has been reported by previous studies in various percentages from 0 % to 100 % [30,65]. Equation (1) was used to identify the best state of the responses.

where y is the anticipated response, b is the regression coefficient, X_i and X_j are the parameters (variables), i is the linear coefficient, j is the quadratic coefficient, k is the number of factors calculated to optimise the responses, and ε is the random error [53]. In this study, a set of mathematical modelling and statistical analysis in the RSM software has been used to optimise the variables. The influence of each parameter has been determined through interaction among the variables studied using the analysis of variance (ANOVA).

2.3. Mix proportions

The reference concrete mix is a normal concrete without UPOFA or POC. The W/B ratio for all concrete mixtures was constant to 0.42. The tests were designed on the basis of the CCD technique. The experimental tests contained two parts, namely, density test and water absorption test. The water absorption has been tested according to ASTM C 642–13 [66]. Table 3 shows the factors and parameters, whilst Table 4 show the 13 concrete mixtures by two factors and two responses.

2.4. Specimen preparation

The produced concrete was mixed by a dry mixer in the laboratory for a total time of 9 min, including 4 min for mixing the dry materials. Two variables, which were the POC proportion to partially/fully replace coarse aggregate and the UPOFA proportion to partially replace cement, were investigated in this study. UPOFA was used to replace cement at 0 %, 10 %, 20 % and 30 % of the total weight of the binder. POC aggregate was used to replace the normal coarse aggregate partially and fully. Other parameters, such as, fine aggregate and water/binder ratio, were kept fix at 700 kg/m^3 and 0.42, respectively.

3. Results and discussion

3.1. Microstructure properties of UPOFA and POC

The scanning electron microscope (SEM) test was performed to recognise the variations in the POFA morphologies. POFA was salted using different ways: including oven-dried raw POFA by the electrical oven at temperature 110 ± 10C for 24 h, then grounded to obtain GPOFA by Laos Angeles machine. The GPOFA was heated by the electrical furnace at high temperature of up to 600 °C to obtain the treated POFA (TPOFA). The TPOFA was ground again by the Laos Angeles machine to obtain ultrafine POFA (UPOFA). The results of SEM/EDX show that the particle shape was irregular, angular and has a porous texture, whereas the particle size of UPOFA decreases when the increase in grinding time (Fig. 4).

The results of SEM/EDX for the UPOFA, which was obtained by the second grounding process are shown in Fig. 4. The particle size of UPOFA was less than those of GPOFA and TPOFA particles, and the shape was generally semi-circular and usually angular. The EDX test was used to obtain better information on the chemical components of materials contributed in the concrete mix. The main components of UPOFA was silica (Si), which accounted more than 67 %, as shown in Table 1 and Fig. 4.The changes in the mechanical properties and chemical composition of the UPOFA were due to the various treatment procedures. The specific surface area and particle size of UPOFA particles were only 1.962 m^2/g and 0.982 μm, respectively. This reference to that UPOFA higher surface area and a smaller particle size than those of the raw POFA and the cement. The carbon content was reduced and identified by the SEM/EDX test obviously. The carbon content was explored in temperately high concentration of POFA that was not exposed to high temperature. Therefore, the carbon content and LOI were reduced, and the SiO_2 content increased when compared with the raw POFA and GPOFA. The heat treatment process also increased the contents of Fe_2O_3 and Al_2O_3. Consequently, according to the requirements of ASTM C618, the UPOFA can be classified as a mineral admixture class F (ASTM, 2005).

In terms of POC, the SEM test was conducted to determine the microstructural properties of POC, whereas the energy dispersive X-ray (EDX) was used after polishing and pre-coating the sample tested by gold. Fig. 5 shows the presence of large amount of voids spread on the POC surface. The large voids can be clearly visible. As a result, these micro voids may cause cracks on the concrete surface, especially when connected to each other, thereby reducing the concrete strength. Fig. 5 shows the SEM test of POC aggregates.

The required tests were completed to examine the efficiency and effect of UPOFA as a partial cement replacement and POC as

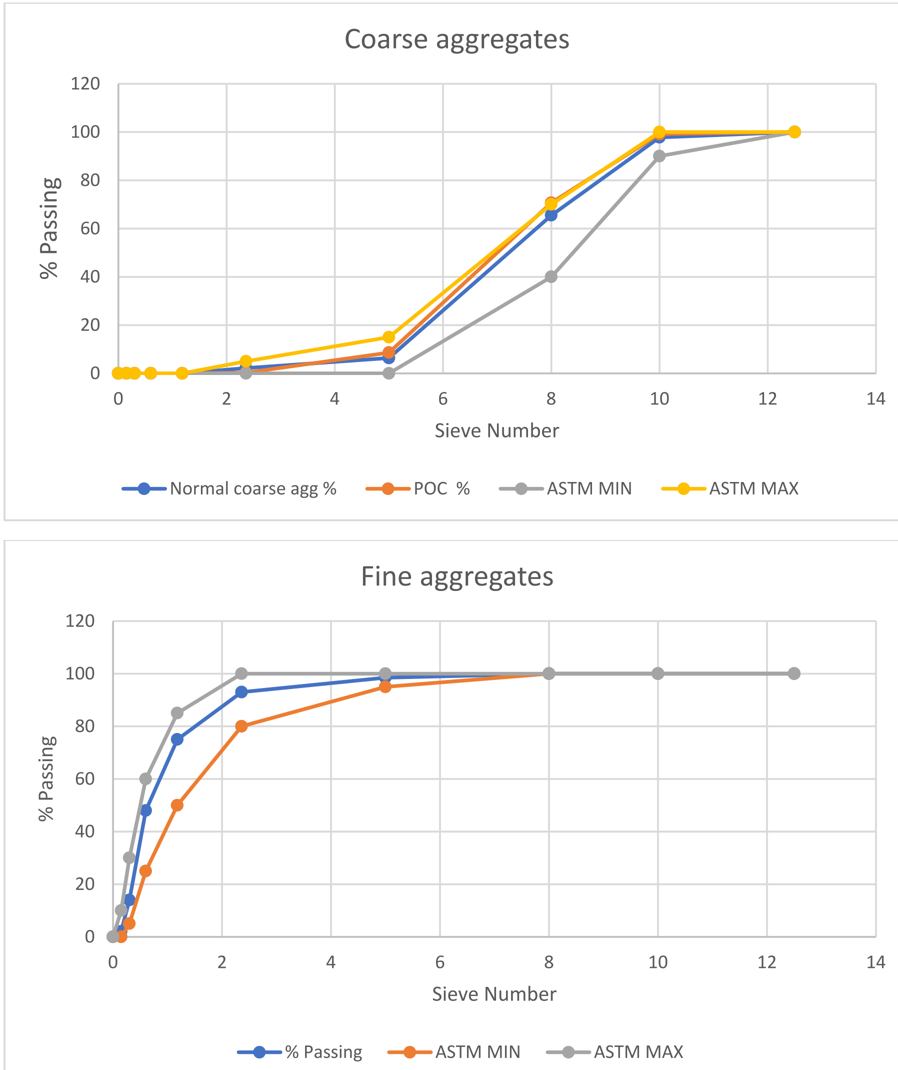

Fig. 3. Sieve analysis of aggregates used.

Table 3
Code, unit and ranges for the optimisation of independent variables.

Variables	code	Unit	Coded variable levels		
			−1	**0**	**+1**
UPOFA	A	%	0	15	30
POC aggregate	B	%	0	50	100

coarse aggregate on the microstructure, density and water absorption of concrete. Table 3 shows the factors, namely, UPOFA and POC, adopted in this study as variables, whereas Table 4 shows that 13 runs have been performed on the basis of the central composite design (CCD). The relationship between the two factors (e.g. POC% and UPOFA %) and the two responses (e.g. density and water absorption) were investigated using the RSM. The RSM is a common software that uses mathematical and statistical techniques for developing and analysing models amongst many independent responses and variables [67]. This model was created based on the actual values. The CCD was developed to predict the mathematical prediction equations. The expected results (Y) were calculated to evaluate the factors and as a function of X_1 (UPOFA) % and X_2 (POC) %. These results can be found in Equation (1), the sum of constant, two first-order effects (iX_1 and X_2), one interaction ieffect (X_1X_2) and two second-order effects (X_{21} and X_{22}).

3.2. Density

In this study, 13 concrete mixtures were used to determine the hardened density. The density test was measured after 28 days of casting for all samples (Fig. 6). The density of POC concrete (POCC) was lower than that of normal-weight concrete for all concrete mixtures. However, its density is still higher than other types of LWAC, such as concrete made of oil palm shell (OPS) and coconut shell [68]. The density of the concrete depends mainly on the density of the comprising materials, particularly the aggregate [30]. As reported by Rashid et al. [69], the bulk density of POC is less than that the normal coarse aggregate, which is the main reason for reducing the density of POCC. As illustrated in Fig. 6, the density of POCC mixtures was lower than the control mix for all the concrete mixtures. According to Euro code 2 Part 1–1, the density of normal weight concrete (NWC) ranges between 2300 and

Table 4
Proportions of concrete mixtures by RSM.

Mix no.	UPOFA %	POC %	UPOFA Kg/m³	POC Kg/m³	Cement Kg/m³	Fine aggregate Kg/m³	Coarse aggregate kg/m³	Water/binder
1	0	0	0	0	450	700	900	0.42
2	30	0	108	0	315	700	900	0.42
3	0	100	0	604	450	700	0	0.42
4	30	100	108	604	315	700	0	0.42
5	0	50	0	302	450	700	450	0.42
6	30	50	108	302	315	700	450	0.42
7	15	0	54	0	382.5	700	900	0.42
8	15	100	54	604	382.5	700	0	0.42
9	15	50	54	302	382.5	700	450	0.42
10	15	50	54	302	382.5	700	450	0.42
11	15	50	54	302	382.5	700	450	0.42
12	15	50	54	302	382.5	700	450	0.42
13	15	50	54	302	382.5	700	450	0.42

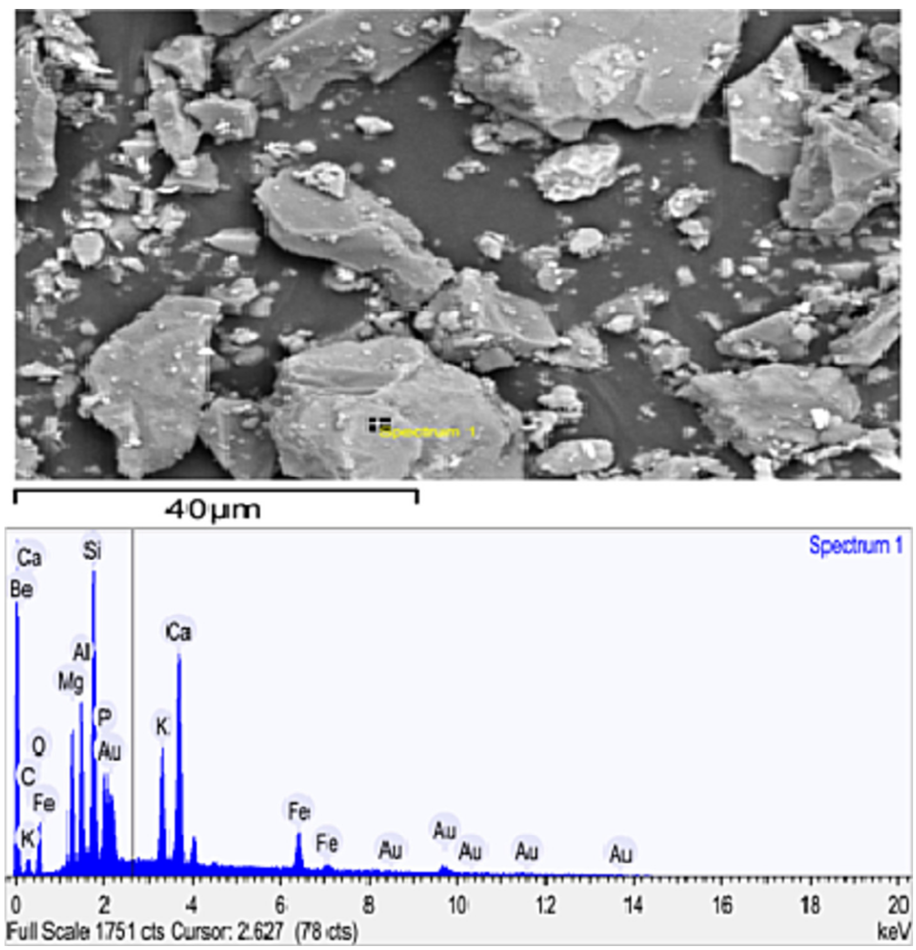

Fig. 4. SEM/EDX of UPOFA.

2500 kg/m³, whereas the structural LWACs (SLWAC) is < 2200 kg/m³ [70].

Islam et al. [61] reported that the replacement of cement by using 40 % UPOFA reduced the density of SLWAC by 20 %. Abutaha et al. [60] noted that the density of concrete decreased by 15 % when normal coarse aggregate was totally replaced by POC, and declined by 3 % when normal fine aggregate was totally replaced by POC. As shown in Table 5 and Fig. 6, the POC has an effective role in decreasing the density of concrete, especially with 100 % replacement level. Furthermore, the UPOFA contributed in the decrease in the density of concrete because its specific gravity is less than that of the normal cement.

Fig. 6 shows that the mix 1 recorded the highest density in both cases (demoulded and oven-dried density). The high density of the control mix is because the specific gravity of normal coarse aggregate and cement are larger than those of POC and UPOFA, respectively. Meanwhile, the second high density was recorded by mix 7 when 15 % of UPOFA, which has specific gravity less than cement, was used to replace cement (Fig. 6). Recently, Muthusamy et al. [71] investigated the long-term mechanical properties of LWAC that contained 100 % POC as coarse aggregate and ground UPOFA as partial cement replacement of 10 %, 20 %, 30 % and 40 %. They observed that the density value ranges between 1819 and 1850 kg/m³ according to the UPOFA replacement level. Hamada

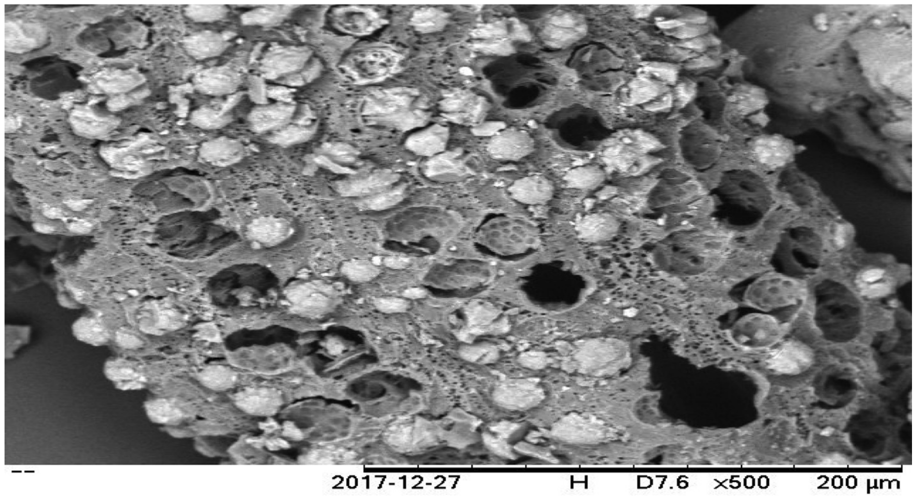

Fig. 5. Micro voids on the POC surface by SEM test.

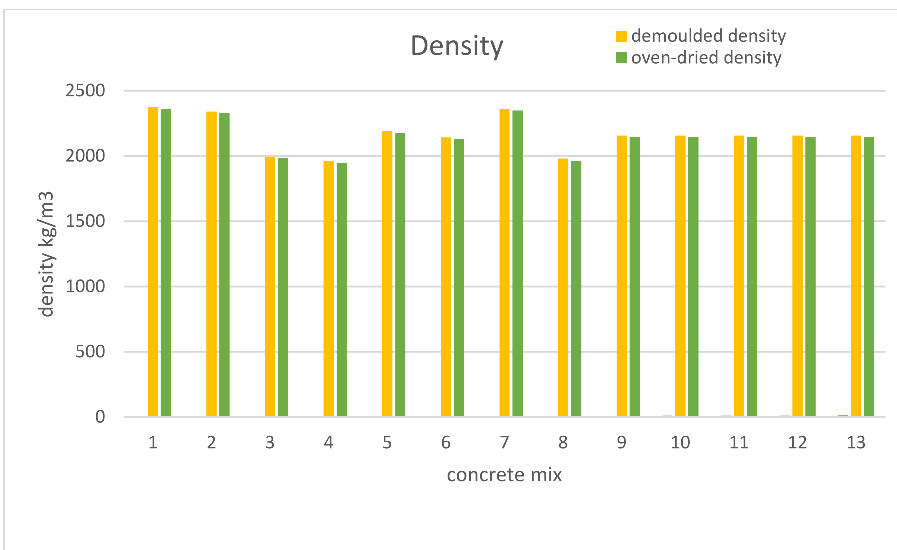

Fig. 6. Density of LWAC.

Table 5
Air-dried density and oven-dried density of LWAC.

Mix design	Factor 1, POC %	Factor 2, POFA%	Density kg/m^3	
			Air-dried	Oven-dried
M1	0	0	2397	2360
M2	30	0	2361	2327
M3	0	100	2017	1985
M4	30	100	1972	1945
M5	0	50	2213	2175
M6	30	50	2163	2130
M7	15	0	2378	2348
M8	15	100	1991	1960
M9	15	50	2176	2145
M10	15	50	2176	2145
M11	15	50	2176	2145
M12	15	50	2176	2145
M13	15	50	2176	2145

et al. [30] concluded that the concrete containing 10 %–30 % UPOFA as cement replacement and 0 %–100 % POC as coarse aggregate has a density that range from 2020 to 2382 kg/m^3 because of the lower specific gravity of POC compared with the normal aggregate.

In contrast, the lower density was measured in mix 4, which recorded 1972 and 1945 kg/m^3 for demoulded and oven-dried density, respectively. Ahmmad et al. [58] produced the oven-dried density of 1971 kg/m^3 due to the use of 100 % POC as coarse aggregate in the concrete mixture, and this value is very close to the density value obtained by mix 4. The low density of this mix is due to the lower specific gravity of POC as compared with normal coarse aggregates. This results along with study conducted before [72]. Abutaha et al. [60] concluded that the density of 100 % POC as coarse aggregate was 2074 kg/m^3. The density of POCC containing UPOFA was about 21 % less than that of NWC in mix 1, however, it is still higher than other kinds of LWAC, such as OPS and coconut shell aggregates, whereas the density of 100 % POCC was 2025 kg/m^3 [73]. Ahmad et al., [74] used the POC as coarse aggregate in LWAC. They produced a dry density of around 2020 kg/m^3 and a compressive strength of around 42 MPa at the 28th day.

3.3. Water absorption

Water absorption is significant in determining the ability of concrete to resist environmental conditions [75]. The water absorption test of all concrete specimens was conducted on the 100 mm^3 cube specimens at the ages of 7, 28, 90, 180 and 360 days. The specimens were oven-dried in an electric oven at 110 ℃ for 24 h before the test. Subsequently, the water absorption test of the concrete specimen was conducted after being immersed in water for 30 min. Equation (2) can be applied to determine the water absorption value.

$$\text{Water absorption}\,(\%) = \frac{\text{Ma} - \text{Mo}}{\text{Mo}} \times 100 \quad (2)$$

Where M_a = weight of the concrete sample after immersion (g) M_o = weight of the oven-dried concrete sample (g).

Fig. 7 and Table 6 show the effect of replacement cement by UPOFA and replacement coarse aggregate by POC on the water absorption. The POC aggregate has a significant role in increasing water absorption because of its pore structure [76,77]. In this regard, the interfacial zone (ITZ) and microstructure of LWAC are influenced by the high water absorption in the POCC [78]. Neville [79] stated that water absorption alone could not be used to determine the quality of concrete. Mostly, low water absorption indicate the quality of concrete to a certain extent [80]. Razak et al. [81] observed that the water absorption of LWA affects the interfacial region of LWAC and the microstructure of the hardened binder paste owing to the proportion of the pore area in the ITZ, which increases with the absorption of aggregate. Aslam et al. [68] reported that the rise in the replacement level of OPS in POCC increased the water absorption of the POCC. Aslam et al. [82] stated that the nature of the physical properties of POC aggregate suggests its higher level of porosity compared with normal coarse aggregates. The existing chemical reaction of the porous LWA decreased the pores around the aggregate and caused the compaction of LWAC to be lower than water absorption. Muthusamy et al. [71] reported that the addition of 10 % UPOFA as cement replacement had an effective role in the refinement of voids in concrete because of the pozzolanic reaction, which resulted in lower water absorption values.

Fig. 7 shows the control concrete mix that recorded the lowest water absorption from the 7 days until 360 days. Meanwhile, Mix 4, which contains 30 % UPOFA and 100 % POC, recorded the highest water absorption at all curing days. The high-water absorption of POCC resulted from the high water absorption of POC aggregates [58,83]. Hamada et al. [30] used UPOFA and POC as partial cement replacement and POC as partial/fully coarse aggregate replacement. They obtained 54 % higher water absorption than that of the control specimen because of using 100 % POC aggregate. Abutaha et al. [84] investigated the LWAC that contained different replacement levels of POC as coarse aggregate. They also used a POC powder as filler to produce high-strength concrete. They observed that the water absorption at the 28th day was < 2.5 %. The water absorption at the 90th and 180th days were more favourable because of the influence of silica content in POCC.

4. Results of mathematical modelling and statistical analysis

The empirical relationships between the responses and the factors are expressed by second-order polynomial, as shown in Equations (3 and 4). According to the experimental program, each of the responses (e.g. density and water absorption) could be forecasted by the regression analysis that provided the interaction between the responses and variables. The CCD experimental design data

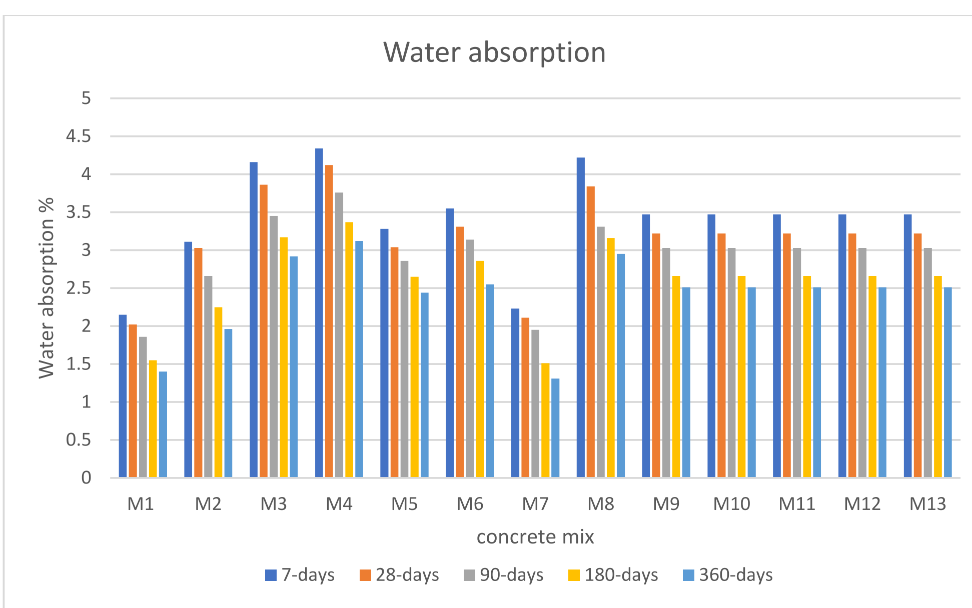

Fig. 7. Water absorption of concrete containing UPOFA and POC.

Table 6
Water absorption of LWAC samples.

Mix no	Factor 1, UPOFA %	Factor 2, POC %	Water absorption %				
			7 day	28 day	90 day	180 day	360 day
M1	0	0	2.15	2.02	1.86	1.55	1.4
M2	30	0	3.11	3.03	2.66	2.25	1.96
M3	0	100	4.16	3.86	3.45	3.17	2.92
M4	30	100	4.34	4.12	3.76	3.37	3.12
M5	0	50	3.28	3.04	2.86	2.65	2.44
M6	30	50	3.55	3.31	3.14	2.86	2.55
M7	15	0	2.23	2.11	1.95	1.51	1.31
M8	15	100	4.22	3.84	3.31	3.16	2.95
M9	15	50	3.47	3.22	3.03	2.66	2.51
M10	15	50	3.47	3.22	3.03	2.66	2.51
M11	15	50	3.47	3.22	3.03	2.66	2.51
M12	15	50	3.47	3.22	3.03	2.66	2.51
M13	15	50	3.47	3.22	3.03	2.66	2.51

could assist the mathematical forecasting equations, as illustrated below.

Density = $+2146.00–19.67\ A - 190.83B - 1.75\ AB + 4\ A^2 + 5.5\ B^2$ (3)

Water absorption = $+\ 2.48 + 0.145\ A + 0.72B - 0.09\ AB + 0.098\ A^2 – 0.2666\ B^2$ (4).

4.1. Model development

In this research, RSM was used to assess the combined influence of UPOFA and POC aggregate on the properties of concrete and build a relationship between the variables and measured responses. Multi-objective optimisation was performed to identify the optimised concrete mixtures by improving the density and reducing water absorption. Various models were used to derive the mathematical relationships between independent variables and responses in the RSM analysis. The CCD model is a more reliable model and is most generally used. This type is selected because (α) is the distance from the design centre to the axial run, which depends on the points in the factorial design portion [85].

4.2. Perturbation plots and predictive efficiency of the responses

Perturbation plots in RSM technique show an important parameter by exhibiting variations in response to each variable. The perturbation plot for density was illustrated in Fig. 8, which suggests that the POC aggregate has a more significant effect on the density than the UPOFA. However, density decreases with the increase in POC and UPOFA in concrete mixtures. Meanwhile, the water absorption increased due to increment of POC and UPOFA replacement levels in concrete mix (Fig. 8).

Fig. 8 illustrates the effect of UPOFA and POC on reducing density through the perturbation plots. A curvature in POC % replacement exhibited higher sharpness than the UPOFA % replacement level in the density and water absorption tests. This result indicates that the density and water absorption in this mixing execution were more critical to POC than UPOFA.

4.3. Statistical models and analysis of variance

Table 7 displays the ANOVA results for the response (e.g. density and water absorption) parameters. Considering that the P values are < 0.05, all models in this study are significant at the 5 % confidence level. However, if the P values for the responses are greater than 0.05, the result will be not significant. Table 7 showed the validity of the model and the responses. The density has more contributions to the responses than to water absorption (Table 7). The interaction amongst factors was insignificant. The predicted and actual results have evident correlation. The diagnostics plots of responses indicated that density and water absorption are the most effective and reliable parameters (Figs. 9 and 10, respectively).

Table 7 illustrates the model validation parameters made of two responses. The analysis by ANOVA displays reliable confidence because of the assessment of the response's efficiencies. Last study by Ghafari et al. [86] stated that if the R^2 value less and close to 1 is better and eligible, then an agreement with the adjusted R^2 is necessary, thereby pointing a satisfying amendment of the quadratic model of the empirical data.

4.4. Normal probability plot

Data were analysed to evaluate the actual versus predicted plots and normality of residuals for density and water absorption of concrete. Figs. 9 and 10 show the normal probability plot of the actual versus predicted and residuals for the density and water absorption, respectively.

According Figs. 9 and 10, in the density probability plot, the plotted points far from the distribution fitted line while in the water absorption seemed to be closer to the distribution fitted line. Notably, the predicted versus actual distribution plots was a better choice for analysing density and water absorption compared with normal plots.

The result obtained showed that the cubic model is aliased. Moreover, the predicted R^2 agreed reasonably well with the adjusted R^2 because of the difference of < 0.2. The Adeq precision was used to measure the signal-to-noise ratio. The predicted R^2 showed how well the developed model can be used to predict the response.

According to Table 8, the two models were successfully related to reproducibility. The diagnostic plots and actual versus predicted value plots are illustrated in Fig. 10. The diagnostic plots assist in judging the model's satisfaction and adequacy [87,88]. Fig. 10 shows the actual versus predicted value plots of density and water absorption. These figures illustrate that all responses (density and water absorption) from the models are well accorded with the observed values.

4.5. Process analysis

Fig. 10 show the response surface plots for density and water absorption. The comparative influence of UPOFA and POC aggregate on density and water absorption are cleared by the perturbation plots (Fig. 8). However, the combined effects of UPOFA and POC aggregates on density and water absorption are illustrated

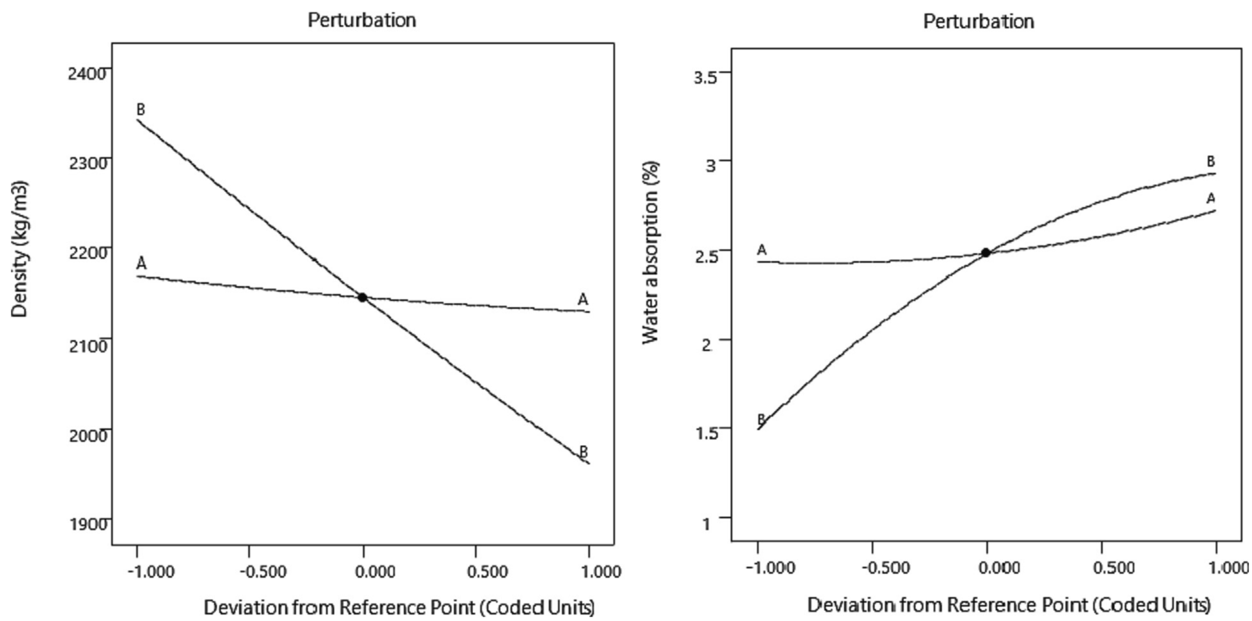

Fig. 8. Perturbation plot for density and water absorption.

Table 7
ANOVA results for response surface quadratic model parameters.

Responses	Source	Sum of Squares	df	Mean Square	F-value	p-value	
Density	Model	2.210E + 05	5	44208.13	3422.57	< 0.0001	significant
	A-UPOFA	2320.67	1	2320.67	179.66	< 0.0001	
	B-POC	2.185E + 05	1	2.185E + 05	16916.45	< 0.0001	
	AB	12.25	1	12.25	0.9484	0.3626	
	A^2	44.19	1	44.19	3.42	0.1068	
	B^2	83.55	1	83.55	6.47	0.0385	
	Residual	90.42	7	12.92			
	Lack of Fit	90.42	3	30.14			
	Pure Error	0.0000	4	0.0000			
	Cor Total	2.211E + 05	12				
Water absorption	Source	Sum of Squares	df	Mean Square	F-value	p-value	
	Model	3.47	5	0.6930	52.51	< 0.0001	significant
	A-UPOFA	0.1261	1	0.1261	9.56	0.0175	
	B-POC	3.11	1	3.11	235.67	< 0.0001	
	AB	0.0324	1	0.0324	2.45	0.1611	
	A^2	0.0268	1	0.0268	2.03	0.1974	
	B^2	0.1962	1	0.1962	14.87	0.0062	
	Residual	0.0924	7	0.0132			

in the contour 2D and 3D surface response plots, as presented in Figs. 11 and 12, respectively. Fig. 11 illustrates that the density decreased dramatically because of the increasing replacement level of coarse aggregates by POC, whereas the increase in the replacement level of cement by UPOFA has a lower effect on density.

Fig. 12 shows that the water absorption of concrete mix decreased clearly with the increase in the replacement level of POC, as well as decreased slightly with the increase in the replacement level of UPOFA.

The influences of the experiments on UPOFA and POC replacement level on the density and water absorption are demonstrated in the 3D surface response plots, as shown in Figs. 11 and 12, respectively. The figures illustrate that the replacement levels of coarse aggregate by POC and OPC by UPOFA increased, density decreased, and water absorption increased.

UPOFA and POC have a significant effect on the density and water absorption of concrete. The POC is in the range of 0.0 %–100 %, whereas the UPOFA is in the range of 0 %–30 %. The obtained results indicated the pozzolanic reaction of the ultrafine particle size of UPOFA and a high content of SiO_2.

The optimisation standards for density and water absorption are shown in Table 9. The standards for completing the goal of the desired replacement of UPOFA and POC aim to minimise density and water absorption at the 360th day.

Table 10 summarises the optimum solutions identified by the CCD within the RSM technique. The best solution of desirability for the test 1 of 0.435 is shown in Table 10. The aim of each optimisation method was designed according to the weight or importance factor.

5. Optimisation of multiple responses

To determine the best values of responses in the LWAC containing UPOFA and POC aggregate, the important parameters were optimised by using the RSM using the numerical optimisation. Fig. 13 shows that the UPOFA replacement level was less sensitive

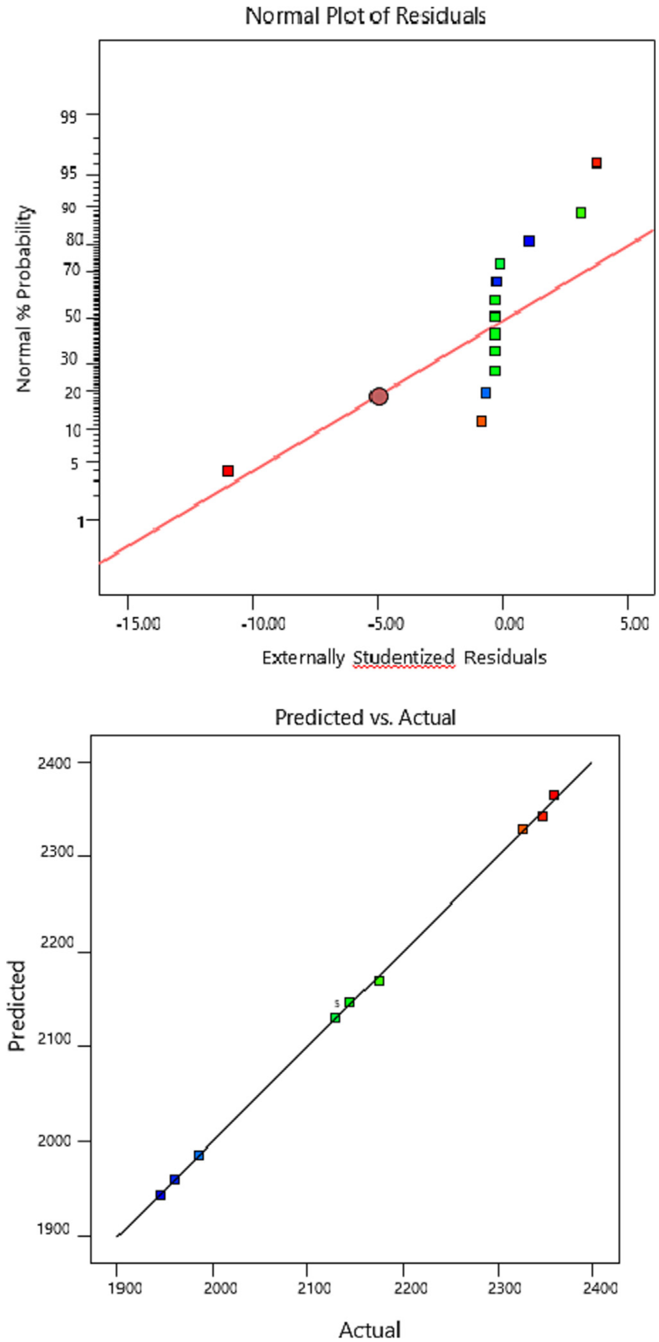

Fig. 9. Diagnostics plots, normal probability and the actual versus the predicted plot of density.

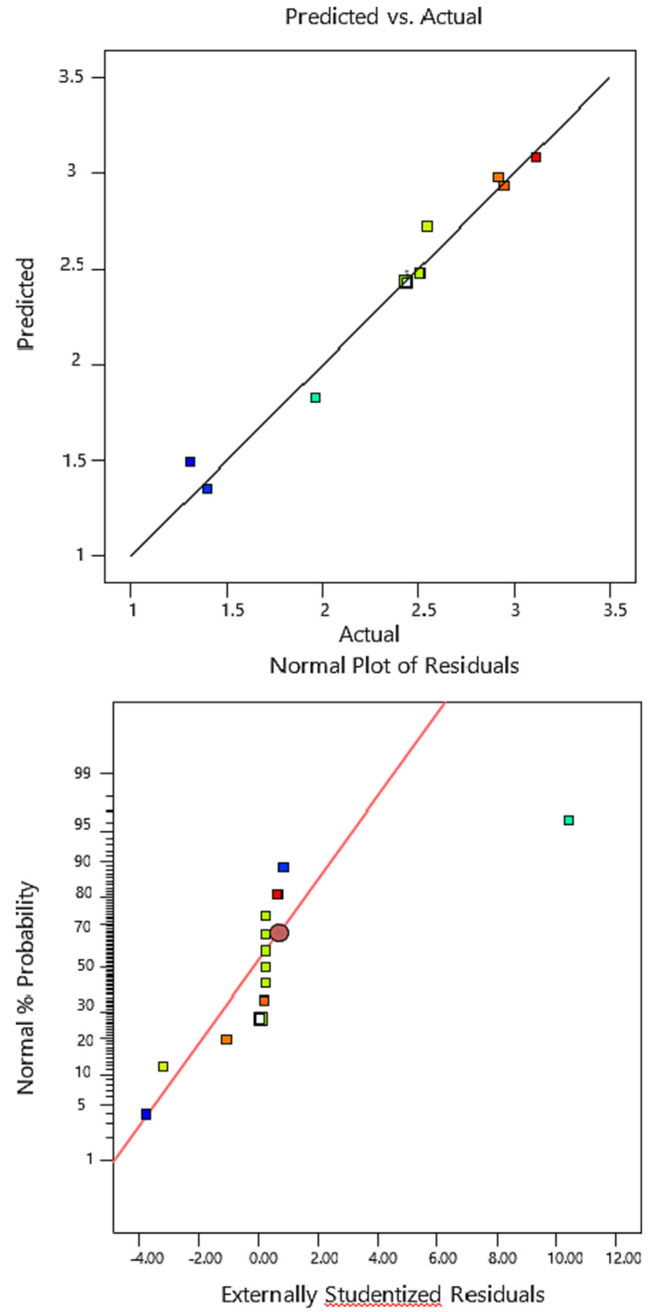

Fig. 10. Diagnostics plots, normal probability and the actual versus the predicted plot of water absorption.

than that of POC coarse aggregate in the concrete mixture related to the density of concrete but in the contrary to water absorption (Fig. 13). The RSM statistical software extracted from Design-Expert software was utilised to optimise the concrete properties, as well as to minimise the cement content and normal coarse aggregates in the concrete mixtures.

The equations of the model have been combined to obtain the process variables. The optimum replacement level was 10.208 % for the UPOFA and 43.59 % for the POC aggregate with an accompanied density and water absorption of 2177.14 % and 2.341 %, respectively for desirability = 0.435 and solution 1 out of 2 as in Table 9.

Based on the above results, the effect of POC replacement brings more negative impact to the concrete in comparison with UPOFA

Table 8
Model validation for the responses.

	Density	Water absorption
Standard deviation (SD)	3.59	0.1149
Mean	2150.38	2.4
R^2	0.9996	0.9740
Predicted R^2	0.9964	0.7716
Adjusted R^2	0.9993	0.9555
Adeq Precision	172.4261	22.1660

replacement level. This result could be attributed to the lower density and stiffness of POC compared with normal coarse aggregates. Meanwhile, the UPOFA has properties that are somewhat similar to cement. Therefore, the effect might be lower than that in the POC.

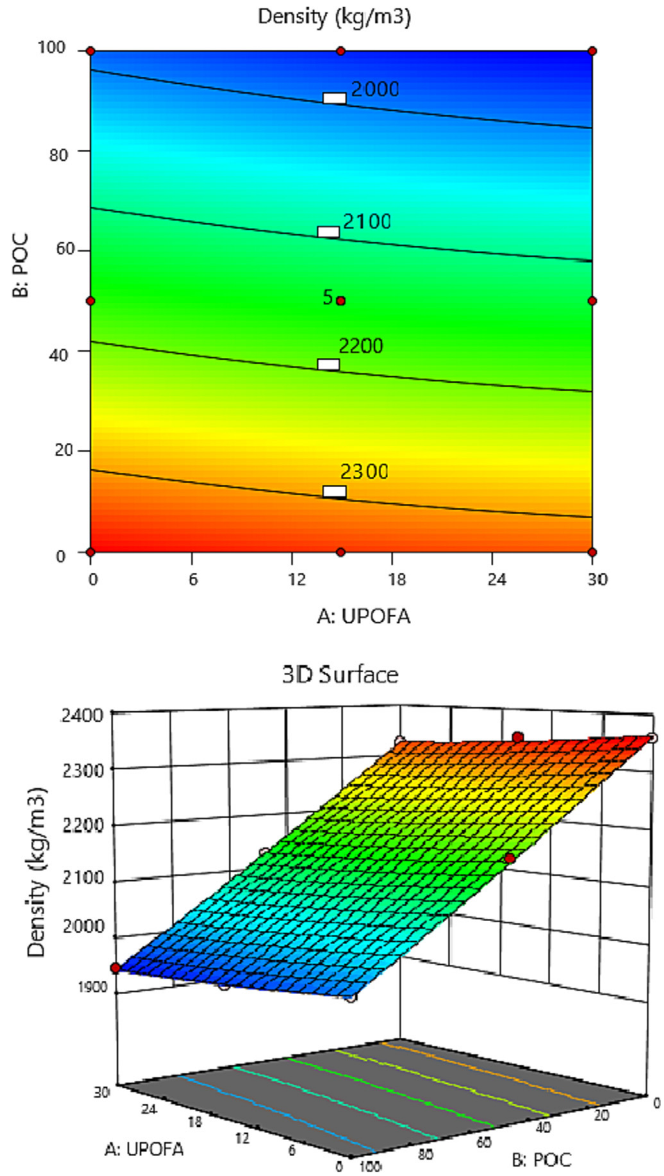

Fig. 11. Contour 2D and 3D plots of density.

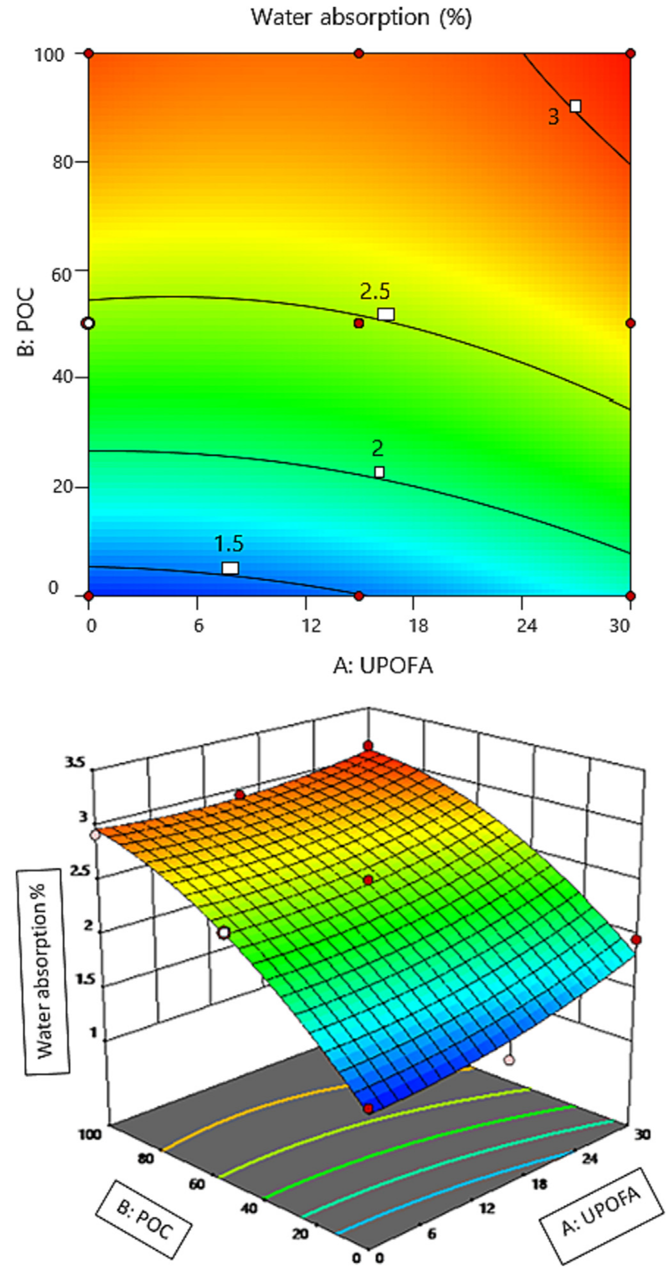

Fig. 12. Contour 2D and 3D plots of water absorption.

Table 9
Optimisation standards of individual responses for LWAC.

Number	UPOFA	POC	Density	Water absorption	Desirability	
1	**10.208**	**43.597**	**2177.148**	**2.341**	**0.435**	**Selected**
2	10.176	43.962	2175.795	2.347	0.435	

Table 10
Optimum ratios and related predicted responses.

Name	**Goal**	**Lower Limit**	**Upper Limit**	**Importance**
A:UPOFA	is in range	0	30	3
B:POC	is in range	0	100	3
Density	minimize	1945	2360	5
Water absorption	minimize	1.31	3.12	5

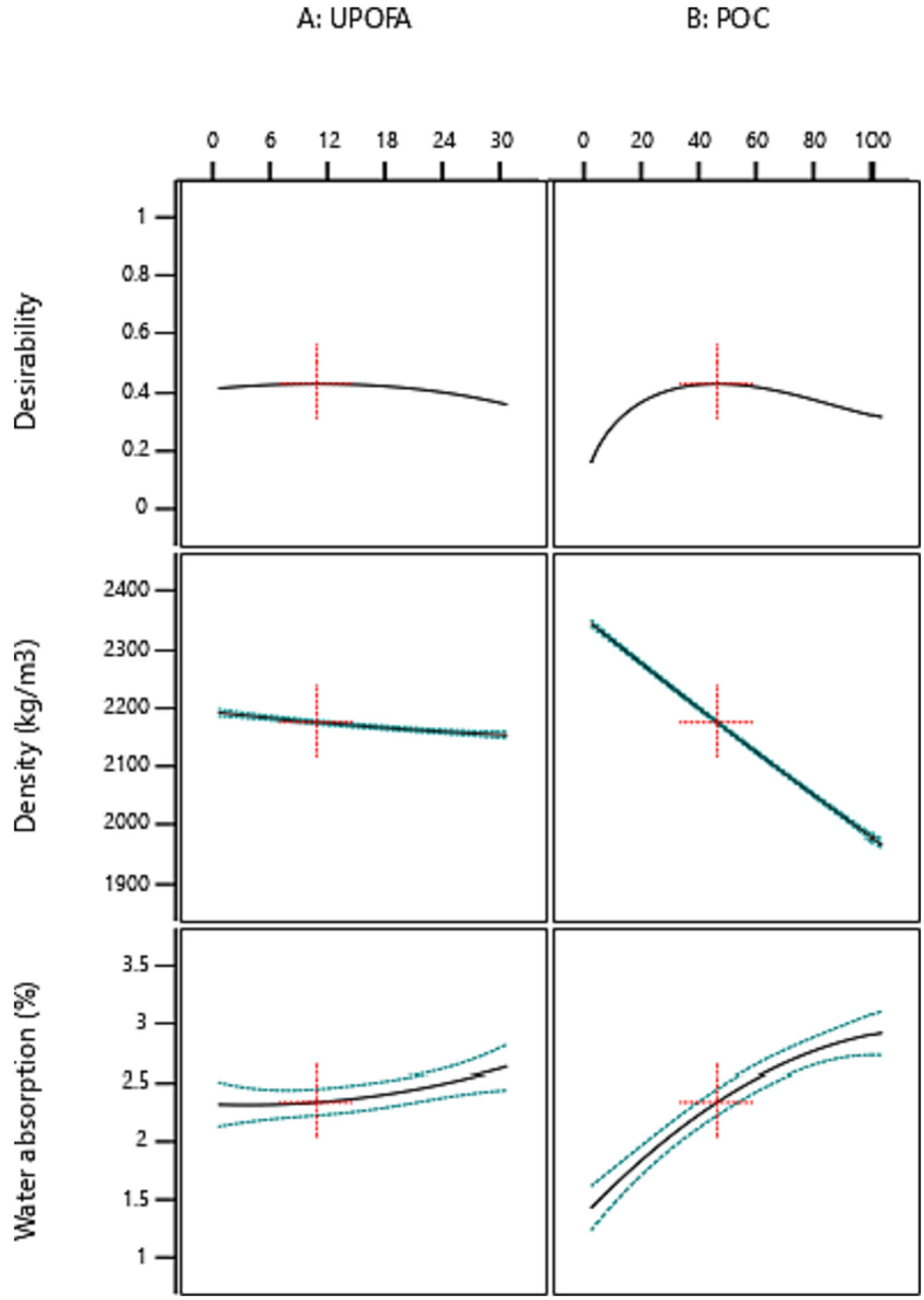

Fig. 13. Graphical views for optimised density and water absorption LWAC.

6. Conclusions

A RSM is a dependable statistical, mathematical and designing modelling. It is also an optimisation tool for determining the maximum replacement levels of OPC with UPOFA and POC to minimise the use of cement and natural aggregates in the production of cement and improve their properties. The inclusion of UPOFA and POC tends to reduce the density and increase the water absorption clearly, and the detailed conclusion can be listed in some points.

RSM by Design-Expert version 12 was adopted to determine two variables of LWAC to predict and optimise the density and water absorption of LWAC.\.

The quadratic regression could suitably predict the experimental results with the R2 of 0.9996 and 0.974 for density and water absorption, respectively.

The desirability function of optimisation of the multi-response system was 0.435, that is, the density of 2177 kg/m3 can be achieved by UPOFA of 10.208 and POC of 43.597 %.

For future studies, the performance of concrete exposed to different curing conditions and aggressive environments must be explored.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

this study was supported by University Malaysia Pahang, Malaysia (Grant no. PGRS200373).

References

[1] Lim SK, Tan CS, Lim OY, Lee YL. Fresh and hardened properties of lightweight foamed concrete with palm oil fuel ash as filler. Constr Build Mater 2013/09/01/ 2013.;46:39–47.
[2] Zeyad AM, Johari MAM, Tayeh BA, Yusuf MO. Pozzolanic reactivity of ultrafine palm oil fuel ash waste on strength and durability performances of high strength concrete. J Clean Prod 2017;144:511–22.
[3] Hamada HM, Jokhio GA, Yahaya FM, Humada AM, Gul Y. The present state of the use of palm oil fuel ash (POFA) in concrete. Constr Build Mater 2018;175:26–40.
[4] Safiuddin M, Jumaat MZ, Salam M, Islam M, Hashim R. Utilization of solid wastes in construction materials. Int J Phys Sci 2010;5:1952–63.
[5] Aslam M, Shafigh P, Jumaat MZ, Lachemi M. Benefits of using blended waste coarse lightweight aggregates in structural lightweight aggregate concrete. J Clean Prod 2016;119:108–17.
[6] Mohammed BS, Al-Ganad MA, Abdullahi M. Analytical and experimental studies on composite slabs utilising palm oil clinker concrete. Constr Build Mater 2011;25:3550–60.
[7] Hemalatha T, Mapa M, George N, Sasmal S. Physico-chemical and mechanical characterization of high volume fly ash incorporated and engineered cement system towards developing greener cement. J Clean Prod 2016;125:268–81.
[8] Yang K-H, Song J-K, Song K-I. Assessment of CO 2 reduction of alkali-activated concrete. J Clean Prod 2013;39:265–72.
[9] Yang K-H, Jung Y-B, Cho M-S, Tae S-H. Effect of supplementary cementitious materials on reduction of CO 2 emissions from concrete. J Clean Prod 2015;103:774–83.
[10] Zeyad AM, Johari MAM, Tayeh BA, Yusuf MO. Efficiency of treated and untreated palm oil fuel ash as a supplementary binder on engineering and fluid transport properties of high-strength concrete. Constr Build Mater 2016;125:1066–79.
[11] G, Jokhio, H, Hamada, A, Humada, Y, Gul, A, Abu-Tair, "Environmental benefits of incorporating palm oil fuel ash in cement concrete and cement mortar," in *E3S Web of Conferences*, 2020, p. 03005.
[12] Tayeh BA. Effects of marble, timber, and glass powder as partial replacements for cement. J Civil Eng Constr 2018;7:63–71.
[13] Tayeh BA, Al Saffar DM, Aadi AS, Almeshal I. Sulphate resistance of cement mortar contains glass powder. J King Saud University-Eng Sci 2019.
[14] B. A, Tayeh, M. W, Hasaniyah, A, Zeyad, and M. O. J. J. o. C. P, Yusuf, "Properties of concrete containing recycled seashells as cement partial replacement: A review," vol. 237, p. 117723, 2019.
[15] Ramezanianpour A, Malhotra V. Effect of curing on the compressive strength, resistance to chloride-ion penetration and porosity of concretes incorporating slag, fly ash or silica fume. Cem Concr Compos 1995;17:125–33.
[16] Osborne G. Durability of Portland blast-furnace slag cement concrete. Cem Concr Compos 1999;21:11–21.
[17] Li G, Zhao X. Properties of concrete incorporating fly ash and ground granulated blast-furnace slag. Cem Concr Compos 2003;25:293–9.
[18] Mijarsh M, Johari MM, Ahmad Z. Synthesis of geopolymer from large amounts of treated palm oil fuel ash: application of the Taguchi method in investigating the main parameters affecting compressive strength. Constr Build Mater 2014;52:473–81.
[19] Lim NHAS, Ismail MA, Lee HS, Hussin MW, Sam ARM, Samadi M. The effects of high volume nano palm oil fuel ash on microstructure properties and hydration temperature of mortar. Constr Build Mater 2015;93:29–34.
[20] H, Hamada, F, Yahaya, K, Muthusamy, A, Humada, "Effect of incorporation POFA in cement mortar and desired benefits: a review," in *IOP Conference Series: Earth and Environmental Science*, 2019, p. 012060.
[21] H. M, Hamada, A, Alya'a, F. M, Yahaya, K, Muthusamy, B. A, Tayeh, and A. M, Humada, "Effect of high-volume ultrafine palm oil fuel ash on the engineering and transport properties of concrete," *Case Studies in Construction Materials*, vol. 12, p. e00318, 2020.
[22] Hamada HM, Thomas BS, Yahaya FM, Muthusamy K, Yang J, Abdalla JA, et al. Sustainable use of palm oil fuel ash as a supplementary cementitious material: a comprehensive review. J Build Eng 2021;40:102286.
[23] Johari MM, Zeyad A, Bunnori NM, Ariffin K. Engineering and transport properties of high-strength green concrete containing high volume of ultrafine palm oil fuel ash. Constr Build Mater 2012;30:281–8.
[24] A. M, Zeyad, B. A, Tayeh, A. M, Saba, M, Johari, "Workability, setting time and strength of high-strength concrete containing high volume of palm oil fuel ash," *The Open Civil Engineering Journal,* vol. 12, 2018.
[25] Tay J-H. Ash from oil-palm waste as a concrete material. J Mater Civ Eng 1990;2:94–105.
[26] Tay J-H, Show K-Y. Use of ash derived from oil-palm waste incineration as a cement replacement material. Resour Conserv Recycl 1995;13:27–36.
[27] Safiuddin M, Abdus Salam M, Jumaat MZ. Utilization of palm oil fuel ash in concrete: a review. J Civ Eng Manag 2011;17:234–47.
[28] H. M, Hamada, F, Yahaya, K, Muthusamy, A, Humada, "Comparison study between POFA and POCP in terms of chemical composition and physical properties-Review paper," in *IOP Conference Series: Earth and Environmental Science*, 2019, p. 012004.
[29] H. M, Hamada, F, Yahaya, K, Muthusamy, A, Humada, "Effect of incorporation POFA in cement mortar and desired benefits: a review," *IOP Conference Series: Earth and Environmental Science,* vol. 365, p. 012060, 2019/11/07 2019.
[30] Hamada HM, Yahaya FM, Muthusamy K, Jokhio GA, Humada AM. Fresh and hardened properties of palm oil clinker lightweight aggregate concrete incorporating Nano-palm oil fuel ash. Constr Build Mater 2019;214:344–54.
[31] Jaturapitakkul C, Tangpagasit J, Songmue S, Kiattikomol K. Filler effect and pozzolanic reaction of ground palm oil fuel ash. Constr Build Mater 2011;25:4287–93.
[32] Zeyad AM, Johari MAM, Abutaleb A, Tayeh BA. The effect of steam curing regimes on the chloride resistance and pore size of high–strength green concrete. Constr Build Mater 2021;280:122409.
[33] Chindaprasirt P, Homwuttiwong S, Jaturapitakkul C. Strength and water permeability of concrete containing palm oil fuel ash and rice husk–bark ash. Constr Build Mater 2007;21:1492–9.
[34] Sata V, Jaturapitakkul C, Kiattikomol K. Influence of pozzolan from various by-product materials on mechanical properties of high-strength concrete. Constr Build Mater 2007;21:1589–98.
[35] Tangchirapat W, Jaturapitakkul C, Chindaprasirt P. Use of palm oil fuel ash as a supplementary cementitious material for producing high-strength concrete. Constr Build Mater 2009;23:2641–6.
[36] Zeyad AM, Johari MAM, Alharbi YR, Abadel AA, Amran YM, Tayeh BA, et al. Influence of steam curing regimes on the properties of ultrafine POFA-based high-strength green concrete. J Build Eng 2021;38:102204.
[37] H. M, Hamada, G. A, Jokhio, F. M, Yahaya, A. M, Humada, "Applications of Nano palm oil fuel ash and Nano fly ash in concrete," in *IOP Conference series: Materials Science and Engineering*, 2018, p. 012068.
[38] Hussin MW, Lim N, Sam ARM, Samadi M, Ismail MA, Ariffin NF, et al. Long term studies on compressive strength of high volume nano palm oil fuel ash mortar mixes. Jurnal Teknologi 2015;77:15–20.
[39] M. W, Hussin, N, Lim, A. R, M. Sam, M, Samadi, M. A, Ismail, N. F, Ariffin, *et al.*, "Long term studies on compressive strength of high volume nano palm oil fuel ash mortar mixes," *Jurnal Teknologi77*, 2015.
[40] Hamada H, Tayeh B, Yahaya F, Muthusamy K, Al-Attar A. Effects of nano-palm oil fuel ash and nano-eggshell powder on concrete. Constr Build Mater 2020;261:119790.
[41] Tu T-Y, Chen Y-Y, Hwang C-L. Properties of HPC with recycled aggregates. Cem Concr Res 2006;36:943–50.
[42] Huda MN, Jumat MZB, Islam AS. Flexural performance of reinforced oil palm shell & palm oil clinker concrete (PSCC) beam. Constr Build Mater 2016;127:18–25.
[43] Hamada HM, Thomas BS, Tayeh B, Yahaya FM, Muthusamy K, Yang J. Use of oil palm shell as an aggregate in cement concrete: a review. Constr Build Mater 2020;265:120357.
[44] Hamada HM, Jokhio GA, Al-Attar AA, Yahaya FM, Muthusamy K, Humada AM, et al. The use of palm oil clinker as a sustainable construction material: a review. Cem Concr Compos 2020;106:103447.
[45] Hamada H, Alattar A, Yahaya F, Muthusamy K, Tayeh BA. Mechanical properties of semi-lightweight concrete containing nano-palm oil clinker powder. Phys Chem Earth, Parts a/b/c 2021;121:102977.
[46] Hamada HM, Al-Attar AA, Tayeh B, Yahaya FBM. Optimizing the concrete strength of lightweight concrete containing nano palm oil fuel ash and palm oil clinker using response surface method. Case Stud Constr Mater 2022;16:e01061.
[47] Ahmmad R, Jumaat M, Bahri S, Islam AS. Ductility performance of lightweight concrete element containing massive palm shell clinker. Constr Build Mater 2014;63:234–41.
[48] Shafigh P, Mahmud HB, Jumaat MZB, Ahmmad R, Bahri S. Structural lightweight aggregate concrete using two types of waste from the palm oil industry as aggregate. J Clean Prod 2014;80:187–96.
[49] Mo KH, Alengaram UJ, Jumaat MZ. Compressive behaviour of lightweight oil palm shell concrete incorporating slag. Constr Build Mater 2015;94:263–9.
[50] Kabir SMA, Alengaram UJ, Jumaat MZ, Yusoff S, Sharmin A, Bashar II. Performance evaluation and some durability characteristics of environmental friendly palm oil clinker based geopolymer concrete. J Clean Prod 2017/09/10/ 2017.;161:477–92.
[51] Kabir SA, Alengaram UJ, Jumaat MZ, Sharmin A, Bashar II. Performance evaluation and some durability characteristics of environmental friendly palm oil clinker based geopolymer concrete. J Clean Prod 2017.

[52] Myers RH, Montgomery DC, Anderson-Cook C. Process and product optimization using designed experiments. Response surface methodol 2002:328–35.
[53] Soares R, Mohamed A, Venturini WS, Lemaire M. Reliability analysis of non-linear reinforced concrete frames using the response surface method. Reliab Eng Syst Saf 2002;75:1–16.
[54] Cho T. Prediction of cyclic freeze–thaw damage in concrete structures based on response surface method. Constr Build Mater 2007;21:2031–40.
[55] Aldahdooh M, Bunnori NM, Johari MM. Evaluation of ultra-high-performance-fiber reinforced concrete binder content using the response surface method. Mater Des 2013;1980–2015(52):957–65.
[56] D. C, Montgomery, "Design and analysis of experiments, Minitab manual," ed: Wiley, USA, 2008.
[57] Aldahdooh M, Bunnori NM, Johari MM. Influence of palm oil fuel ash on ultimate flexural and uniaxial tensile strength of green ultra-high performance fiber reinforced cementitious composites. Mater Des 2014;1980–2015 (54):694–701.
[58] R, Ahmmad, M. Z, Jumaat, U. J, Alengaram, S, Bahri, M. A, Rehman, H, bin Hashim, "Performance evaluation of palm oil clinker as coarse aggregate in high strength lightweight concrete," *Journal of Cleaner Production*, vol. 112, pp. 566-574, 2016.
[59] Ahmmad R, Alengaram UJ, Jumaat MZ, Sulong NR, Yusuf MO, Rehman MA. Feasibility study on the use of high volume palm oil clinker waste in environmental friendly lightweight concrete. Constr Build Mater 2017;135:94–103.
[60] Abutaha F, Razak HA, Kanadasan J. Effect of palm oil clinker (POC) aggregates on fresh and hardened properties of concrete. Constr Build Mater 2016;112:416–23.
[61] Islam A, Alengaram UJ, Jumaat MZ, Bashar II, Kabir SA. Engineering properties and carbon footprint of ground granulated blast-furnace slag-palm oil fuel ash-based structural geopolymer concrete. Constr Build Mater 2015;101:503–21.
[62] Aldahdooh M, Bunnori NM, Johari MM. Development of green ultra-high performance fiber reinforced concrete containing ultrafine palm oil fuel ash. Constr Build Mater 2013;48:379–89.
[63] Tangchirapat W, Jaturapitakkul C. Strength, drying shrinkage, and water permeability of concrete incorporating ground palm oil fuel ash. Cem Concr Compos 2010;32:767–74.
[64] Tangchirapat W, Saeting T, Jaturapitakkul C, Kiattikomol K, Siripanichgorn A. Use of waste ash from palm oil industry in concrete. Waste Manag 2007;27:81–8.
[65] Kanadasan J, Razak HA, Subramaniam V. Properties of high flowable mortar containing high volume palm oil clinker (POC) fine for eco-friendly construction. J Clean Prod 2018;170:1244–59.
[66] Astm C. 642, Standard test method for density, absorption, and voids in hardened concrete. Annual book of ASTM standards 2006;4:02.
[67] Simpson TW, Poplinski J, Koch PN, Allen JK. Metamodels for computer-based engineering design: survey and recommendations. Eng Comput 2001;17:129–50.
[68] Aslam M, Shafigh P, Alizadeh Nomeli M, Zamin Jumaat M. "Manufacturing of high-strength lightweight aggregate concrete using blended coarse lightweight aggregates,". J Build Eng 2017/09/01/ 2017.;13:53–62.
[69] Rashid MA, Salam MA, Shill SK, Hasan MK. Effect of replacing natural coarse aggregate by brick aggregate on the properties of concrete. Dhaka Univ Eng Technol J 2012;1:17–22.
[70] J. L, Clarke, *Structural lightweight aggregate concrete*: CRC Press, 1993.
[71] Muthusamy K, Mirza J, Zamri NA, Hussin MW, Majeed APA, Kusbiantoro A, et al. Properties of high strength palm oil clinker lightweight concrete containing palm oil fuel ash in tropical climate. Constr Build Mater 2019;199:163–77.
[72] Alengaram UJ, Mahmud H, Jumaat MZ. Enhancement and prediction of modulus of elasticity of palm kernel shell concrete. Mater Des 2011;32:2143–8.
[73] Aslam M, Shafigh P, Nomeli MA, Jumaat MZ. Manufacturing of high-strength lightweight aggregate concrete using blended coarse lightweight aggregates. J build eng 2017;13:53–62.
[74] H, Ahmad, M, Hilton, S, Mohd, N, Mohd Noor, "Mechanical properties of palm oil clinker concrete," 2007.
[75] Palla R, Karade S, Mishra G, Sharma U, Singh L. High strength sustainable concrete using silica nanoparticles. Constr Build Mater 2017;138:285–95.
[76] Ahmmad R, Alengaram UJ, Jumaat MZ, Sulong NHR, Yusuf MO, Rehman MA. Feasibility study on the use of high volume palm oil clinker waste in environmental friendly lightweight concrete. Constr Build Mater 2017/03/15/ 2017.;135:94–103.
[77] Alnahhal MF, Alengaram UJ, Jumaat MZ, Abutaha F, Alqedra MA, Nayaka RR. Assessment on engineering properties and CO2 emissions of recycled aggregate concrete incorporating waste products as supplements to Portland cement. J Clean Prod 2018;203:822–35.
[78] Lo TY, Cui HZ, Tang WC, Leung WM. The effect of aggregate absorption on pore area at interfacial zone of lightweight concrete. Constr Build Mater 2008/04/01/ 2008.;22:623–8.
[79] A. M, Neville, "Properties of Concrete, 4th," *London: Pitman Publishing*, vol. 687, p. 331, 2011.
[80] S. H, Kosmatka, W. C, Panarese, B, Kerkhoff, *Design and control of concrete mixtures* vol. 5420: Portland Cement Association Skokie, IL, 2002.
[81] Razak HA, Chai H, Wong H. Near surface characteristics of concrete containing supplementary cementing materials. Cem Concr Compos 2004;26:883–9.
[82] Aslam M, Shafigh P, Jumaat MZ. Oil-palm by-products as lightweight aggregate in concrete mixture: a review. J Clean Prod 2016;126:56–73.
[83] Mohammed BS, Foo W, Abdullahi M. Flexural strength of palm oil clinker concrete beams. Mater Des 2014;53:325–31.
[84] Abutaha F, Razak HA, Ibrahim HA, Ghayeb HH. Adopting particle-packing method to develop high strength palm oil clinker concrete. Resour Conserv Recycl 2018;131:247–58.
[85] Montgomery DC. Design and analysis of experiments. John wiley & sons; 2017.
[86] Ghafari S, Aziz HA, Isa MH, Zinatizadeh AA. Application of response surface methodology (RSM) to optimize coagulation–flocculation treatment of leachate using poly-aluminum chloride (PAC) and alum. J Hazard Mater 2009;163:650–6.
[87] Bashir MJ, Aziz HA, Yusoff MS, Adlan MN. Application of response surface methodology (RSM) for optimization of ammoniacal nitrogen removal from semi-aerobic landfill leachate using ion exchange resin. Desalination 2010;254:154–61.
[88] R. H, Myers, D. C, Montgomery, C. M, Anderson-Cook, *Response surface methodology: process and product optimization using designed experiments*: John Wiley & Sons, 2016.