Journal of Ceramic Processing Research. Vol. 21, No. 6, pp. 667~682 (2020)
(Received 8 July 2020, Received in revised form 30 August 2020, Accepted 4 September 2020)
https://doi.org/10.36410/jcpr.2020.21.6.667

J O U R N A L O F
Ceramic Processing Research

Optimization of rice husk ash (RHA) as partial replacement of cementing material in structural ceramic composite concrete using response surface methodology (RSM) statistical experimental design

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Rapid development in the concrete industry leads to a higher demand for cement consumption worldwide. Due to this, the production of cement has become very crucial, resulting in a high carbon footprint and pollution along the process. Therefore, the utilization of agricultural by-products as cement replacement will help to reduce pollution caused by conventional cement production and therefore reduce the unsystematic waste management. Rice husk ash contains high silica content that makes it a potential material to partially replace cement in concrete production. This is because, the reaction between rice husk ash and cement can improve the compressive strength of the concrete. With the aid of response surface methodology, the optimization of utilizing rice husk ash as a partial replacement of cement in concrete can be achieved. Therefore, concrete incorporated with rice husk ash with high and optimum compressive strength can be produced.

Keywords: rice husk ash (RHA), Concrete, Cement.

Introduction

The growth of cement production around the world is expected to keep increasing with the infrastructure development due to increment of population. The progress of this production making researchers to find alternative material as a replacement of cement due to high possibly of shortcoming natural resource. Moreover, the cement production caused the emission of CO_2 and high energy used which results in negative effect in environment [1]. The replacement of cement from waste material is vital in order to increase the sustainability in green construction [2]. For example, the utilization of waste materials such as fly ash [3-5], recycled copper slag [6], sugarcane bagasse ash [7, 8], and corncob ash [9] have been reported. These wastes are considered as alternative for cement because they possess pozzolanic properties [10].

Besides that, there are numerous reports that suggest the utilization of rice husk ash (RHA) as a partial replacement in body formulation of concrete production [11-13]. The source of RHA is abundant and highly generated annually because 90% of rice plantation are produced and consumed in Asian Region [14, 15]. Hence, RHA is the best option as supplementary cementitious material (SCM) due to widely available resource. In addition, the utilization of rice husk ash as a pozzolanic material in cement and concrete provides several advantages, such as improved strength and durability properties, reduced materials cost due to cement savings and environmental benefits related to the disposal of waste materials and to reduced carbon di oxide emissions [16]. In the other work, Zareei et al. (2017) have reported that concrete with high compressive strength compared to standard concrete could be produced by substituting 10% of cement with RHA [17]. The pozzolanic properties of RHA which caused a reaction between SiO_2 and $Ca(OH)_2$ during cement hydration process and thus enhanced the properties of RHA-mixed cement [18]. The other factors that enhanced the RHA-mixed cement properties can be associated to the formation rate of calcium silicate hydroxide (C-S-H) from the reaction between Ordinary Portland Cement (OPC) and water [19]. The positive utilization effect of RHA will be able to reduce the problem arise by the abundant of RHA generated [20].

Although the replacement of RHA into cement

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production can increases the performance of cement but a further increment of RHA would reduce the compressive strength of concrete due slight cementitious properties of RHA than conventional cement [17]. In a work reported by Hwang et al. (2011) where they observed a decrement performance of concrete when the addition of RHA beyond 20% [12]. Hence, the optimum percentage of RHA need to be determined because it will influence the performance of cement-mixed with RHA.

Most of the utilization of RHA in cement production are reported without the use of response surface methodology (RSM). Aydar et al. (2018) mentioned that RSM is helpful for creating, improving, and enhancing the reaction variable [21]. In addition, RSM can be used to optimize one or more responses for examples maximize strength and also to minimize cost [22].

In this work, the compressive strength of a concrete affected by RHA replacement (10, 20 and 30 wt%) and curing time (3, 5 and 7 days) is reported. The statistical analysis including model adequacy checking, analysis of variance (ANOVA), main effect and interaction plots as well as the regression analysis were performed for each response. The aim of this work is to obtain a correct body formulation of concrete incorporated with RHA with the aid of statistical design.

Methodology

Material

Ordinary Portland Cement (OPC) was produced by one of the local cement manufacturers in Malaysia. Sand aggregate is used as a structural filler for the concrete. Black and Grey RHAs were obtained from BERNAS Paddy Processing Centre, Penang, Malaysia.

Method

The concrete was formulated based on M-20 concrete, which composed of cement, sand, and aggregate with a ratio of 1:1.5:3 [23]. For this study, the cement ratio consisted of a combination of cement and RHA (10 wt.%, 20 wt.%, and 30 wt.%). Two types of RHA (black RHA and grey RHA) were used throughout the study. The raw materials (RHA and OPC) were also characterized in terms of chemical composition (XRF) and mineralogical property (XRD).

Firstly, raw materials are mixed in a dry condition for 2 minutes, then water was added and mixed for another 3 minutes using Heidolph mixer at constant mixing speed. The fresh concrete was then poured into the plastic mold with a dimension of 10 cm × 10 cm × 5 cm. The concrete was de-molded after 24 hours and cured in a tank of water. The concrete samples were tested at the concrete age of 3, 5 and 7 days after curing.

The final cured concrete is then characterized in terms of compressive test, porosity test, water absorption test, and also surface and phase analysis. Compressive test (ASTM C109), effective porosity, and water absorption (ASTM C642-97) tests were performed to determine the mechanical properties of the concrete samples.

Results and Discussion

Chemical Composition of Raw Materials

Table 1 listed the composition of raw materials that were determined by XRF. Black RHA shows a high concentration of silicon dioxide, which is 92.4%, and grey RHA is 91.0%. Cement has a high concentration in calcium oxides, which is 76.7%. The usage of RHA as a partial replacement for cement is important because it has a high content of silicon dioxide (SiO_2) that will react with calcium oxides from the cement to enhance the strength of concrete by the formation of calcium silicate hydrate (C-S-H) gel.

Mineralogical Analysis

Fig. 1(a) shows the XRD pattern of black RHA. The crystallinity of black RHA is 53.9% showing that black RHA being incinerated at a temperature below 700 °C. The color of black RHA was formed due to incomplete combustion of rice husk [24].

On the contrary, Fig. 1(b) reveals the XRD pattern for Grey RHA that forms an amorphous region where its crystallinity is 44.7% that indicates Grey RHA being incinerated above 700 °C. As the temperature of incineration increase above 700 °C, the mineralogy of silica in RHA started to change to crystalline [25]. The purity of silica is highly affected by chemical treatment compared to thermal treatment. The grey color of RHA was formed due to the strong interaction between potassium and silica ion that causes the formation of potassium silicate combined with carbon. Therefore, the grey color of RHA was formed during incineration [26].

Table 1. Composition of oxides in raw materials.

Compound	Materials		
	Black RHA	Grey RHA	Cement
Al_2O_3	0.539	0.217	2.57
Cl	-	0.111	-
CaO	0.595	0.7	76.7
Fe_2O_3	-	0.165	2.01
K_2O	5.7	6.69	1.93
MgO	0.262	-	1.17
MnO	0.118	0.138	0.24
P_2O_5	0.266	0.749	-
SiO_2	92.4	91.0	13.7
SO_3	-	0.175	1.41
TiO_2	-	-	0.128

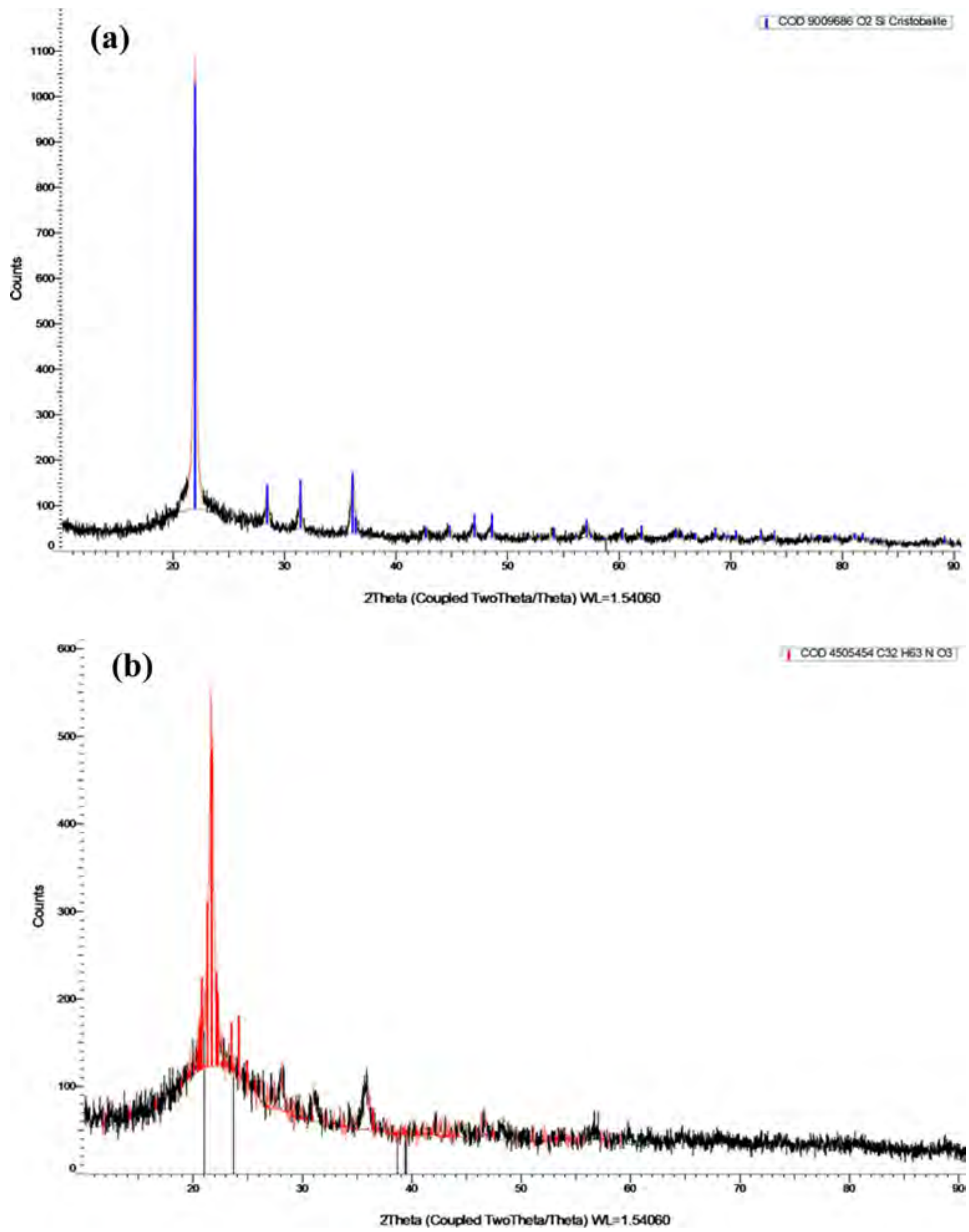

Fig. 1. XRD Pattern of (a) Black RHA and (b) Grey RHA.

Central Composite Design

Central Composite Design is an experimental design, useful in response surface methodology for building a second-order (quadratic) model for the response variable. Table 2 and Table 3 show the experimental design matrix and response for black and grey RHA, which sum up to a total of 26 experimental runs in random order with 2 replications, using MINITAB 16. After that, coding was used to denote the level or range of each evaluated factor on scale '-1' for 10% and 3 days, '0' for 20% and 5 days, and '+1' for 30 % and 7 days. Subsequently, statistical analysis, including model adequacy checking, analysis of variance (ANOVA), main effect and interaction plots and regression analysis were performed for each response.

Model Adequacy Checking

Khan et al. (2017) have reported that the assumption of residuals by statistical analysis can be proven by model adequacy check [22]. In general, statistical subject residuals can be described as the difference between actual and prediction value. In this study, the actual response values were obtained from Table 2 and Table 3.

Fig. 2(a)-(d) shows the residual plots for compressive strength, water absorption, apparent density, and bulk density of concrete that incorporated with black RHA. By analyzing all the normal probability plot from graph present from black RHA, it was observed the residual plots shows two types of pattern which is light tail distribution for compressive, water absorption and

Table 2. Experimental design matrix of central composite design for BRHA.

Run order	Factors		Responses			
	Wt.% of Black RHA (BRHA)	Curing Time (days)	Compressive Strength (MPa)	Water Absorption (%)	Apparent Density (g/cm^3)	Bulk Density (g/cm^3)
1.	20(0)	5(0)	4.20	11	2.22	1.83
2.	30(+1)	7(+1)	3.20	9	1.80	1.49
3.	20(0)	5(0)	4.10	10	1.86	1.49
4.	20(0)	5(0)	4.30	9	1.40	1.22
5.	20(0)	5(0)	3.80	11	1.55	1.30
6.	20(0)	7(+1)	11.86	11	1.71	1.40
7.	30(+1)	5(0)	2.80	14	1.57	1.29
8.	20(0)	5(0)	5.40	11	1.74	1.44
9.	20(0)	5(0)	5.60	8	1.74	1.52
10.	10(-1)	7(+1)	9.50	9	1.37	1.20
11.	10(-1)	5(0)	6.50	4	1.84	1.60
12.	10(-1)	7(+1)	7.60	9	1.48	1.30
13.	30(+1)	3(-1)	2.50	12	1.76	1.43
14.	20(0)	5(0)	5.10	12	1.66	1.35
15.	20(0)	5(0)	5.20	24	3.30	1.83
16.	20(0)	3(-1)	5.00	10	1.84	1.55
17.	10(-1)	5(0)	6.60	4	1.55	1.44
18.	20(0)	5(0)	5.50	11	2.05	1.65
19.	30(+1)	3(-1)	2.20	17	1.86	1.40
20.	20(0)	5(0)	5.70	9	2.14	1.77
21.	20(0)	3(-1)	4.70	11	1.85	1.50
22.	30(+1)	7(+1)	3.20	12	1.91	1.50
23.	20(0)	7(+1)	10.67	13	1.96	1.55
24.	10(-1)	3(-1)	8.90	11	1.70	1.41
25.	30(+1)	5(0)	3.00	12	1.78	1.49
26.	10(-1)	3(-1)	9.30	11	1.79	1.47

Factor I: Wt.% of BRHA; ‘(-1)’ represents 10 wt.%, ‘(0)’ represents 20 wt.%, ‘(+1)’ represents 30 wt.%
Factor II: Curing Time; ‘(-1)’ represents 3 days, ‘(0)’ represents 5 days, ‘(+1)’ represents 7 days

Table 3. Experimental design matrix of central composite design for GRHA.

Run order	Factor		Response			
	Wt.% of Grey RHA (GRHA)	Curing Time (days)	Compressive Strength (MPa)	Water Absorption (%)	Apparent Density (g/cm^3)	Bulk Density (g/cm^3)
1.	20(0)	5(0)	13.23	10	1.63	1.35
2.	30(+1)	7(+1)	10.00	7	1.46	1.26
3.	20(0)	5(0)	15.70	12	1.49	1.22
4.	20(0)	5(0)	15.00	11	1.42	1.22
5.	20(0)	5(0)	14.40	9	2.50	1.64
6.	20(0)	7(+1)	18.40	9	1.75	1.47
7.	30(+1)	5(0)	8.33	11	1.60	1.31
8.	20(0)	5(0)	16.50	11	1.97	1.61
9.	20(0)	5(0)	15.60	8	2.35	1.81
10.	10(-1)	7(+1)	12.20	7	1.97	1.68
11.	10(-1)	5(0)	10.70	3	1.94	1.74
12.	10(-1)	7(+1)	12.00	10	1.47	1.28
13.	30(+1)	3(-1)	7.24	9	1.76	1.48
14.	20(0)	5(0)	15.30	1	1.80	1.49
15.	20(0)	5(0)	16.50	1	2.00	1.60
16.	20(0)	3(-1)	14.70	8	1.97	1.60
17.	10(-1)	5(0)	11.50	5	1.76	1.54
18.	20(0)	5(0)	13.93	10	1.81	1.49
19.	30(+1)	3(-1)	5.60	15	4.30	1.32
20.	20(0)	5(0)	16.50	7	1.97	1.61
21.	20(0)	3(-1)	14.00	12	1.95	1.50
22.	30(+1)	7(+1)	11.10	10	1.94	1.53
23.	20(0)	7(+1)	17.80	9	1.68	1.42
24.	10(-1)	3(-1)	9.40	8	1.68	1.44
25.	30(+1)	5(0)	8.58	11	2.27	1.49
26.	10(-1)	3(-1)	9.08	8	1.59	1.47

Factor I: Wt.% of GRHA; ‘(-1)’ represents 10 wt.%, ‘(0)’ represents 20 wt.%, ‘(+1)’ represents 30 wt.%
Factor II: Curing Time; ‘(-1)’ represents 3 days, ‘(0)’ represents 5 days, ‘(+1)’ represents 7 days

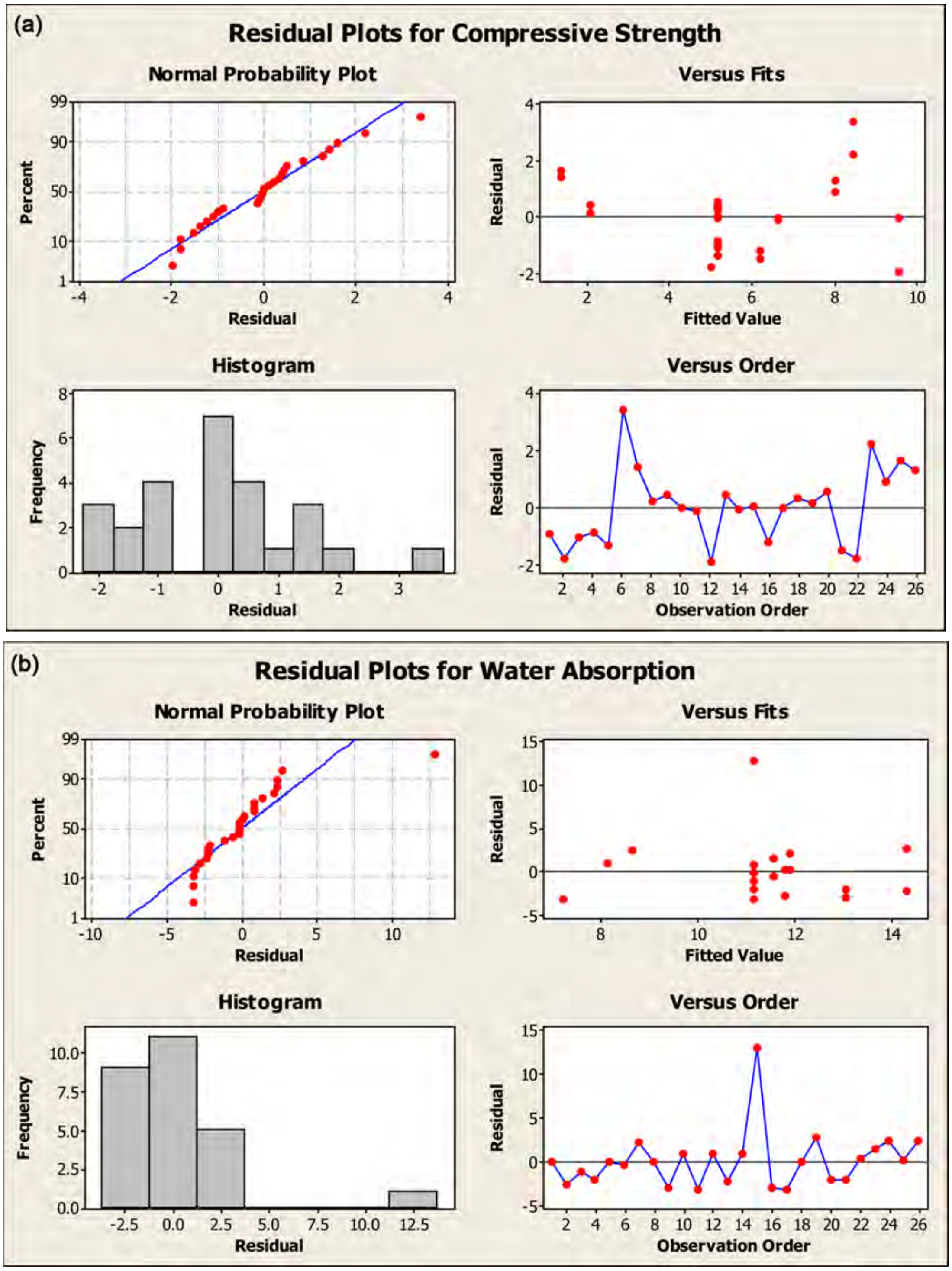

Fig. 2. (a) Residual plots for compressive strength of black RHA; (i) Normal probability plot, (ii) Histogram of frequency versus residual, (iii) Residual versus fits, (iv) Residual versus observation order of data. (b) Residual plots for water absorption black RHA; (i) Normal probability plot, (ii) Histogram of frequency versus residual, (iii) Residual versus fits, (iv) Residual versus observation order of data. (c) Residual plots for apparent density black RHA; (i) Normal probability plot, (ii) Histogram of frequency versus residual, (iii) Residual versus fits, (iv) Residual versus observation order of data. (d) Residual plots for bulk density black RHA; (i) Normal probability plot, (ii) Histogram of frequency versus residual, (iii) Residual versus fits, (iv) Residual versus observation order of data.

apparent density that indicate this side of the distribution produces outliers at a reduced rate from what expect with a normal distribution, a light tail often means that all the observations are piled up near a boundary for the distribution [27]. This pointed out that compressive strength, water absorption, apparent density, and bulk density fulfilled the first criteria of model adequacy checking and were normally distributed [28].

Meanwhile, Fig. 3(a)-(d) show residual plots for compressive strength, water absorption, apparent density,

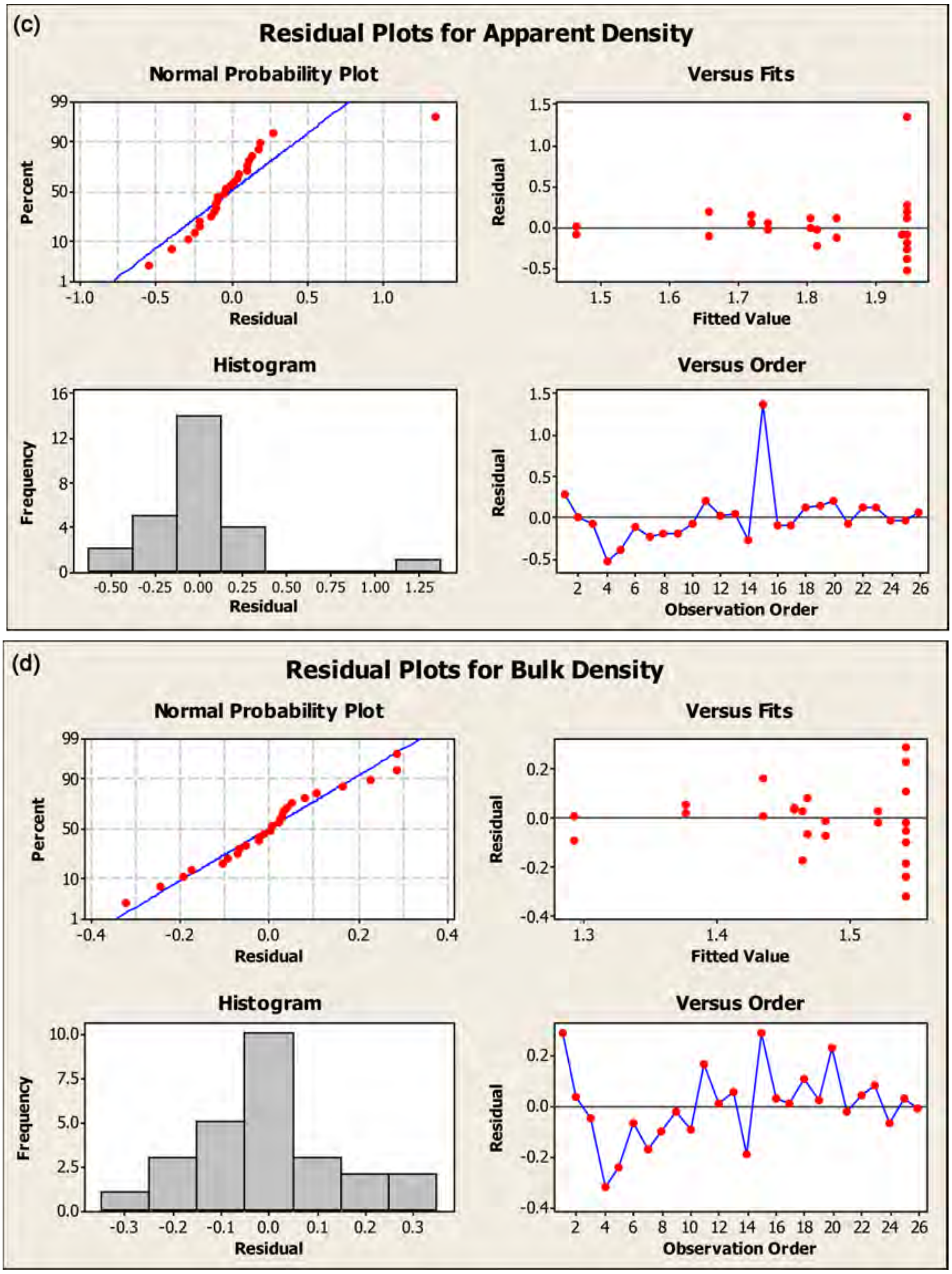

Fig. 2. Continued.

and bulk density of concrete containing grey RHA. The normal probability plots of grey RHA were scattered along the straight line indicating normal distribution of the evaluated properties. Thus, the first criteria of model adequacy checking were fulfilled. Next, all the histogram plots show bell-shaped patterns which indicates that all of the data were normally distributed, and this further supports the normal distribution data of compressive strength, water absorption, apparent density, and bulk density.

After that, residuals versus fitted value plots illustrated that the data points for compressive strength, water absorption, apparent density, and bulk density that use black and grey RHA are distributed randomly, ensuring that constant variance criteria of residuals [29]. The residual versus observation order plots indicate that

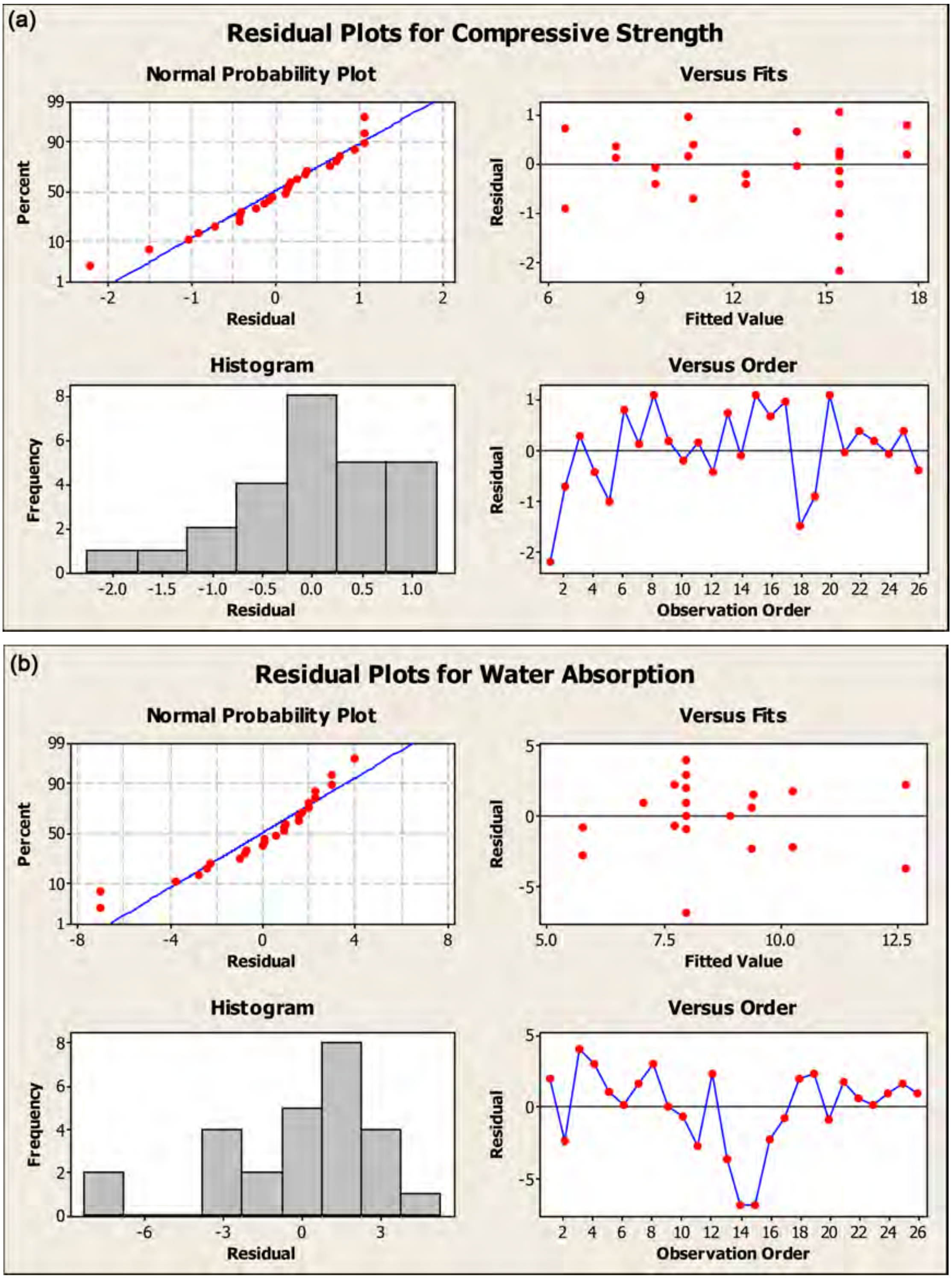

Fig. 3. (a) Residual plots for compressive strength grey RHA; (i) Normal probability plot, (ii) Histogram of frequency versus residual, (iii) Residual versus fits, (iv) Residual versus observation order of data. (b) Residual plots for water absorption grey RHA; (i) Normal probability plot, (ii) Histogram of frequency versus residual, (iii) Residual versus fits, (iv) Residual versus observation order of data. (c) Residual plots for apparent density grey RHA; (i) Normal probability plot, (ii) Histogram of frequency versus residual, (iii) Residual versus fits, (iv) Residual versus observation order of data. (d) Residual plots for bulk density grey RHA; (i) Normal probability plot, (ii) Histogram of frequency versus residual, (iii) Residual versus fits, (iv) Residual versus observation order of data.

residual points are completely random despite observation order. This implies that residual was independent with each other obeying the third assumption.

Analysis of Variance

Analysis of Variance or commonly known as ANOVA is a test of the hypothesis that the means of two or more populations are equal [30]. It is conducted

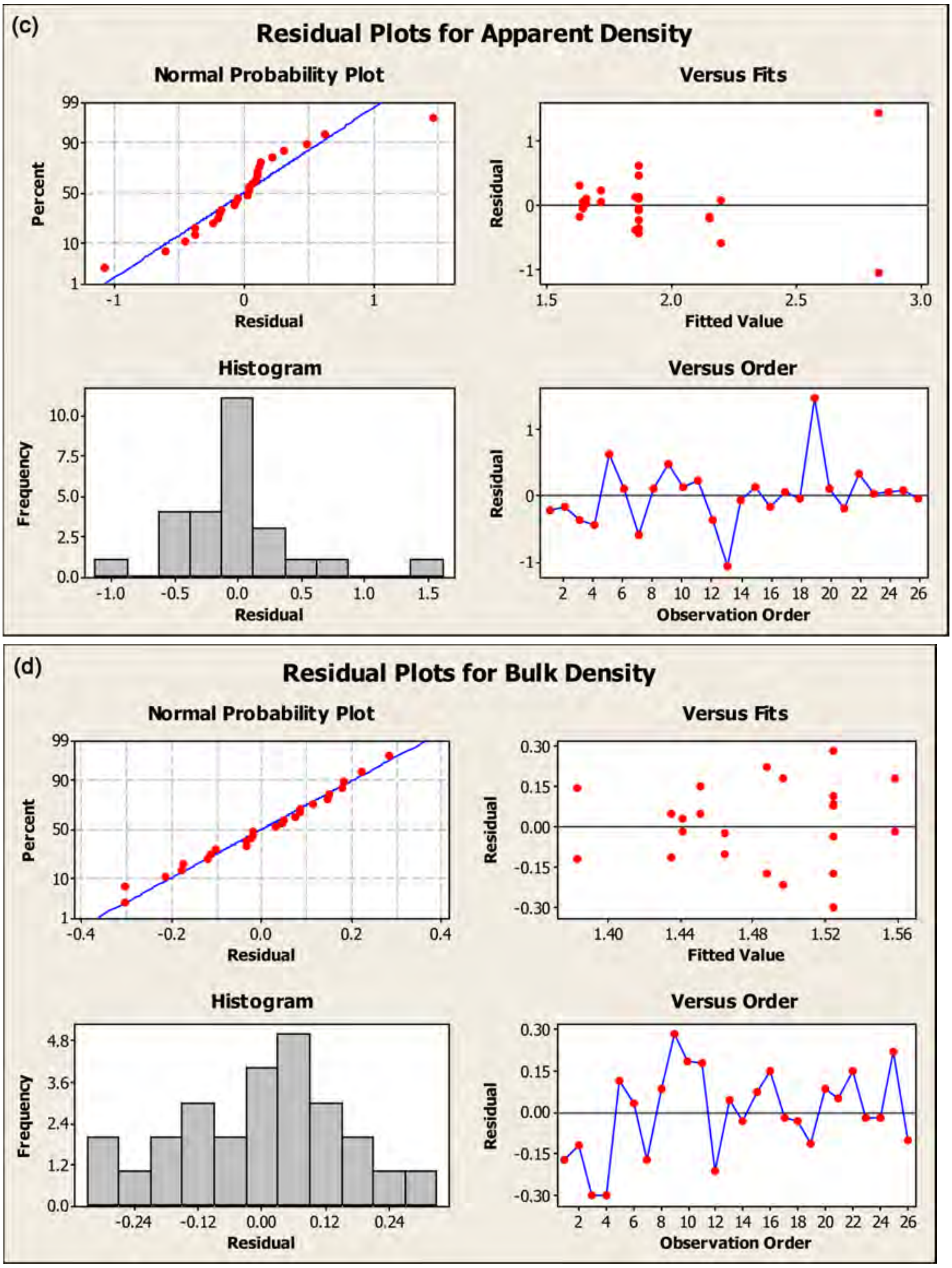

Fig. 3. Continued.

in order to observe the significant effect of operating factors on responses of a particular developed product. In this study, the significant effect of weight percentage of black and grey rice husk as and curing time to the responses such as compressive strength, water absorption, apparent density, and bulk density could be determined by observing the probability value or known as 'p-value'. Most of the researcher has agreed that the p-value has to be equal or smaller than 0.05 so that operating factor is statically significant in investigating response leading to rejection of the null hypothesis of ANOVA.

Table 4(a)-(d) present ANOVA for compressive strength, water absorption, apparent density, and bulk

Table 4(a). ANOVA for compressive strength of concrete incorporated with BRHA.

Sources	DF	Seq. SS	Adj. SS	Adj.MS	F-value	P-value
wt.% RHA	1	82.687	82.687	82.687	38.17	0.000
Curing Time	1	15.030	15.030	15.030	6.94	0.016
wt.% RHA*Curing Time	1	0.980	0.980	0.980	0.45	0.509
Error	17	7.277	7.277	0.428		
Total	25	168.536				

Table 4(b). ANOVA for water absorption of concrete incorporated with BRHA.

Sources	DF	Seq. SS	Adj. SS	Adj.MS	F-value	P-value
wt.% RHA	1	65.333	65.333	65.333	5.01	0.037
Curing Time	1	6.750	6.750	6.750	0.52	0.480
wt.% RHA*Curing Time	1	2.000	2.000	2.000	0.15	0.699
Error	17	205.90	205.90	12.11		
Total	25	350.96				

Table 4(c). ANOVA for apparent density of concrete incorporated with BRHA.

Sources	DF	Seq. SS	Adj. SS	Adj.MS	F-value	P-value
wt.% RHA	1	0.07521	0.07521	0.07521	0.54	0.471
Curing Time	1	0.02708	0.02708	0.02708	0.19	0.664
wt.% RHA*Curing Time	1	0.06661	0.06661	0.06661	0.48	0.497
Error	17	2.6984	2.6984	0.1587		
Total	25	3.3120				

Table 4(d). ANOVA for bulk density of concrete incorporated with BRHA.

Sources	DF	Seq. SS	Adj. SS	Adj.MS	F-value	P-value
wt.% RHA	1	0.002700	0.002700	0.002700	0.10	0.754
Curing Time	1	0.008533	0.008533	0.008533	0.32	0.578
wt.% RHA*Curing Time	1	0.036450	0.036450	0.036450	1.37	0.256
Error	17	0.49480	0.49480	0.02911		
Total	25	0.67206				

density for black RHA. From the analysis, it was found that the p-value for wt.% of RHA replacement and curing time linear factor and also wt.% * curing time interaction factor is zero (0.000) for compressive strength response by black RHA. The smaller p-value than 0.05 indicates that factor could be regarded to have a higher effect on response [31]. However, the p-value for other response such as water absorption, apparent density, and bulk density are higher than 0.05, which mean it is not statistically significant and indicates weak evidence against the null hypothesis. For water absorption, Saraswathy and Song (2007) have mentioned in their study where concrete that uses RHA is slightly low compared to concrete that fully uses cement [32].

Meanwhile, Table 5(a)-(d) present ANOVA for compressive strength, water absorption, apparent density, and bulk density for grey RHA. It was found that the p-value for wt.% of RHA replacement and curing time linear factor is zero (0.000) for compressive strength response by grey RHA. This indicates that wt.% and curing time have a significant effect on compressive strength of concrete that incorporated with grey RHA as [31] have reported that if the p-value is 0.05 and lower. The p-value for water absorption is 0.056 for wt.% RHA and 0.049 for curing time, these p-values indicate also indicate that wt.% RHA and curing time have a significant effect toward water absorption of grey RHA.

However, the p-value for water absorption, apparent density, and bulk density of black RHA and apparent density and bulk density of grey RHA were not significant. This is because all of the p-values from the responses mentioned have exceeded the minimum limit of the p-value, which is 0.05. The insignificant of the p-value for all responses due to the factor which is wt.% RHA and curing time do not affect the responses in this study. This due to the factor that the replacement of cement by RHA only affecting the compressive strength of the concrete due to the reaction between SiO_2 in RHA and OPC, which produced the addition of C-S-H that responsible to the strengthening of the concrete. Hence, it can be concluded that addition of RHA in concrete does not affect the water absorption, bulk density, and apparent density as the role of RHA

Table 5(a). ANOVA for compressive strength of concrete incorporated with GRHA.

Sources	DF	Seq. SS	Adj. SS	Adj.MS	F-value	P-value
wt.% RHA	1	16.403	16.403	16.403	19.94	0.000
Curing Time	1	38.449	38.449	38.449	46.73	0.000
wt.% RHA*Curing Time	1	0.806	0.806	0.806	0.98	0.334
Error	17	14.417	14.417	0.848		
Total	25	297.604				

Table 5(b). ANOVA for water absorption of concrete incorporated with GRHA.

Sources	DF	Seq. SS	Adj. SS	Adj.MS	F-value	P-value
wt.% RHA	1	40.333	40.333	40.333	4.12	0.056
Curing Time	1	5.333	5.333	5.3333	0.54	0.049
wt.% RHA*Curing Time	1	8.000	8.000	8.0000	0.82	0.377
Error	17	179.00	179.00	10.5294		
Total	25	264.46				

Table 5(c). ANOVA for apparent density of concrete incorporated with GRHA.

Sources	DF	Seq. SS	Adj. SS	Adj.MS	F-value	P-value
wt.% RHA	1	0.71053	0.71053	0.71053	2.75	0.113
Curing Time	1	0.74003	0.74003	0.74003	2.86	0.106
wt.% RHA*Curing Time	1	1.00111	1.00111	1.00111	3.87	0.063
Error	17	4.7848	4.7848	0.2815		
Total	25	7.6920				

Table 5(d). ANOVA for bulk density of concrete incorporated with GRHA.

Sources	DF	Seq. SS	Adj. SS	Adj.MS	F-value	P-value
wt.% RHA	1	0.015408	0.015408	0.015408	0.50	0.488
Curing Time	1	0.000300	0.000300	0.000300	0.01	0.922
wt.% RHA*Curing Time	1	0.003613	0.003613	0.003613	0.12	0.736
Error	17	0.56794	0.56794	0.3341		
Total	25	0.67746				

in concrete only affecting the compressive strength of the concrete.

Main Effect and Interaction Plots

Main effect plot demonstrates the effect of factor (with different levels) to the changes in a particular response. In this general factorial design, the main factor that evaluated were weight percentage (wt.%) of black and grey RHA and curing time. Meanwhile, the interaction plot illustrated the combination of effects of both main factors (with different levels) to the particular response (compressive strength, water absorption, apparent density, and bulk density).

Compressive Strength

Fig. 4(a) and Fig. 4(b) show main effects plots for compressive strength for black and grey RHA. From the main effects plot, it was observed that by increasing weight percentage of black RHA from 10 wt.% (coded as '-1') to 30 wt.% (coded as '1') it shows the decreasing trend due to black RHA is incomplete combustion of rice husk and mostly has lower amorphous silica, higher loss of ignition (LOI) and lower SiO_2 content than grey RHA [24]. For curing time, it shows a decreasing trend from 3 days (coded as '-1') to 5 days (coded as '0').

However, the trend suddenly increases when curing time increase to 7 days (coded as '1'). Fig. 4(b) show the main effects of compressive strength for grey RHA. From the main effects plot, it was observed that increasing the weight percentage of grey RHA from 10 wt.% (coded as '-1') to 20 wt.% (coded as '0') show an increasing trend. However, further increasing to 30 wt.% (coded as '1') reduced the compressive strength of the concrete. Curing time for grey RHA show an increasing trend from 3 days (coded as '-1') to 5 days (coded as '0') and finally show a constant trend for 7 days (coded as '1').

Fig. 5(a) shows that the interaction plots for black RHA are not parallel, which means strong interaction among factor (weight percentage of grey RHA and curing time). It is observed that the lesser weight percentage of black RHA replacement resulting in the higher compressive strength of the concrete. At the same time, the interaction plot for grey RHA in Fig. 5(b) show that the lines were not parallel, which is

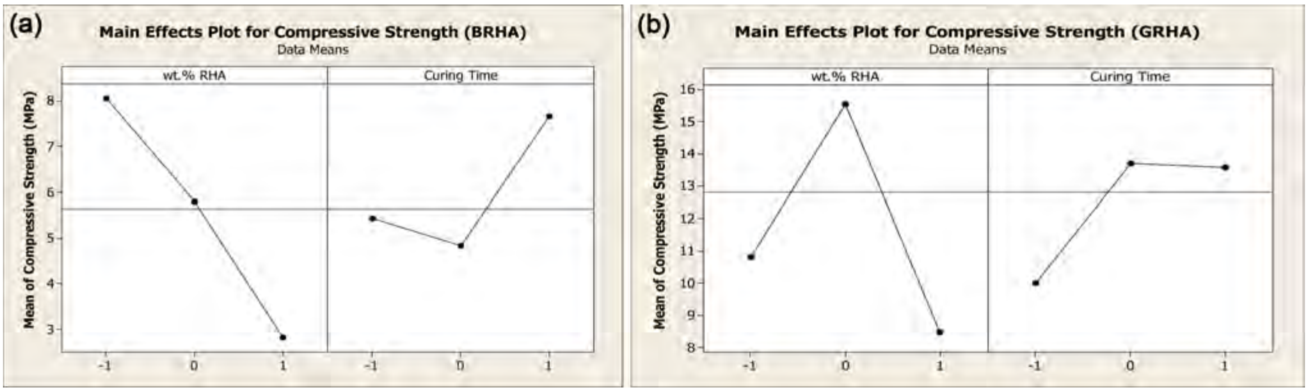

Fig. 4. (a) Main Effects Plots for Compressive Strength (BRHA). (b) Main Effects Plots for Compressive Strength (GRHA).

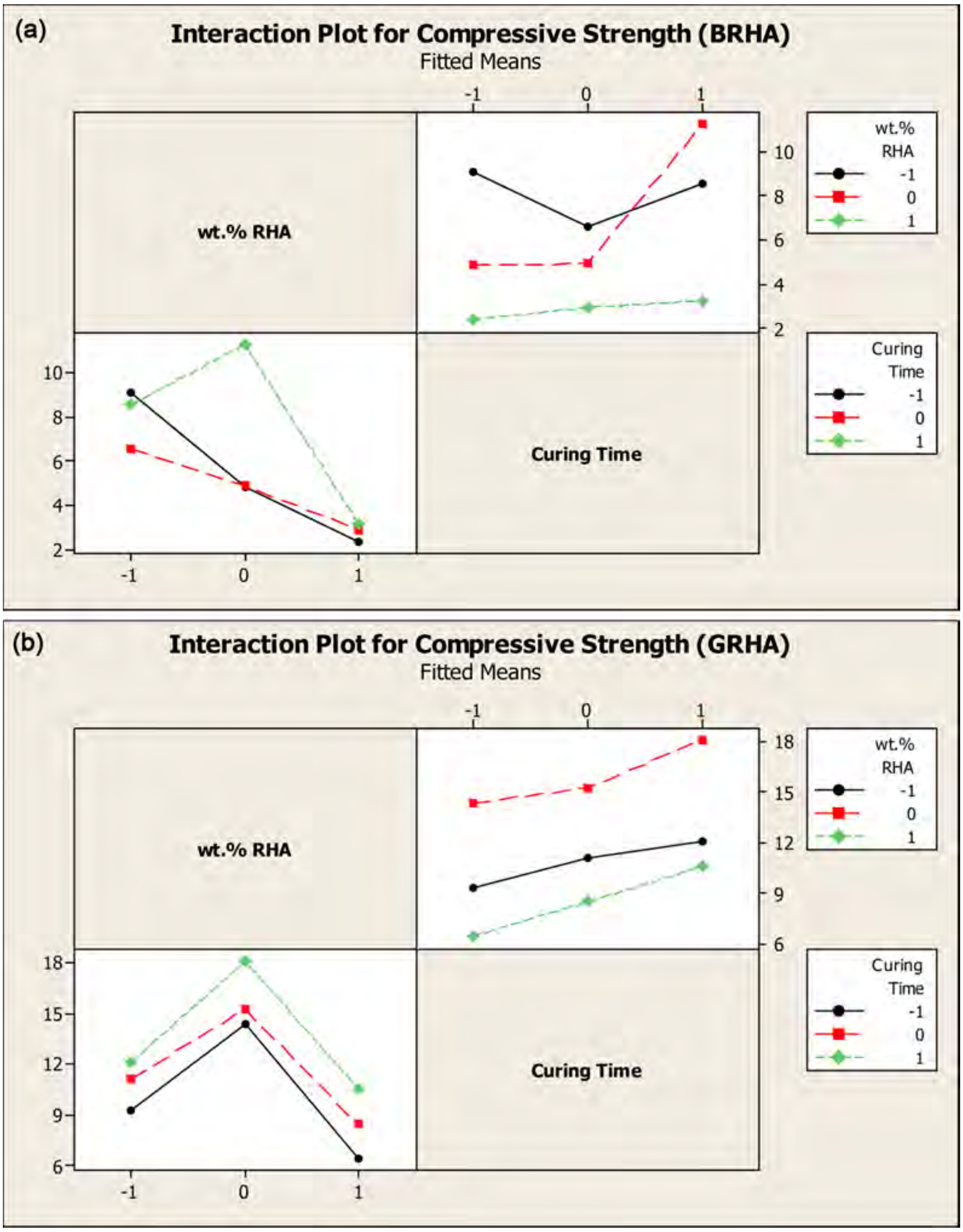

Fig. 5. (a) Interaction Plot for Compressive Strength (BRHA). (b) Interaction Plot for Compressive Strength (GRHA).

suggesting that there is a strong interaction among factor (weight percentage of grey RHA and curing time). Further analysis of the plot has revealed that for all weight percentage of RHA added, the compressive strength of the concrete increase with longer curing time. Concrete added 20 wt.% of grey RHA combine with 7 days of curing time show the highest compressive strength. The effect of curing time toward the concrete also shows that decreasing trend where the more prolonged the curing time, the lower the compressive strength of the concrete.

Water Absorption

Fig. 6(a), Fig. 6(b), show the main effect, while Fig. 7(a) and Fig. 7(b) interaction plot for water absorption for both black and grey RHA. By observing the main effect plot of water absorption, it is revealed that increasing the weight percentage of both types of RHA contributes to higher water absorption for the concrete. The main effect plots show a decreasing trend from 3 days (coded as '-1') to 7 days (coded as '1') for both black and grey RHA.

From the interaction plot of water absorption, the highest water absorption is concrete that incorporated with 30 wt.% of RHA, while 7 days of curing time show the highest result of water absorption for black RHA. However, the interaction plot of water absorption for grey RHA show an increasing pattern for curing days but a decreasing pattern for weight percentage. The highest water absorption is concrete incorporated with 30 wt.% of grey RHA due to the higher RHA replacement in cement the higher porous of the concrete

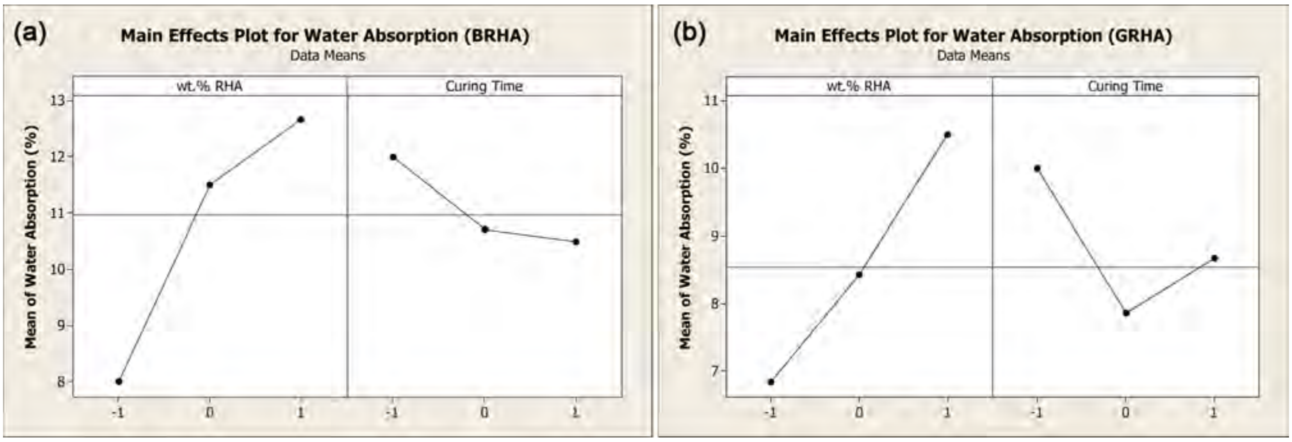

Fig. 6. (a) Main Effects Plots for Water Absorption (BRHA). (b) Main Effects Plots for Water Absorption (GRHA).

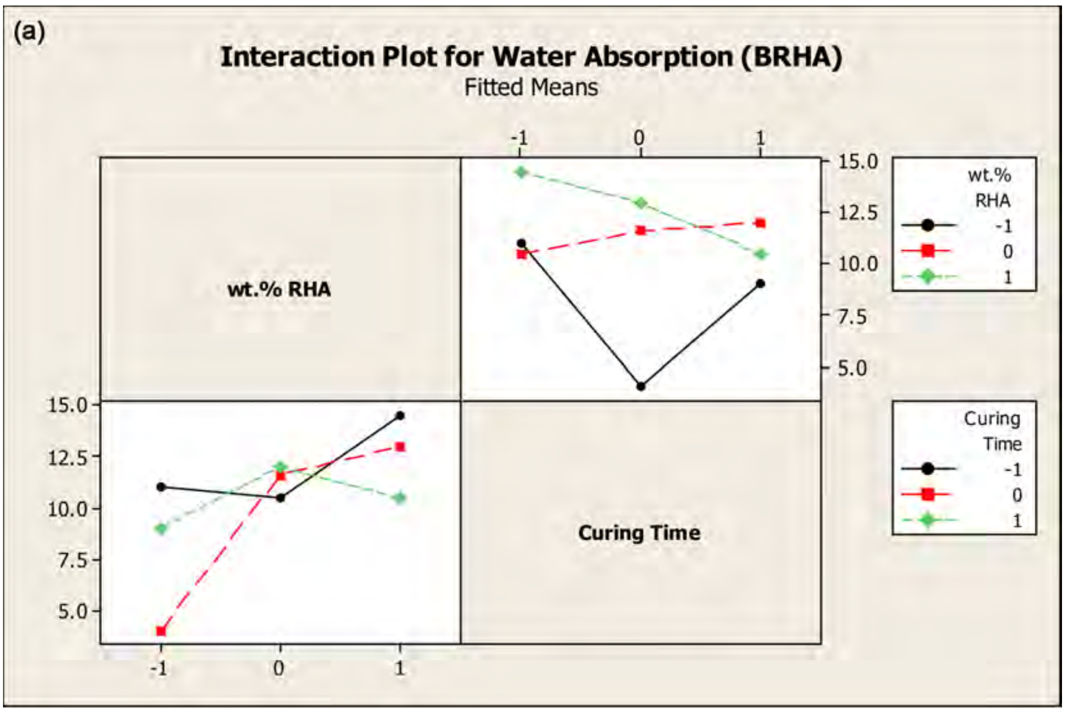

Fig. 7. (a) Interaction Plots for Water Absorption (BRHA). (b) Interaction Plots for Water Absorption (GRHA).

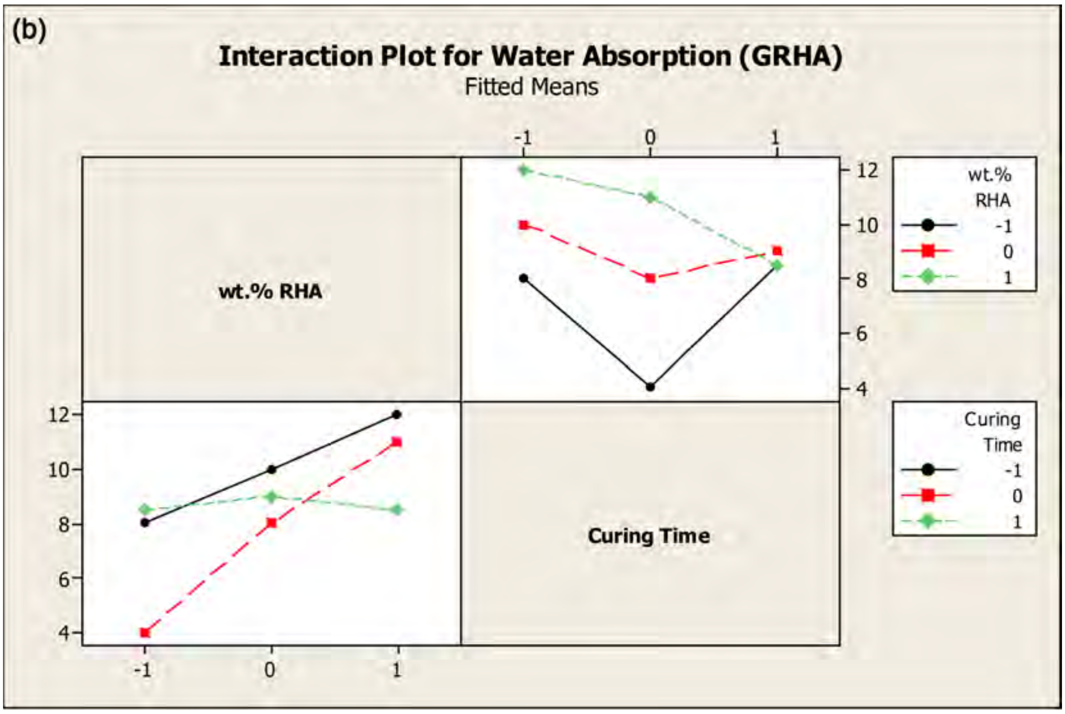

Fig. 7. Continued.

products, which lead to higher water absorption [33].

Apparent Density

Fig. 8(a) and Fig. 8(b) show the main effect plot for black and grey RHA while Fig. 9(a) and Fig. 9(b) show interaction plot for both types of RHA. From the observation of the main effect plot, black and grey RHA show an increasing trend, but for black RHA, it started to decrease when the weight percentage of RHA is 20 wt.% to 30 wt.%. The curing time shows a decreasing pattern for grey RHA as the day's increase form 3 days (code as '-1') to 7 days (coded as '1'). Conversely, black RHA shows an increasing trend from 3 days (coded as '-1') to 5 days (coded as 0). After that, the trend started to decrease to 7 days (coded as '1').

Fig. 9(a) and Fig. 9(b) show the interaction plot for black and grey RHA for apparent density. From the observation for black RHA, it shows 20 wt.% (coded as '0') and 5 days (coded as '0') show the highest reading. Meanwhile, from observation of grey RHA, the line is parallel to each other. This indicates that no interaction occurs among the response, whether weight percentage or curing time [34].

Bulk Density

Fig. 10(a) and Fig. 10(b) show the main effect plot for bulk density for black and grey RHA. From the observation, the main effect plot for black RHA show an increasing trend from 10 wt.% to 20 wt.% for

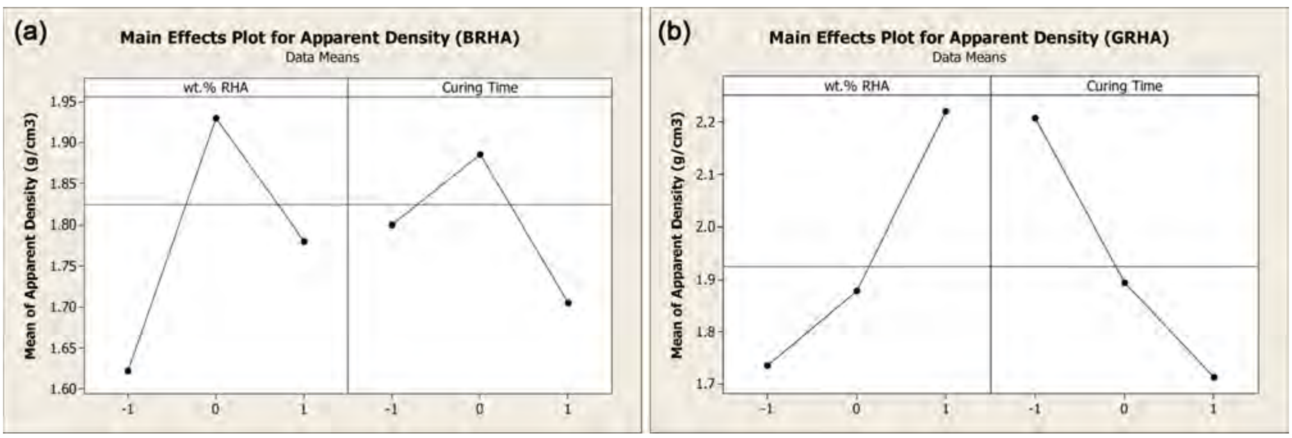

Fig. 8. (a) Main Effects Plots for Apparent Density (BRHA). (b) Main Effects Plots for Apparent Density (GRHA).

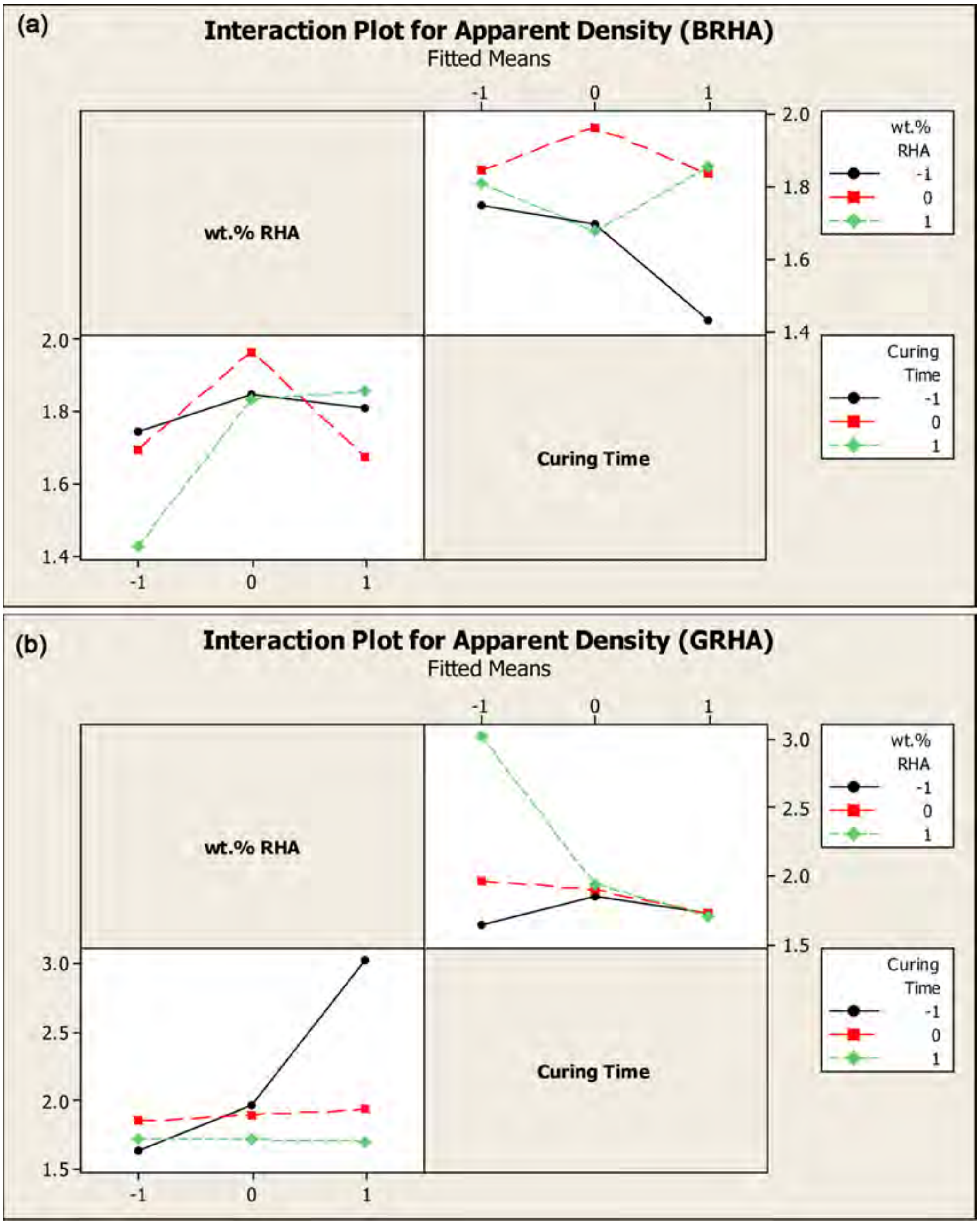

Fig. 9. (a) Interaction Plots for Apparent Density (BRHA). (b) Interaction Plots for Apparent Density (GRHA).

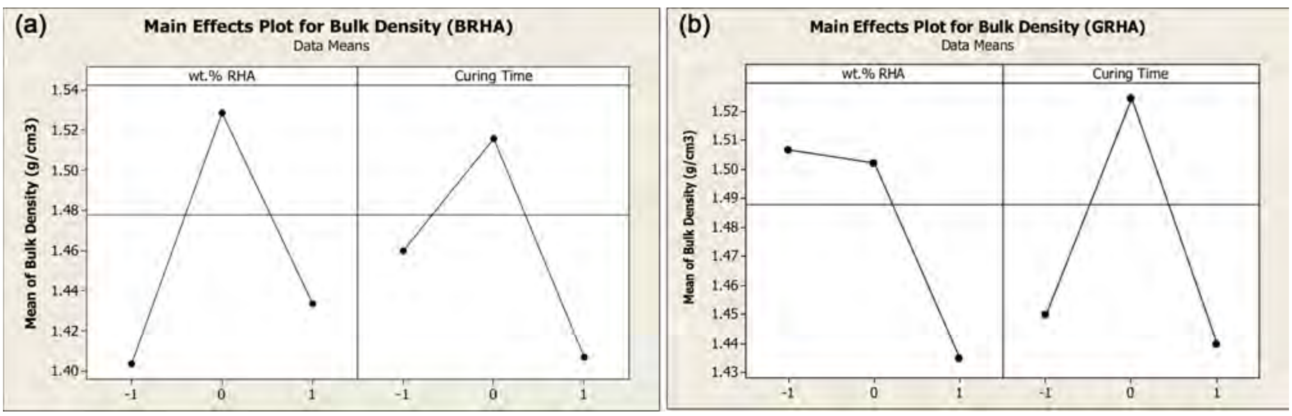

Fig. 10. (a) Main Effects Plot for Bulk Density (BRHA). (b) Main Effects Plot for Bulk Density (GRHA).

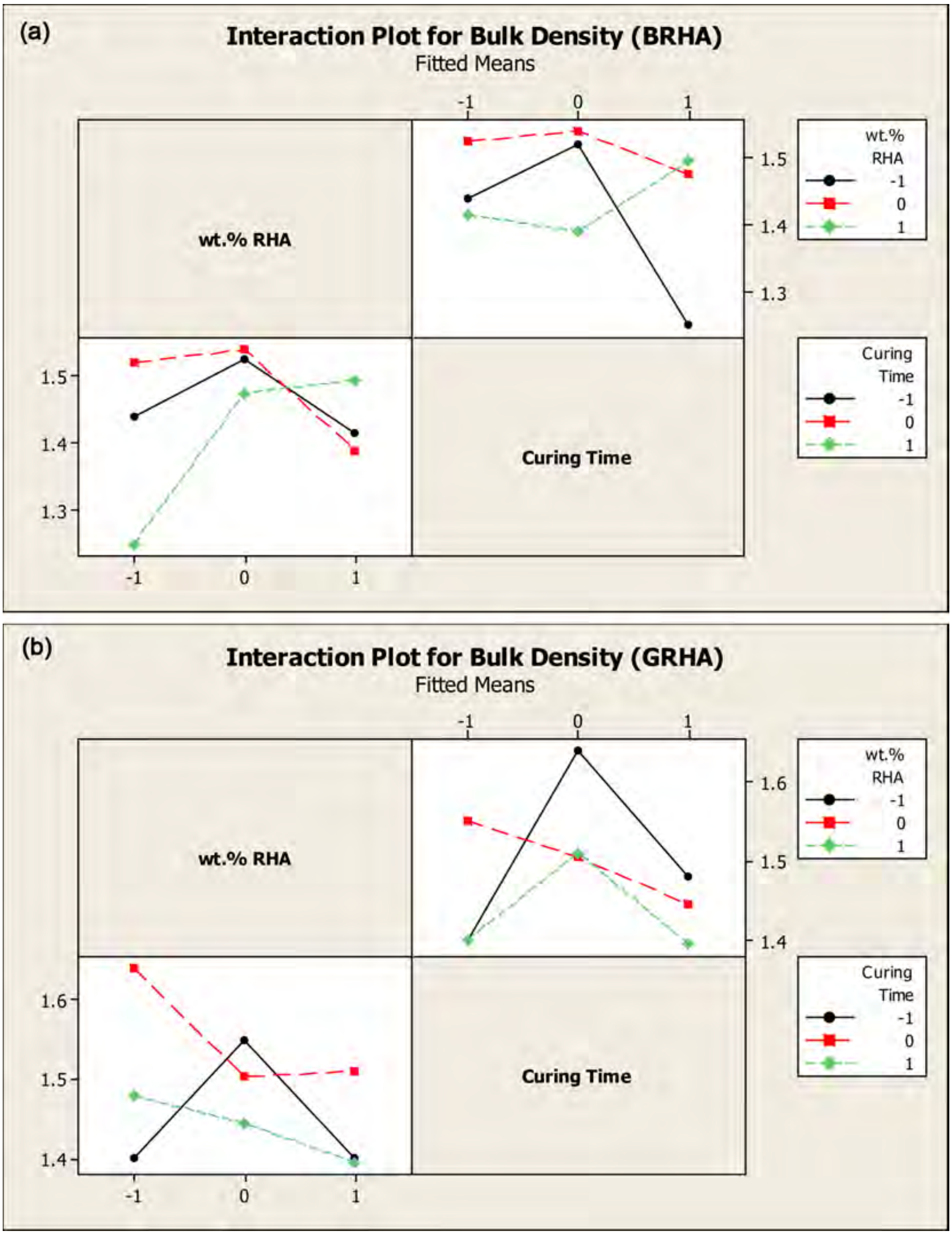

Fig. 11. (a) Interaction Plot for Bulk Density (BRHA). (b) Interaction Plot for Bulk Density (GRHA).

weight percentages and 3 days to 5 days for curing time. Then, it shows a decreasing trend to 30 wt.% and 7 days. From the results of grey RHA, the weight percentage of RHA show a decreasing pattern, while for curing time show both increase and decrease pattern. It starts to increase from 10 wt.% to 20 wt.% and decrease from 20 wt. % to 30. wt.%.

For the interaction plot in Fig. 11(a), 20 wt.% of RHA and 5 days of curing time show the highest reading. After that, Fig. 11(b) for grey RHA show that 10 wt.% and 5 days of curing time show the highest reading, among others variable response.

Conclusion

In this study, the utilization of RHA as a partial replacement of cementing material in concrete by using a statistical experimental design was successfully done. Based on the result obtained from compressive strength, water absorption, bulk density, apparent density also from XRD and XRF results, which show positive finding where it indicated that the suitability of RHA to partially replace cement in concrete. This results further supported by analysis through statistical experimental design that shows the p-value of all responses that indicated responses have a significant effect on the factor. From the data, the best RHA replacement for black RHA was the combination of 20 wt.% RHA and 7 days of curing time due to it have higher compressive strength, which is 11.86 and 10.67 MPa compared to another sample. A similar result also can be observed for grey RHA that shows the highest compressive strength of 17.80 and 18.4 MPa. According to Bahri et al. (2018), the difference between the compressive strength of grey and black RHA was affected by their crystallinity in which amorphous silica has a higher pozzolanic reaction compared to crystalline silica. Higher pozzolanic reaction means more C-S-H were produced during the reaction, which leads to higher compressive strength [24].

Acknowledgments

The authors would like to thank the Faculty of Bioengineering and Technology, University Malaysia Kelantan (UMK), for providing the research facilities in order to complete this project.

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