Engineering Solid Mechanics 10 (2022) 263-268

Contents lists available at GrowingScience

Engineering Solid Mechanics

homepage: www.GrowingScience.com/esm

Concrete compressive strength of mix proportioning cockle shell, glass powder and epoxy resin under hot water curing condition through response surface methodology

Sugito[a,b*], Sofia W. Alisjahbana[a,c] and Hery Riyanto[b]

[a]*Department of Civil Engineering, Tarumanagara University, Jakarta 11440, Indonesia*
[b]*Department of Civil Engineering, Bandar Lampung University, Bandar Lampung 35142, Indonesia*
[c]*Department of Civil Engineering, Bakrie University, Jakarta 12940, Indonesia*

A R T I C L E I N F O

Article history:
Received 26 January 2022
Accepted 25 March 2022
Available online
26 March 2022

Keywords:
Cockle shell
Compressive strength
Concrete
Glass powder
Waste

A B S T R A C T

Nowadays, the significant demand for concrete has become a problem in concrete using aggregate from waste. Using standard concrete is recommended to reduce the breakdown of buildings. Unfortunately, standard materials used to produce previous concrete are not entirely environmentally friendly. As a result, many researchers have committed their awareness to identifying eco-friendlier substitutions in manufacturing concrete substitution aggregate from waste. In this respect, this paper discussed the proposed efficient procedure to indicate the compressive strength from mixed proportioning cockle shell, glass powder, and epoxy resin as concrete under hot water curing conditions (60 °C, 4 hr) using response surface methodology. The experimental design used in this research uses a response surface methodology. There are three aggregates to be investigated, namely cockle shell powder, glass powder and epoxy resin under hot water curing condition (60 °C, 4 hr). Under hot water curing conditions, this research discovered that adding 4.0% cockle shell powder and 10.0% glass powder increased the compressive strength to 104.68 MPa. On the other hand, 4.0% cockle shell powder, 10.0% glass powder and 2% epoxy resin under hot water curing conditions improved the compressive strength to 115.70 MPa. It was therefore inferred that the use of both cockle shell powder and glass powder to produce cleaner and compressive strength concrete is applicable, both mechanically and environmentally.

1. Introduction

Effective by-product waste management is critical for environmental sustainability. One waste management strategy is to utilize by-product waste materials in the building sector to decrease waste material landfills. Additionally, more sustainable, clean, and green buildings may be accomplished by using waste materials. Also, most raw materials used in the manufacturing of concrete are natural aggregates, which are often extracted from mines and river beds or dredged from sea shelves (Soundarya, 2021). These operations have resulted in significant environmental harm, including ecological disturbance and soil, air, and water pollution. As a result, the construction industry promotes the inclusion of sustainability concerns into manufacturing processes by using solid waste products as aggregate in concrete. Further, it was stated that repurposing waste materials may help save resources and, as a result, reduce trash disposal in the industries concerned. Two of the waste materials, potentially successfully utilized as coarse aggregate in conventional concrete, were cockle shell and waste glass (Ruslan et al., 2022; Zam et al., 2019).

* Corresponding author.
E-mail addresses: sugito@ubl.ac.id (Sugito)

doi: 10.5267/j.esm.2022.4.001

Nowadays, various materials are employed as supplementary alternatives to cement in concrete mixes, either combined with the cement or added independently like material aggregate from waste (Aslani et al., 2018; Joshi et al., 2020; Mo et al., 2018; Mohamad et al., 2021). However, the concrete strength assessment in existing constructions is necessary even for its material aggregate from waste. High-strength concrete is a type of concrete that offers superior mechanical qualities, namely compressive strength of more than 40 MPa (Hameed et al., 2021). In the engineering scope, accurately estimating the mechanical properties of materials is a concern that must be studied carefully because it can become a severe problem in the future (Cebro & Sitorus, 2019; Sitorus et al., 2020). However, finding all the treatment combinations of the tested materials to get higher compressive strength requires considerable effort and money. Therefore, several researchers related to this concrete use a response surface approach (Kareem et al., 2019; Moodi et al., 2018; Poorarbabi et al., 2020). After evaluating the literature, it is found that while there are some models, an efficient way to predict compressive strength should be considered. Therefore, the objective of this paper is to evaluate an efficient procedure to forecast the compressive strength of concrete from mix proportioning cockle shell, glass powder and epoxy resin under hot water curing condition (60°C, 4 hr) through response surface methodology.

2. Material and method

2.1 Design of experiment

This research included the British Research Establishment's class 3 design. 17 experimental runs were generated using the response surface approach's CCD. The number of experiments has described the optimal value that this study must carry out. Three types of concrete fillers at various levels have been prepared (cockle shell, waste glass, and epoxy resin). Table 1 presents the physical properties of the materials used in this study. Cockle shell powder as a concrete filler is designed with levels of 0, 1, 1.5, 2, 2.5 3, 3.5 and 4%. Glass powder as a concrete filler is designed with levels of 1.5, 2, 2.5, 3, 3.5, 4, 6, 8% and 10%. Epoxy resin is designed with levels of 0 and 13%. Responses defined as the compressive strength.

Table 1
The parameters of the fine aggregate used in concrete

Materials of concrete	Bulk dry specific gravity	Bulk SSD specific gravity	Apparent specific gravity	Absorption (%)
Cockle shell powder	2.83	2.84	2.86	0.30
Glass powder	2.48	2.50	2.54	0.91

2.2 Experimental procedure

All runs' experimental designs were created using D. Expert software (v.12). Manual mixing was used to complete the concrete casting, including cockle shell powder and glass powder. A mixing method lasting about 8 minutes was used to assure the homogeneity of the concrete matrix. Following mixing all constituent elements, fresh concrete was put in lubricated molds. Then, new concrete was compressed using a poker vibrator until a consistent density was obtained. The specimens were then left for 4 hr in hot water (60°C) before being demolded with cylindrical molded concrete. Testing was undertaken after seven days after curing. After demolding, all specimens were measured compressive strength using UTM (UTM-RTF-1350, 250 kN, 0.5 kN/s). On cylindrical specimens (diameter of 100, height of 200 mm), compressive strengths were determined following ASTM C109-11.

2.3 RSM approach

The influence of cockle shell powder, glass powder, and epoxy resin as independent variables on compressive strength responses under hot water curing conditions (60 °C, 4 hr) was projected by RSM. This technique evaluated the combined impact of these factors to get the desired results with the least amount of effort (Akkuş and Yaka, 2021; Huu et al., 2019; Meng et al., 2020). The data will be analyzed statistically using analysis of variance. Compressive strength response data were analyzed. The reading findings from the ANOVA analysis contain the model's P-significance. After analyzing the entire reaction, the compressive strength is optimized based on the discovered variables and responses. The optimization process begins with establishing a priority scale for each element and response.

The optimization procedure was created to determine the ideal values for three independent variables that provide desirable response variables. Using graphical optimization to visualize response models, we determined the effect of cockle shell powder, glass powder, and epoxy resin on concrete compressive strength under hot water curing conditions (60 °C, 4 hr). The ultimate goal of numerical optimization was to increase compressive strength. The objective of this approach was to maximize compressive strength to provide values for cockle shell powder, glass powder, and epoxy resin that were practicable.

3. Results and discussion

3.1 Establishment of mathematical models

We studied the effect of independent factors (epoxy resin, cockle shell, and glass waste) on the compressive strength performance of concrete in hot curing water. Using experimental data, response variables were predicted using linear coefficient calculations. According to the ANOVA results, linear models might describe compressive strength. The first and two equations illustrate the response surface approach's regression equations for each response.

$$C1 = 89.57 + 8.23CP + 6.87GP, \quad (1)$$
$$C2 = 87.53 - 8.25ER + 9.22CP + 13.66GP, \quad (2)$$

where CP, GP, and ER are cockle shell powder (%, w/w), glass powder (%, w/w), and epoxy resin (%, w/w), respectively, and C1, and C2 are predict compressive strength for each mixing of concrete (mixing type 1 and mixing type 2). In the C1 type of concrete mixing, it is known that the addition of cockleshell powder and glass powder can increase the compressive strength of the concrete. In addition, in the C2 type of concrete mixing, it is known that the addition of epoxy resin can reduce the compressive strength of concrete mixed with cockleshell powder and glass powder. However, the substitution with cockleshell powder and glass powder in the concrete has an effect that will strengthen the compressive strength of the concrete. This is in line with the research results of Khankhaje et al. (2017) who found an increase in the strength of concrete mixed with cockleshell and shell from palm oil. The three parameters (cockle shell powder, glass powder and epoxy resin) under hot curing water (60 °C, 4 hr) were optimized using RSM in a total of 17 tests. The results show that the maximum compressive strength of concrete under hot curing condition (60 °C, 4 hr) obtained was 94.08 MPa using cockle shell powder of 3% (w/w), and glass powder of 2% (w/w) and without epoxy resin, while the minimum compressive strength of concrete obtained was 48.19 MPa using the glass powder of 2% (w/w), epoxy resin of 13% (w/w) and without cockle shell powder.

3.2 Model's adequacy

Adequacy quantifies the proposed model's power to predict the output response. Analysis of variance (ANOVA) was used to determine the models' adequacy. The ANOVA results for compressive strength are given in Table 2 and Table 3. A high F-value and a low P-value reflect the created model's importance (Hamouda et al., 2015; Yirgu et al., 2021). The results show that the effect of cockle shell powder and glass powder under hot curing water to compressive strength are not significant. On the other hand, the effect of cockle shell powder, glass powder, and epoxy resin under hot curing water on compressive strength was significant. Significant models are those with a p-value less than 0.05.

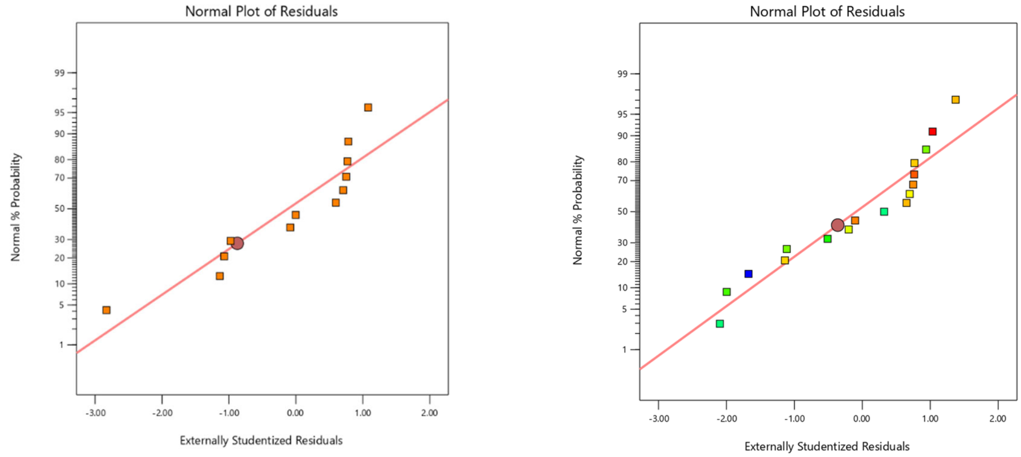
Table 1
Effect of cockle shell powder and glass powder under hot curing water

Source	Sum of squares	df	Mean square	F-value	p-value
Model	191.98	2	95.99	1.71	0.2345
Cockle shell powder	186.45	1	186.45	3.32	0.1016
Glass powder	14.53	1	14.53	0.2591	0.6230
Residual	504.76	9	56.08		
Total	696.74	11			

Table 2
Effect of epoxy resin, cockle shell powder and glass powder under hot curing water

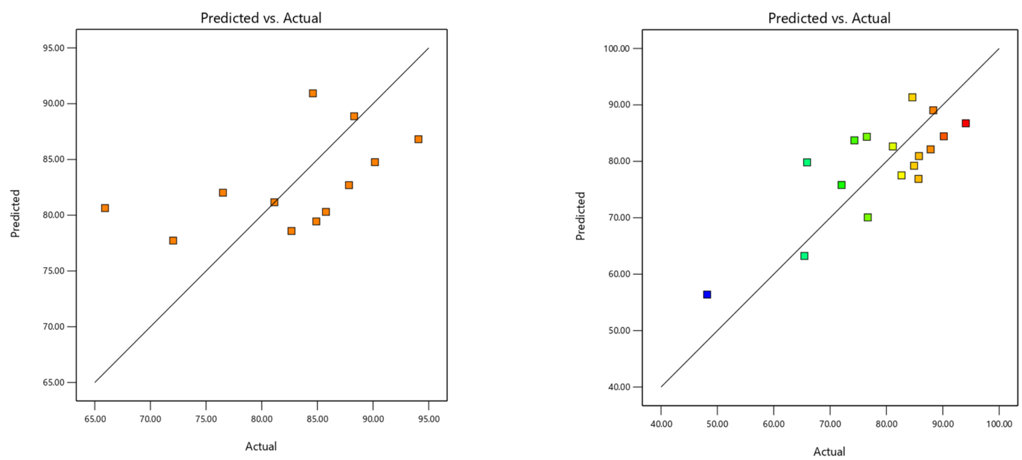
Source	Sum of squares	df	Mean square	F-value	p-value
Model	1276.89	3	425.63	6.91	0.0050
Epoxy resin	361.52	1	361.52	5.87	0.0308
Cockle shell powder	280.93	1	280.93	4.56	0.0523
Glass powder	524.06	1	524.06	8.51	0.0120
Residual	800.89	13	61.61		
Total	2077.78	16			

In case of the effect of cockle shell powder and glass powder under hot curing water to compressive strength, CP is significant parameter terms. On the other hand, the effect of cockle shell powder, glass powder, and epoxy resin under hot curing water to compressive strength, CP, GP, and ER are significant parameter terms. Adequate precision calculates the signal-to-noise ratio, and its weight of more than 3 is satisfactory. For both types of mixing for compressive strength, the values of adequate precision are 3.52 (CP and GP) and 9.18 (CP, GP, and ER), respectively, which indicates a satisfactory indication. Along with the ANOVA, a normal plot of the residuals and a graph of the actual vs. expected values were created. The normal plot of residuals is used to validate the model's normalcy assumptions, while the projected vs. actual values graph displays the constructed model's predictive performance. The normal plots of residuals of the compressive strength on two type mixing are shown in Fig. 1. All points are on a line, which implies that the mistake is regularly distributed. Fig. 2 depicts expected vs. real values for UTS, impact toughness, and hardness. The points are near the actual values, indicating that the projected values are accurate.



Effect of CP and GP Effect of CP, GP and ER

Fig. 1. Normal plot of residuals concrete under hot curing water to compressive strength



Effect of CP and GP Effect of CP, GP and ER

Fig. 2. Predicted vs. actual (b) of residuals concrete under hot curing water to compressive strength

3.3 Response surface plots for the effect of cockle shell powder and glass powder to compressive strength

Fig. 3 illustrates the interaction effect of cockle shell powder and glass powder on the compressive strength of concrete in hot curing water. The three-dimensional surface graph corresponds to the compressive strength response of the linear model. The graph indicates that adding cockle shell powder and glass powder gives growths the compressive strength to be maksimum. Compressive strength increases with the increase in cockle shell powder from 0 to 4 % (w/w) and glass powder from 2 to 10% (w/w). These results are in close accord with the previous work of Zhang et al. (2020), who identified that mix design for recycled aggregate directly affects compressive strength.

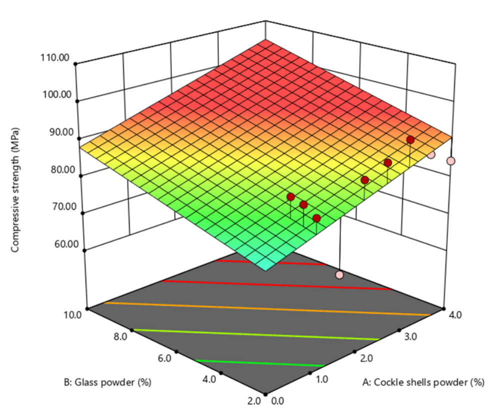


Fig. 3. Compressive strength of effect cockle shell powder and glass powder in hot curing water on concrete

3.4 Response surface plots for the effect of cockle shell powder, glass powder and epoxy resin to compressive strength under hot curing

Fig. 4 illustrates the interaction effect of cockle shell powder, glass powder, and epoxy resin on the compressive strength of concrete during curing in hot water. The three-dimensional surface graph corresponds to the compressive strength response of the linear model. The figure shows that the compressive strength increases when cockle shells powder concentration grows to a maximum value and subsequently declines as epoxy resin concentration drops. These findings are consistent with Hammoudi et al. (2019) research, which identified that mix design for recycled concrete aggregates directly affects compressive strength.

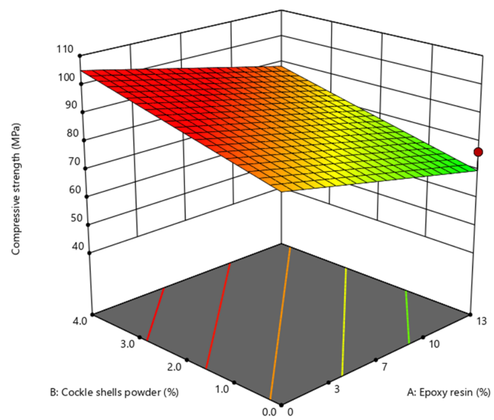


Fig. 4. Compressive strength of effect cockle shell powder and epoxy resin in hot curing water on concrete

3.5 Optimum compressive strength

The optimum of composition concrete (cockle shell powder, glass powder and epoxy resin) under hot curing water (60ºC, 4 hr) to achieve maximum compressive strength are displayed in Table 4. As shown in the table, the maximum compressive strength is obtained when cockle shell powder is used at a concentration of 4.0% and glass powder is used at a concentration of 10.0%. While on mixing type 2, the highest compressive strength is achieved at cockle shell powder of 4%, glass powder of 10.0% and epoxy resin of 2%. Interestingly, the highest compressive strength values were achieved at the same input cockle shell powder and glass powder. However, the difference in compressive strength between the two types of concrete mixing increases 10.53%. These findings are consistent with prior research by Hameed et al. (2021), which established that the composition of concrete directly affects compressive strength.

Table 3
Optimum compressive strength

Input/ output	Value		Units	Goal
	Mix type-1	Mix type-2		
Input parameters				
Cockle shell powder	4.0	4.0	%	Maximize
Glass powder	10.0	10.0	%	Maximize
Epoxy resin	0	2	%	In-range
Output responses				
Compressive strength	104.68	115.70	MPa	Maximize

4. Conclusion

The compressive strength of mixed concrete aggregates combination of cockle shell powder, glass powder, and epoxy resin under hot water curing conditions (60 °C, 4 hr), was optimized in this study. The compressive strength of concrete mixed with cockle shell powder, glass powder and epoxy resin with hot water curing conditions (60 °C, 4 hr) is identified to be higher than that of standard concrete. However, the combination of cockle shell powder, glass powder and epoxy resin increased compressive strength by 10.53% better than without the use of epoxy resin. It was found that 4.0% cockle shell powder and 10.0% glass powder under hot water curing conditions improved the compressive strength until 104.68 MPa. On the other hand, 4.0% cockle shell powder, 10.0% glass powder and 2% epoxy resin under hot water curing conditions improved the compressive strength to 115.70 MPa. Optimized values are a fantastic technique to create ecologically friendly concrete from the trash. RSM was determined to be capable of generating a large amount of information in a short period and with the fewest possible experiments.

References

Akkuş, H., & Yaka, H. (2021). Experimental and statistical investigation of the effect of cutting parameters on surface roughness, vibration and energy consumption in machining of titanium 6Al-4V ELI (grade 5) alloy. *Measurement, 167*, 108465.

Aslani, F., Ma, G., Wan, D. L. Y., & Muselin, G. (2018). Development of high-performance self-compacting concrete using waste recycled concrete aggregates and rubber granules. *Journal of Cleaner Production, 182*, 553-566.

Cebro, I. S., & Sitorus, A. (2019). Performance evaluation of a hand tractor to climbing sloping land. *International Journal of Scientific and Technology Research, 8*(7), 781-785.

Hameed, M. M., AlOmar, M. K., Baniya, W. J., & AlSaadi, M. A. (2021). Prediction of high-strength concrete: high-order response surface methodology modeling approach. *Engineering with Computers*. doi:10.1007/s00366-021-01284-z

Hammoudi, A., Moussaceb, K., Belebchouche, C., & Dahmoune, F. (2019). Comparison of artificial neural network (ANN) and response surface methodology (RSM) prediction in compressive strength of recycled concrete aggregates. *Construction and Building Materials, 209*, 425-436. doi:https://doi.org/10.1016/j.conbuildmat.2019.03.119

Hamouda, H. I., Nassar, H. N., Madian, H. R., Amr, S. S. A., & El-Gendy, N. S. (2015). Response surface optimization of bioethanol production from sugarcane molasses by Pichia veronae strain HSC-22. *Biotechnology research international, 2015*.

Huu, N., Phuoc, D., Huu, T., & Thu, H. (2019). *Optimization of The FDM Parameters to Improve The Compressive Strength of The PLA-copper Based Products.* Paper presented at the IOP Conference Series: Materials Science and Engineering.

Joshi, S., Goyal, S., & Reddy, M. S. (2020). Influence of biogenic treatment in improving the durability properties of waste amended concrete: A review. *Construction and Building Materials, 263*, 120170.

Kareem, M., Bamigboye, G., Olawale, S., Tijani, M., Ishola, K., & Olawuyi, O. (2019). A Response Surface Approach for Determining Optimal Mix Parameters for Normal Strength Concrete. *journal of Engineering and Environmental Sciences, 1*(1).

Khankhaje, E., Salim, M. R., Mirza, J., Salmiati, Hussin, M. W., Khan, R., & Rafieizonooz, M. (2017). Properties of quiet pervious concrete containing oil palm kernel shell and cockleshell. *Applied Acoustics, 122*, 113-120. doi:https://doi.org/10.1016/j.apacoust.2017.02.014

Meng, F., Li, Y., Yuan, S., Wang, W., Zheng, Y., & Osman, M. K. (2020). Multiobjective combination optimization of an impeller and diffuser in a reversible axial-flow pump based on a two-layer artificial neural network. *Processes, 8*(3), 309.

Mo, K. H., Alengaram, U. J., Jumaat, M. Z., Lee, S. C., Goh, W. I., & Yuen, C. W. (2018). Recycling of seashell waste in concrete: A review. *Construction and Building Materials, 162*, 751-764.

Mohamad, N., Muthusamy, K., & Ismail, M. A. K. E. G. (2021). Cockle Shell as Mixing Ingredient in Concrete: A Review. *CONSTRUCTION, 1*(2), 9-20.

Moodi, Y., Mousavi, S. R., Ghavidel, A., Sohrabi, M. R., & Rashki, M. (2018). Using response surface methodology and providing a modified model using whale algorithm for estimating the compressive strength of columns confined with FRP sheets. *Construction and Building Materials, 183*, 163-170.

Poorarbabi, A., Ghasemi, M., & Moghaddam, M. A. (2020). Concrete compressive strength prediction using non-destructive tests through response surface methodology. *Ain Shams Engineering Journal, 11*(4), 939-949.

Ruslan, H. N., Muthusamy, K., Ariffin, N. F., Wahab, M. M. A., & Mohamad, N. (2022). Effect of crushed cockle shell as partial fine aggregate replacement on workability and strength of lightweight concrete. *Materials Today: Proceedings, 48*, 1826-1830.

Sitorus, A., Novrinaldi, & Bulan, R. (2020). Non-invasive moisture content measurement system based on the ESP8266 microcontroller. *Bulletin of Electrical Engineering and Informatics, 9*(3), 924-932. doi:10.11591/eei.v9i3.2178

Soundarya, N. (2021). A review on the physical & chemical properties of sea sand to be used a replacement to fine aggregate in concrete. *Materials Today: Proceedings*.

Yirgu, Z., Leta, S., Hussen, A., Khan, M. M., & Aragaw, T. (2021). Optimization of microwave-assisted carbohydrate extraction from indigenous Scenedesmus sp. grown in brewery effluent using response surface methodology. *Heliyon, 7*(5), e07115. doi:https://doi.org/10.1016/j.heliyon.2021.e07115

Zam, H. P., Abidin, E. Z., Karuppiah, K., & Salit, M. S. (2019). Humidity Controlling Material Development from Diatomite, Waste Glass and Cockle Shell Powder: An Experimental Study. *Malaysian Journal of Medicine and Health Sciences, 15*(204).

Zhang, Q., Feng, X., Chen, X., & Lu, K. (2020). Mix design for recycled aggregate pervious concrete based on response surface methodology. *Construction and Building Materials, 259*, 119776. doi:https://doi.org/10.1016/j.conbuildmat.2020.119776