CONSTRUCTION
E-ISSN: 2785-8731
VOLUME 3, ISSUE 2, 2023, 196 – 206
DOI: https://doi.org/10.15282/construction.v3i2.9685

RESEARCH ARTICLE

Response Surface Methodology Approaches in Producing Amorphous Silica from Rice Straw Ash

A.N. Jamaluddin, S.A. Saad*, S.A. Masjuki, W.N.F. Wan Hassan, S.N. Che Deraman and N. Md Husain

Department of Civil Engineering, International Islamic University Malaysia, 53100 Selangor, Malaysia

ABSTRACT - A large amount of rice straw is produced as crop residue from rice production as an underutilization waste material. The open burning of rice straw can lead to environmental pollution by forming an abundant amount of rice straw ash (RSA) and exposing harmful gases to the atmosphere. Thus, RSA can be used as a cement replacement material due to its high amount of silica. Silica is a helpful additive to cement mix by accelerating the hydration process of cement because of its high reactivity and improving mortar performance. This study focuses amount of high silica of RSA in modified concrete through thermochemical pretreatment via response surface methodology (RSM). The factors involved in the pretreatment of RSA are 0.01M – 0.1M HCl hydrochloric acid, 1 – 3 hours soaking duration, and 60 - 80°C soaking temperature, and a response is the percentage of reactive compound content (SiO_2, Al_2O_3, and Fe_2O_3). Therefore, central composite design (CCD) in the RSM and the analysis of variance (ANOVA) have been used to evaluate the interaction between the factors and response, then simulated and further assess the accuracy of the model to achieve the accurate prediction. As a result, RSM observed that the optimum silica amount in the treated RSA (98.34%) was produced using parameters of 0.06 M HCl, 2 hours of soaking duration, and 70°C soaking temperature in the pretreatment process. After that, it is followed by a burning process at a controlled temperature and a grinding process to produce treated RSA. The prediction given by the RSM was not the sole result but was proved through X-Ray Fluorescence (XRF) analysis. The result of XRF analysis obtained for each model with the same value of each factor (HCl concentration = 0.06 M, soaking duration = 2 hours, and soaking temperature = 70°C) is more than 97.00% and falls between the prediction index range. Thus, the model is validated since the actual experimental result is within the expected range for any involved factor. Hence, the treated RSA was considered a high-quality pozzolanic material incorporated in the mortar production.

ARTICLE HISTORY
Received : 27th Aug. 2023
Revised : 14th Sept. 2023
Accepted : 20th Oct. 2023
Published : 21st Dec. 2023

KEYWORDS
Rice straw ash,
Pretreatment process,
Response Surface Methodology,
Central Composite Design,
Analysis of variance

1.0 INTRODUCTION

Rice is an important grain crop widely produced by all countries, with around 500 million tonnes of rice production annually [1]. Farmers can easily plant paddy crops because those land areas are suitable for rice cultivation. There are more than 75 countries that contribute to produce rice, while China manufactures the most amount of rice. Rice production is one of the major industries for Southeast Asia countries, and it is the activity that contributes to the rural economy and as a staple of food. [2] also emphasize paddy rice production in more than 50 countries over ten years, from 2004 until 2018. Asia was the highest area producing paddy rice while Oceania made the lowest. The development of the paddy field in Malaysia is more than 700,000 hectares, and then there will be around 2 million tonnes of rice straw in every cultivation season [3]. A large amount of rice straw is produced as crop residue from rice production [4].

In Malaysia, the rice straw is known as a residue by farmers. Traditionally, farmers diminish the straw after harvesting by burning the paddy field. The field must be free of straw for the replanting process of the paddy [3]. The open burning of rice straw is the fastest and cheapest way to remove it from the field. Basically, the open burning of rice straw at the paddy field is improper method that caused air pollution, contributed to global warming through the emissions of greenhouse gases, and produced left residues known as rice straw ash (RSA) [5]. [6] agreed that the combustion from the open burning of rice straw at the paddy field and pollutant gasses emitted from it cause pollution.

Furthermore, some farmers practice the natural decomposition method to dispose of rice straw. The natural decomposition method is another way to dispose of the rice straw without undergoing the burning process [6,7]. The natural composting method takes three to four weeks to decompose the rice straw before planting. Commonly, the waste is dumped in landfills. The waste dumped into the land must require a proper landfilling technique to avoid landfill problems. But, [8] mentioned that 90% of the collected wastes dumped at the landfill do not undergo treatment. The improper way of landfill method can cause soil and water contamination, and lead to environmental pollution. Additionally, increasing waste needs more landfill areas to dispose of it [9].

***CORRESPONDING AUTHOR | S.A. Saad** | ✉ asmahanisaad@iium.edu.my

Nowadays, agricultural waste and industrial waste are utilized as cement replacement materials (CRM) to improve the performance of construction materials, decrease the expense of the construction materials, and raise concern about the environment [10,11]. But, those industrial wastes are not easy to get at low prices. Alternatively, agricultural wastes are used in the cementing system to reduce global warming and decrease the number of waste materials [11]. Rice straw is one of the agricultural wastes and is easy to get in all parts of the world. The residues of RSA left after the open burning of rice straw at the paddy field can partially replace cement in mortar production.

Most past researchers used RSA as a partial replacement for cement between 2% to 30% [12–15]. [12] mentioned that the strength of 10% of RSA in cement mortar is higher than the control mixture with 100% cement. The presence of RSA helps to increase the specific surface area, reduce pore size, and improve the strength of specimens. [13] recorded that every percentage of RSA (2% - 8%) had good compressive strength compared to control specimens. [14] also analyzed that the 10% of RSA replaced improved about 6% of its strength compared to the OPC mortar throughout 56 days of curing age. However, [15] reported that the strength of 30% of RSA incorporated in mortar that undergoes air curing is higher than OPC mortar for seven days. Overall, they concluded that the performance of RSA incorporated in the concrete production is better compared to the performance of the control mixture.

For this research, the rice straw cannot be directly used to replace cement because it contains organic materials that can disturb the performance of cement mortar or cement concrete. The RSA must be high in silica to be used as a CRM [16]. As stated in ASTM C 618, the percentage of reactive compound content which are silicon dioxide (SiO_2), aluminium oxide (Al_2O_3), and iron (III) oxide (Fe_2O) of the waste must be more than 70% to be used as CRM [17]. Thus, the RSA undergoes a thermochemical pretreatment process to increase the silica content and decrease other impurities. Then, followed by the burning process at a controlled temperature and the grinding process. Most past researchers only focus on the burning process to produce amorphous silica of RSA [18–20].

For the pretreatment process, the design of the experiment (DOE) using the response surface methodology (RSM) to define the number of samples since each of the factors involved, namely, hydrochloric acid (HCl) concentration, soaking duration, and soaking temperature, have an extensive range. The DOE is an effective tool for defining sample numbers and minimizing time consumption [21]. In general, G. E. P. Box and K. B. Wilson developed RSM in 1951, defining the design of the sequence of the experiments to obtain the optimal response [22]. RSM collects the experimental data of the reaction of interest, constructing an RSM model and designing and optimizing the parameter to satisfy the desired response variables from analysis of variance (ANOVA) analysis. In experimental work, RSM defined finding the optimum response as the crucial step of the optimization process [23].

Several types of RSM can be used for the optimization process. However, two well-known methods are found, i.e., central composite design (CCD) and Box-Behnken design (BBD) [24]. Both ways are usually used in the final optimization of the experiment and can analyze the responses with the independent variables on different ranges, but each technique has various features. But, the predictability of CCD and BBD differ by instance. The result demonstrates that CCD outperforms the other designs in terms of prediction [22]. [22] performed RSM to optimize the formation of cellulose nanocrystals (CNC) in rice straw as a binding agent within the manufacturing of nanocomposites for various applications. As a result, [22] agreed that the CCD in the RSM is useful in specifying the main variables throughout the treatment process to prepare CNC in their experiment.

[25] was chosen the CCD to design the experiment because of its capability to predict the effect factors that influence responses within the set range. [26] justified that the CCD in the RSM is an effective method to identify the optimum amount of nano-silicon needed in the cement mortar to reduce water absorption and crack formation. The CCD concluded that 6.6% is the optimum amount of nano-silicon required for water absorption resistance that improves about 63% on the cement mortar strength. [27] also used the CCD in the RSM to analyze the silica extraction in the rice husk ash through the alkali pretreatment for energy production. Lastly, [27] reported that the CCD in the RSM is an efficient and famous tool used widely across the field. It was utilized to achieve the best results with a limited number of experimental runs.

2.0 METHODOLOGY

The experimental work focuses on producing treated rice straw ash (TRSA) using low hydrochloric acid (HCl) concentration, followed by the burning and grinding processes. First, the design of the experiment (DOE) was used for the pretreatment process since it has several factors with an extensive range through the response surface methodology (RSM) in Design Expert 7.1.6 software. [21,28,29] also used design expert software for the DOE purpose. RSM model is collecting experimental data on the response of interest, building an RSM model and validating its correctness through analysis of variance (ANOVA) analysis, and finally optimizing the parameter to fulfill the stated ideal response variables [30].

As stated by [22,23,26,27,29], the central composite design (CCD) of RSM was the chosen method to define the optimum sample. Thus, this research used a CCD design to interpret the interaction between the variables and the responses involved in the pretreatment process. The flowchart of the methodology was illustrated as shown in Figure 1. The variables involved in the pretreatment process are soaking duration, soaking temperature, and hydrochloric acid (HCl) concentration. However, the responses are the percentage of the reactive compound. The limit range for each variable from [31] is illustrated in Table 1.

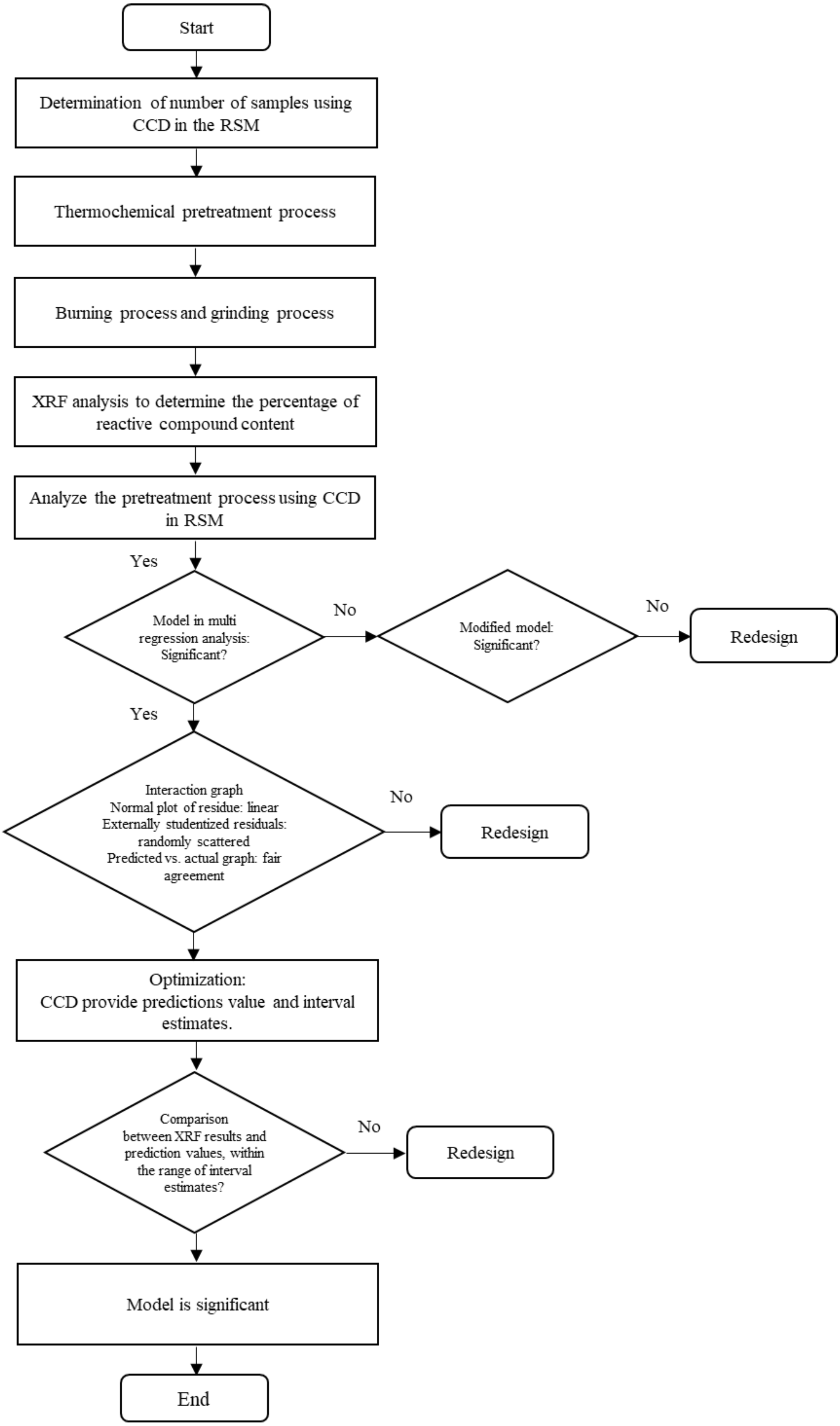

Figure 1. Flowchart of methodology

Table 1. Variable and limit level for independent variables for the thermochemical pretreatment process.

Variables	Unit	Symbol	Level	
			-1	+1
HCl concentration	Molar	A	0.01	0.1
Soaking duration	Hours	B	1	3
Soaking temperature	Degree Celsius	C	60	80

The thermochemical pretreatment process using a dilute acid of HCl is the method that has been conducted to improve the performance of concrete by eliminating the impurities and increasing the amount of amorphous silica content in the rice straw. Thermochemical pretreatment using a dilute acid helps to increase the surface area of RSA and amorphous, making them highly reactive pozzolanic material [19,32]. In previous studies, most researchers used a high concentration of HCl (more than 1 Molar) in the pretreatment process, which can harm the environment [33,34]. For this research, the value of each variable was determined by the RSM as illustrated in Table 2, whereby there are 20 samples involved in this process with different HCl concentrations, soaking duration, and soaking temperature.

First, the raw rice straw was immersed in the dilute HCl solution at a specific temperature for about a particular time. The ratio of rice straw and the dilute HCl solution used for this pretreatment process is 0.5 g: 40 ml. Based on that ratio, 50 g of RS: 4000 ml of dilute HCl solution. Then, the treated rice straw was washed using distilled water until it reached neutral pH (pH 7) and dried in the oven at 110℃ for about 24 hours. After that, each sample undergoes the burning and grinding processes. At last, the X-ray fluorescence (XRF) analysis was conducted to obtain the value of response 1 (percentage of reactive compound content). The XRF analysis result will be filled in the Design Expert 7.1.6 software for the optimization analysis.

Table 2. Samples involved in the pretreatment process defined by DOE

No. of run	HCl concentration (Molar)	Soaking duration (Hours)	Soaking temperature (Degree Celsius)
1.	0.06	2.00	70.00
2.	0.06	2.00	70.00
3.	0.10	1.00	60.00
4.	0.10	3.00	60.00
5.	0.06	2.00	70.00
6.	0.06	2.00	80.00
7.	0.06	2.00	70.00
8.	0.06	2.00	70.00
9.	0.10	3.00	80.00
10.	0.10	2.00	70.00
11.	0.01	1.00	80.00
12.	0.01	3.00	80.00
13.	0.10	1.00	80.00
14.	0.06	3.00	70.00
15.	0.06	1.00	70.00
16.	0.01	1.00	60.00
17.	0.01	2.00	70.00
18.	0.01	3.00	60.00
19.	0.06	2.00	70.00
20.	0.06	2.00	70.00

3.0 RESULT AND DISCUSSION

First of all, the X-Ray Fluorescence (XRF) result for non-treated rice straw ash (NTRSA) recorded that the NTRSA consists of 32.38% of magnesium oxide (MgO), 20.16% of calcium oxide (CaO), 9.40% of potassium oxide (K_2O), 24.1% of silicon dioxide (SiO_2), 8.99% of aluminium oxide (Al_2O_3), and 0.05% of iron (III) oxide (Fe_2O). Based on the XRF result of NTRSA, the ash is not suitable to be used as cement replacement material (CRM) since it is does not meet the requirement of ASTM C 618. Thus, it proved that the NTRSA cannot directly used as CRM in mortar production. Alternatively, the thermochemical pretreatment process using low concentration of acid is used to increase the percentage of reactive compound content in the rsa that are beneficial for concrete strength development.

Figure 2 shows the Response Surface Methodology (RSM) array of the value of factors for the 20 experimental runs and the results of the thermochemical pretreatment analysis. Based on the result of response 1 in Figure 2, the percentage of reactive compound content for each experiment involved in the pretreatment process seems to be more than 70%, as mentioned by ASTM C 618. Thus, treated RSA (TRSA) can be used as CRM. The eighth experimental run has the highest percentage of reactive compound content, 99.6%, while the least is 87.21% for the eighteenth experimental run. It shows that the pretreatment process enhances the amount of reactive compound content in the ash.

Run	Factor 1 A:HCl concentration Molar	Factor 2 B:Soaking duration Hours	Factor 3 C:Soaking temperature Degree celcius	Response 1 Percentage of reactive compound content %
1	0.06	2.00	70.00	97.28
2	0.06	2.00	70.00	97.89
3	0.10	1.00	60.00	94.56
4	0.10	3.00	60.00	89.07
5	0.06	2.00	70.00	98.63
6	0.06	2.00	80.00	96.52
7	0.06	2.00	70.00	98.12
8	0.06	2.00	70.00	99.6
9	0.10	3.00	80.00	94.33
10	0.10	2.00	70.00	96.89
11	0.01	1.00	80.00	91.62
12	0.01	3.00	80.00	95.64
13	0.10	1.00	80.00	92.15
14	0.06	3.00	70.00	93.6
15	0.06	1.00	70.00	95.81
16	0.01	1.00	60.00	89.43
17	0.01	2.00	70.00	95.12
18	0.01	3.00	60.00	87.21
19	0.06	2.00	70.00	98.63
20	0.06	2.00	70.00	98.21

Figure 2. RSM array for pretreatment process in design expert 7.1.6

The first analysis of RSM is the determination of multiple regression analysis where the regression model equation was selected for further analyzing the study. The Design Expert was higlighted that model was selected when the p-value of sequential model sum of squares is less than 0.05, p-value of lack of fit tests is more than 0.05 to indicate the model is fitted, and had maximum both adjusted and predicted R-squared in the model summary statistics for response 1 [35–37]. In addition, the minimum or equal the value of degrees of freedom (DOF) is 3 for sequential model sum of squares and lack of fit test in to ensure that the test is significant [26]. The fit model is vital to be obtained in the RSM in order to ensure the predicted model is good and within the expected range [38].

Based on Table 3, the quadratic model had a p-value (<0.0001) less than 0.05 for the sequential model sum of the squares and a p-value (0.2098) more than 0.05 for lack of fit test as per the Design Expert requirement. Both the sequential model sum of the squares and the lack of fit test had a required DOF value. Then, the quadratic model had a maximum adjusted (0.9398) and predicted (0.8265) R-squared for the model summary statistics. Therefore, the quadratic model was chosen as suggested by Design Expert to be used for further analysis. The qudratic model was the highest order polynomial where the additional terms are significant, and the model is not aliased.

Table 3. Fit summary of multi-regression for response 1

The sequential model sum of the squares						
Source	Sum of squares	DOF	Mean square	F-value	p-value	Comment
Mean	1.806E+005	1.00	1.806E+005			
Linear	35.78	3.00	11.93	0.95	0.4480	
2FI	35.22	3.00	11.74	0.92	0.4589	
Quadratic	158.57	3.00	52.86	70.36	<0.0001	Suggested
Cubic	5.13	5.00	1.03	2.15	0.2098	
Residual	2.38	5.00	0.48			
Total	1.808E+005	20.00	9039.80			

Table 4. (cont.)

Lack of fit test						
Source	Sum of squares	DOF	Mean square	F-value	p-value	Comment
Linear	198.92	11	18.08	37.96	0.0004	
2FI	163.70	8	20.46	42.96	0.0003	
Quadratic	5.13	5	1.03	2.15	0.2098	Suggested
Cubic	0.000	0				
Pure Error	2.38	5	0.48			
Model Summary Statistics						
Source	Std. dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	Comment
Linear	3.55	0.1509	-0.0083	-0.5916	377.33	
2FI	3.57	0.2995	-0.0238	-4.2598	1247.02	
Quadratic	0.87	0.9683	0.9398	0.8265	41.13	Suggested
Cubic	0.69	0.9900	0.9618			

Next, the second analysis involved in RSM is analysis of variance (ANOVA). The quadratic model from the multi-regression analysis was used in this analysis. The ANOVA has been conducted to analyze the statistical significance of the model coefficients [33]. The result of ANOVA analysis of response 1 was generated by Design Expert as shown in Table 4. Based on the Design Expert, the minimum or equal the value of DOF is 3, while for pure error is 4 to ensure that the test is significant. The lack of fit is difficult to detect when the fewer value of the degree of freedom [26]. The p-value for this response is less than 0.05, thus the model is significant [26,37,39]. The model will be more significant when the p-value is small [29]. In this case, A, C, AC, A^2, B^2, and C^2 are significant model terms.

Based on Table 4, the F-value of 33.96 implies the model is significant, so there is only a 0.01% chance that an F-value this large could occur due to noise. Furthermore, the lack of fit F-value of 2.15 implies the lack of fit is not substantial relative to the pure error. There is a 20.98% chance that a lack of fit F-value this large could occur due to noise. The value of DOF and pure error of model were within the range that required by Design Expert. The pred R-squared of 0.8265 is in reasonable agreement with the adj R-squared of 0.9398. The value of R-Squared is 0.9683, which is close to 1. When the R-Squared was close to 1, the actual and predicted values had a good agreement and were highly accepted [33]. The Adeq precision measures the signal-to-noise ratio where the desired value is equal or more than 4 [26,27]. For this analysis, the ratio of Adeq precision is 18.289, which indicates an adequate signal. As result, this model can be used to navigate the design space.

Table 5. ANOVA analysis for response 1

Source		Sum of squares	DOF	Mean square	F-value	p-value	Comment
Model		229.57	9	25.51	33.96	<0.0001	Significant
A-HCl concentration		6.08	1	6.08	8.09	0.0174	
B-Soaking duration		1.28	1	1.28	1.70	0.2216	
C-Soaking temperature		20.34	1	20.34	27.07	0.0004	
AB		3.47	1	3.47	4.62	0.0572	
AC		7.77	1	7.77	10.34	0.0092	
BC		24.19	1	24.19	32.20	0.0002	
A^2		5.25	1	5.25	6.99	0.0245	
B^2		19.38	1	19.38	25.79	0.0005	
C^2		7.11	1	7.11	9.47	0.0117	
Residual		7.51	10	0.75			
	Lack of fit	5.31	5	1.03	2.15	0.2098	insignificant
	Pure error	2.38	5	0.48			
Cor total		237.08	19				
Std. Dev.	Mean	C.V.%	PRESS	R-Squared	Adj R-Squared	Pred R-Squared	Adeq Precision
0.87	95.02	0.91	41.13	0.9683	0.9398	0.8265	18.289

Before moving on to optimization analysis, there are three essential graphs for correlation analysis are plotted to ensure that the fitted models are adequate to prevent inaccurate outcomes. All graphs as exhibited in Figure 3 to Figure 5 are generated by Design Expert before continuing the optimization part. A normal probability plot for response 1 is evaluated as illustrated in Figure 3. The externally studentized residuals' normal probability graph in Figure 3 is linear. The data in Figure 3 shows errors when it is normally distributed if they are not linear and it is assumed that the prediction of the model is wrong. Plotting the residuals against the expected response in Figure 4 demonstrates that they are randomly dispersed within the red lines. Thus, it shows that the model is a fitted model since the all points scattered between the red lines. Furthermore, Figure 5 illustrates that the experimental data and the values predicted by Design Expert 7.1.6 correspond rather well. Thus, the model is found to be adequate. Similar results had been discussed and concerned by previous researchers [22,26,27,30].

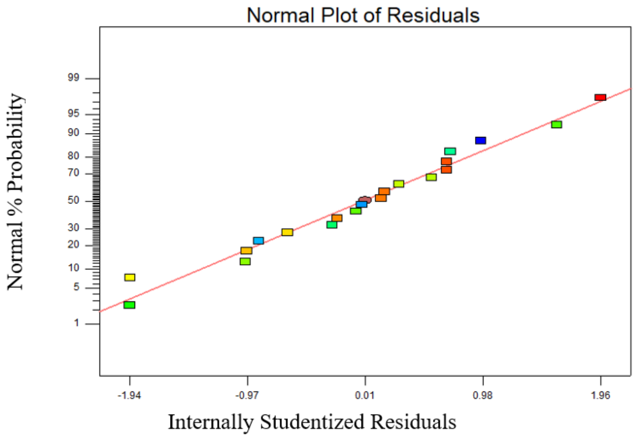

Figure 3. Normal probability graph for runs no 1 - 20

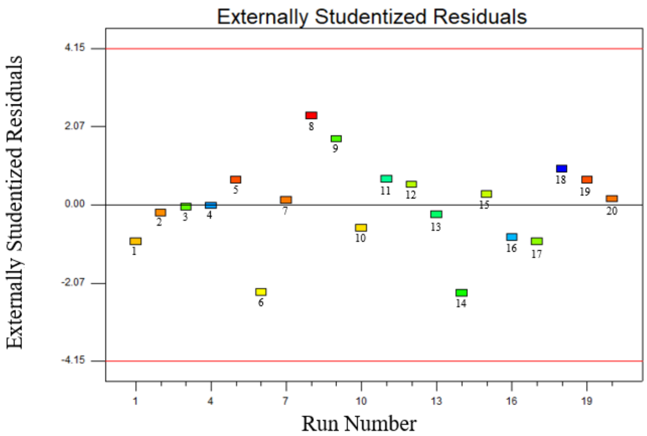

Figure 4. The externally studentized residuals vs. predicted response graph for run no 1 - 20

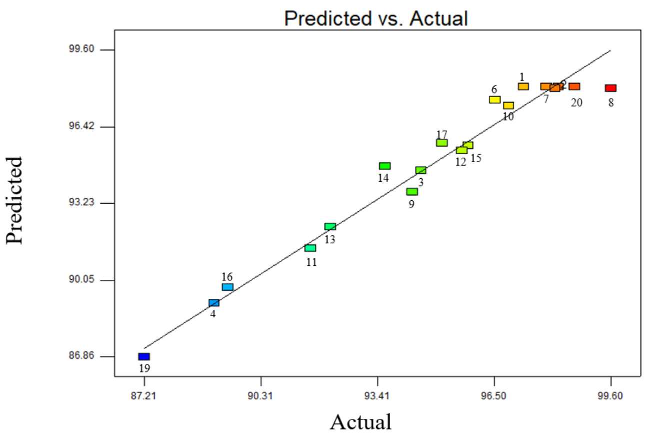

Figure 5. Numerical vs. experimental results graph for runs no 1 - 20

The fourth analysis is the interaction of factors involved in this analysis which is depicted in the three-dimensional (3D) response surface plot. The 3D contour plot is a planar presentation of the reaction surface in two dimensions. Contours plot also used in the analysis to predict the results [22,37]. Figure 6 (a) shows the interaction between soaking duration and hydrochloric acid (HCl) towards the percentage of reactive compound content. The ash had a high amount of reactive compound content when treated by soaking in a low HCl concentration solution throughout a medium length of time. The reactive compound content was seen to be reduced at a long soaking duration, even using a low HCl concentration. Besides, Figure 6 (b) exhibits the interactive effect of soaking temperature and HCl concentration. The reactive compound content extracted high at the medium temperature of a low HCl concentration of soaking solution. Then, Figure 6 (c) illustrates the interaction between the soaking temperature and soaking duration. The reactive compound content in the ash was increased when soaking in the medium temperature of solution for a medium length of time. A short or long time of soaking duration is not help to increase reactive compound content in the ash.

The percentage of reactive compound content does not necessarily increase when all factors, namely HCl concentration, soaking duration, and soaking temperature, increase. Overall, Figure 6 (a)-(c) shown that the combining high HCl concentration with the long soaking duration and the high soaking temperature does not lead to the highest percentage of reactive compound content. It is also proved that the low HCl concentration, which is less than 0.1 M, can help increase the amount of silica present in the ash (more than 70%).

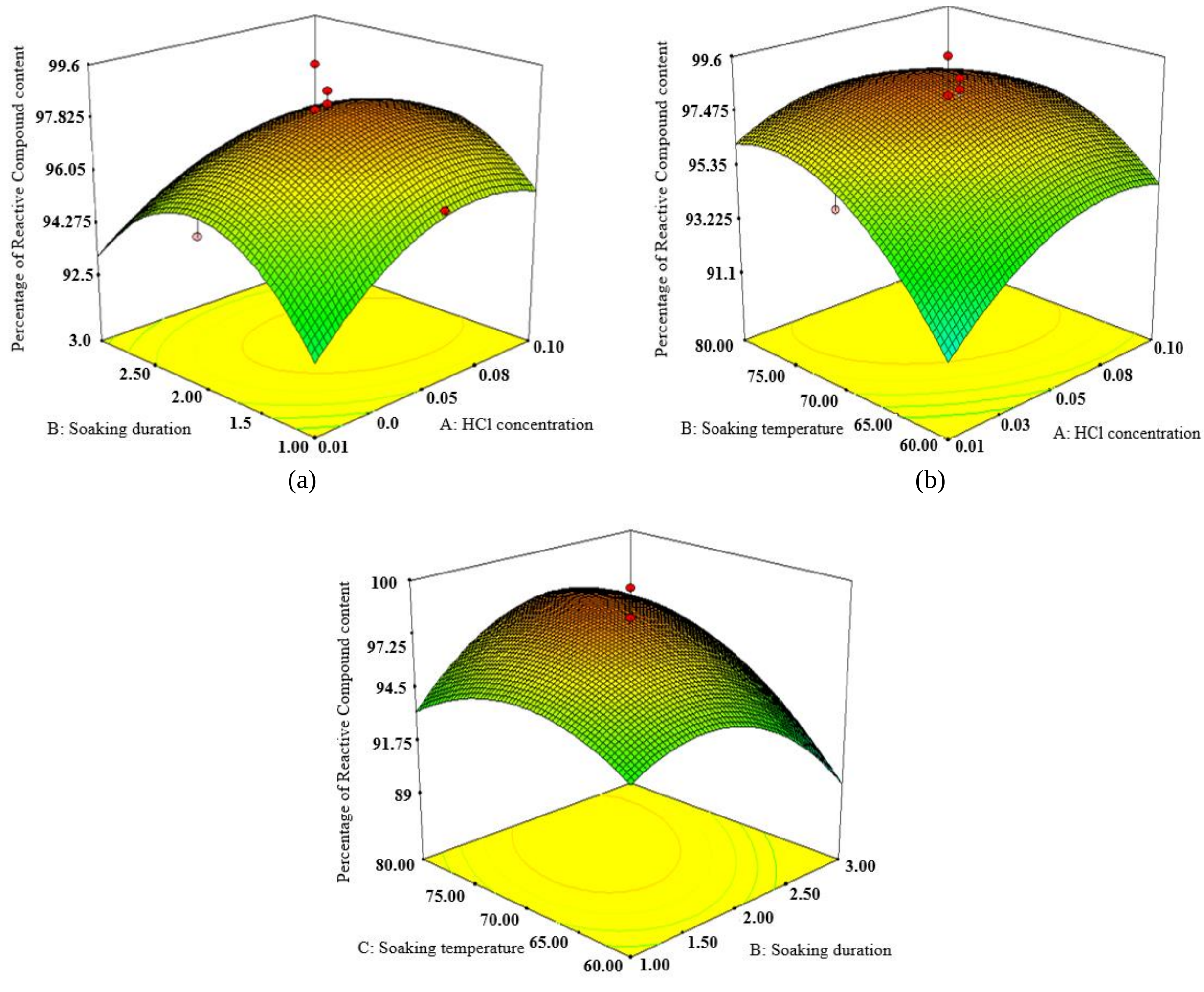

Figure 6. (a) – (c) 3D contour plot for interaction between all factors

The last analysis for the RSM in the Design expert is the optimization analysis. The optimization analysis was continued since the fitted model was obtained in all previous analysis. The optimization analysis was conducted to compare the experimental work with the numrical analysis result.The definition of optimization is the process of raising the efficiency of a system to maximize its advantages. For the optimization analysis result, as shown in Figure 7, one solution was selected by the Design Expert out of the 20 runs with a desirability function of 89.8%. The HCl concentration chosen is 0.06 M, the soaking duration is 2 hours, and the soaking temperature is 70°C.

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
HCl concentration	is in range	0.01	0.1	1	1	3
Soaking duration	is in range	1	3	1	1	3
Soaking temperature	is in range	60	80	1	1	3
Percentage of reactive compound content	maximize	87.21	99.6	1	1	3

Solutions

Number	HCl concentration	Soaking duration	Soaking temperature	Percentage of reactive compound content	Desirability	
1	0.06	2.04	73.74	98.3402	0.898	Selected

1 Solutions found

Figure 7. Table of solution results for this analysis in RSM

The result of XRF analysis is compared to the estimated value from the model to see if the suggested model can adequately predict since it is selected randomly from the design space. From Figure 7, the prediction value of the percentage of reactive compound content in RSM is 98.34%, while the XRF analysis results for each model with the same value of each factor (HCl concentration = 0.06 M, soaking duration = 2 hours, and soaking temperature = 70°C) is above 97.00%. So, the range of XRF analysis results for actual reaction falls between 95% PI low and 95% PI high. The values of 95% PI low and 95% PI high are shown in Figure 8. The model is validated since the actual experimental result is within the expected range for any involved factor.

Factor	Name	Level	Low Level	High Level	Std. Dev.	Coding
A	HCl concentration	0.061	1.00E-02	0.100	0.000	Actual
B	Soaking duration	2.04	1	3.00	0.000	Actual
C	Soaking temperature	73.74	60.00	80.00	0.000	Actual

Response	Prediction	SE Mean	95% CI low	95% CI high	SE Pred	95% CI low	95% CI high
Percentage of reactive compound content	98.3402	0.31	97.66	99.02	0.92	96.29	100.39

Figure 8. Table of prediction results for this analysis in RSM

4.0 CONCLUSION

The satisfaction of using a thermochemical pretreatment process to produce an amorphous silica rice straw ash is proved in this study. Overall, the percentage of reactive compound content in the ashes for each experimental run is more than 87%. Thus, the ashes can be used in concrete production because the reactive compound content (SiO_2, Al_2O_3, and Fe_2O_3) is more than 70%, as mentioned in ASTM C 618 [17]. And then, Response Surface Methodology (RSM) with a central composite design (CCD) has been discovered as a useful method for finding the optimum value of variables. As a result, the optimum experimental condition (HCl concentration = 0.06 M, soaking duration = 2 hours, and soaking temperature = 70°C) has an 89.90% desirability function to obtain a high-quality rice straw ash (RSA). Therefore, the thermochemical pretreatment process using dilute HCl concentration is suitable and effective in increasing the silica amount and decreasing impurities present in the ash. On the other hand, unlike the previous studies, using a high acid concentration in the pretreatment process can harm the environment [19]. However, future work may focus more on the morphology and mechanical properties of RSA in concrete production.

5.0 AUTHOR CONTRIBUTIONS

Aida Nabila Jamaluddin: Software, Writing – Original Draft Preparation.

Siti Asmahani Saad: Supervision, Conceptualization.

Siti Aliyyah Masjuki: Methodology, Investigation.

Wan Nur Firdaus Wan Hassan: Data curation, Validation.

Siti Noratikah Che Deraman: Visualization, Validation.

Nadiah Md Husain: Writing – Reviewing and Editing.

6.0 FUNDING

The support provided by the Ministry of Higher Education Malaysia (MoHE) under the Fundamental Research Grant Scheme, project ID FRGS/1/2019/TK06/UIAM/03/1 for project funding allocation is highly appreciated.

7.0 DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included in the article.

8.0 ACKNOWLEDGEMENT

The author would like to express the highest gratitude to all technicians of the Civil Engineering Department, International Islamic University Malaysia (IIUM), for facilitating adequate facilities and supports for the accomplishment of this study.

9.0 CONFLICTS OF INTEREST

The authors declare no conflict of interest.

10.0 REFERENCES

[1] G. H. M. J. Subashi De Silva and M. W. S. Priyamali, “Potential use of waste rice husk ash for concrete paving blocks: strength, durability, and run-off properties,” *International Journal of Pavement Engineering*, pp. 1–13, 2020.

[2] H.B. Dizaji, T. Zeng, I. Hartmann, D. Enke, T. Schliermann, V. Lenz, and M. Bidabadi, “Generation of high-quality biogenic silica by combustion of rice husk and rice straw combined with pre- and post-treatment strategies-a review,” *Applied Sciences*, vol. 9, no. 6, p. 1083, 2019.

[3] R. M.Z, R. A. C. Rose, J. Mapjabil, and M. Marzuki, “The potential of rice straw in agricultural activities in the MADA Region of Kedah, Malaysia,” *International Journal of Asian Social Science*, vol. 9, no. 4, pp. 295–303, 2019.

[4] Y. Oladosu, M.Y. Rafii, N. Abdullah, U. Magaji, G. Hussin, A. Ramli, and G. Miah, “Fermentation quality and additives: a case of rice straw silage,” *BioMed Research International*, vol. 2016, 2016.

[5] R. P. Venkatesan and K. C. Pazhani, “Strength and durability properties of geopolymer concrete made with ground granulated blast furnace slag and black rice husk ash,” *KSCE Journal of Civil Engineering*, vol. 20, no. 6, pp. 2384–2391, 2016.

[6] G. Athira, A. Bahurudeen, and S. Appari, “Sustainable alternatives to carbon intensive paddy field burning in India: a framework for cleaner production in agriculture, energy, and construction industries,” J. Clean. Prod., vol. 236, p. 117598, 2019, doi: 10.1016/j.jclepro.2019.07.073.

[7] B. A. Goodman, “Utilization of waste straw and husks from rice production: a review,” *Journal of Bioresources and Bioproducts*, vol. 5, no. 3, pp. 143–162, 2020.

[8] Y. Sadef, A. S. Nizami, S. A. Batool, M. N. Chaudary, O. K. M. Ouda, Z. Z. Asam, et al., “Waste-to-energy and recycling value for developing integrated solid waste management plan in Lahore,” *Energy Sources, Part B: Economics, Planning, and Policy*, vol. 11, no. 7, pp. 569–579, 2016.

[9] B. Nagashree, V. Kishore, and M. Malathi, “Studies on geopolymerisation reaction using synthesised activators,” *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 6, no. 11, 2017.

[10] M. V. Madurwar, R. V. Ralegaonkar, and S. A. Mandavgane, “Application of agro-waste for sustainable construction materials: A review,” *Construction and Building Materials*, vol. 38, no. 2, pp. 872–878, 2013.

[11] T. A. El-Sayed, A. M. Erfan, and R. M. Abd El-Naby, “Influence of rice, wheat straw ash and rice husk ash on the properties of concrete mixes,” *Jokull*, vol. 67, no. 5, pp. 103–119, 2017.

[12] M. U. Dabai and M. Muhammad, “Studies on the effect of rice straw ash as admixture of ordinary portland cement mortar,” *International Journal of Innovative Science Engineering and Technology*, vol. 4, no. 7, pp. 112–119, 2017.

[13] F. F. Ataie and K. A. Riding, “Influence of agricultural residue ash on early cement hydration and chemical admixtures adsorption,” *Construction and Building Materials*, vol. 106, pp. 274–281, 2016.

[14] S. Munshi and R. P. Sharma, “Utilization of rice straw ash as a mineral admixture in construction work,” in *Materials Today: Proceedings*, vol. 11, pp. 637–644, 2019.

[15] A. F. Mahmuda, M. W. Tjaronge, and A. A. Amiruddin, “The potential utilization of rice straw ash as cement replacement in mortar material,” in *IOP Conference Series: Earth and Environmental Science*, vol. 419, no. 1, p. 012037, 2020.

[16] J. Roselló, L. Soriano, M. P. Santamarina, J. L. Akasaki, J. Monzó, and J. Payá, “Rice straw ash: a potential pozzolanic supplementary material for cementing systems,” *Industrial Crops and Products*, vol. 103, pp. 39–50, 2017.

[17] M. Kasaniya, M. D. A. Thomas, and E. G. Moffatt, “Development of rapid and reliable pozzolanic reactivity test method,” *ACI Materials Journal*, vol. 116, no. 4, pp. 145–154, 2019.

[18] M. I. Morsy and M. A. Rashwan, “Replacement effect of cement by rice straw ash on cement mortar properties,” *Misr Journal of Agricultural Engineering*, vol. 32, no. 4, pp. 1685–1708, 2015.

[19] S. Munshi and R. P. Sharma, "Investigation on the pozzolanic properties of rice straw ash prepared at different temperatures," *Materials Express*, vol. 8, no. 2, pp. 157–164, 2018.

[20] L. Rodier, K. Bilba, C. Onesippe, and M. Arsene, "Study of pozzolanic activity of bamboo stem ashes for use as partial replacement of cement," *Materials and Structures*, vol. 50, no. 1, pp. 1–14, 2017.

[21] I. I. Ahmed et al., "Optimisation of acid pre-treatment parameters in silica extraction process from cassava periderm," *Materials Today: Proceedings*, vol. 38, pp. 749–755, 2020.

[22] M. Thakur, A. Sharma, V. Ahlawat, M. Bhattacharya, and S. Goswami, "Process optimization for the production of cellulose nanocrystals from rice straw derived α-cellulose," *Materials Science for Energy Technologies*, vol. 3, pp. 328–334, 2020.

[23] J. Zolgharnein, A. Shahmoradi, and J. B. Ghasemi, "Comparative study of box-behnken, central composite, and doehlert matrix for multivariate optimization of Pb (II) adsorption onto robinia tree leaves," *Journal of Chemometrics*, vol. 27, no. 1–2, pp. 12–20, 2013.

[24] J.P. John, "Parametric studies of cement production processes," *Journal of Energy*, vol. 2020, Article ID 4289043, p. 1-17, 2020.

[25] O. U. Izevbekhai, W. M. Gitari, and N. T. Tavengwa, "Optimization of silica extraction from diatomaceous earth using the central composite design of response surface methodology," *South African Journal of Chemistry*, vol. 75, pp. 80–90, 2021.

[26] N. Z. Muhammad et al., "Optimization of nano silicon for integral mixing in cement mortar: a response surface methodology approach," *AIP Conference Proceedings*, vol. 2284, no. 1, p. 020009, 2020.

[27] A. Bazargan, M. Bazargan, and G. McKay, "Optimization of rice husk pretreatment for energy production," *Renewable Energy*, vol. 77, pp. 512–520, 2015.

[28] M. H. Dheyaaldin, M. A. Mosaberpanah, and R. Alzeebaree, "Performance of fiber-reinforced alkali-activated mortar with/without nano silica and nano alumina," *Sustainability*, vol. 14, no. 5, pp. 1–24, 2022.

[29] D. W. Indriani and T. R. Wardhani, "Modeling of extraction of silica rendemen husk rice (Oryza sativa l.) by microwave extraction assisted (MAE) using response surface methodology (RSM)," *IOP Conference Series: Earth and Environmental Science*, vol. 963, no. 1, p. 012048, 2022.

[30] M. Gun, H. Arslan, M. Saleh, M. Yalvac, and N. Dizge, "Optimization of silica extraction from rice husk using response surface methodology and adsorption of safranin dye," *International Journal of Environmental Research*, vol. 16, no. 2, pp. 1–13, 2022.

[31] R. Embong, N. Shafiq, A. Kusbiantoro, and M. F. Nuruddin, "Effectiveness of low-concentration acid and solar drying as pre-treatment features for producing pozzolanic sugarcane bagasse ash," *Journal of Cleaner Production*, vol. 112, pp. 953–962, 2016.

[32] Q. Xu, T. Ji, S. J. Gao, Z. Yang, and N. Wu, "Characteristics and applications of sugar cane bagasse ash waste in cementitious materials," *Materials (Basel).*, vol. 12, no. 1, p. 39, 2018.

[33] T. A. Amibo, S. M. Beyan, and T. M. Damite, "Production and optimization of bio-based silica nanoparticle from teff straw (eragrostis tef) using RSM-based modeling, characterization aspects, and adsorption efficacy of methyl orange dye," *Journal of Chemistry*, vol. 2022, 2022.

[34] J. T. Librea, F. D. Dacanay, Z. Z. Martin, and L. L. Diaz, "Effect of water and acid pre-treatment on the physicochemical properties of rice husk for silica extraction," *IOP Conference Series: Materials Science and Engineering*, vol. 540, no. 1, p. 012007, 2019.

[35] N. Prajapati, P. Kodgire, and S. Singh Kachhwaha, "Comparison of RSM Based FFD and CCD Methods for Biodiesel Production Using Microwave Technique," *Materials Today: Proceedings*, vol. 62, no. P13, pp. 6985–6991, 2022.

[36] A. A. Raheem and M. A. Kareem, "Chemical composition and physical characteristics of rice husk ash blended cement," *International Journal of Engineering Research in Africa*, vol. 32, pp. 25–35, 2017.

[37] F. Farirai, M. O. Daramola, and M. Mupa, "Production of nano silicon particles from sugarcane bagasse ash for solar cell application," University of the Witwatersrand, Johanesburg, 2020.

[38] R. Kumar and M. Reji, "Response surface methodology (RSM): An overview to analyze multivariate data," *Indian Journal of Microbiology Research*, vol. 9, no. 4, pp. 241–248, 2023.

[39] A. A. Raheem and M. A. Kareem, "Optimal raw material mix for the production of rice husk ash blended cement," *International Journal of Sustainable Construction Engineering & Technology*, vol. 7, no. 2, pp. 77–93, 2017.