Predicting The Optimal Compressive Strength of Sustainable Brick Using Response Surface Method (RSM)

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Abstract. *This research uses the Responses Surface Method (RSM) approach to make and optimize environmentally friendly bricks using a PET and epoxy resin mixture. The main input factors for the mixture are PET particles and epoxy resin as adhesive materials, while compressive strength is the primary response of the sustainable brick produced. RSM-based Central Composite Design (CCD) was used to assess the influence of PET particle variables (1-5mm) and epoxy resin ratio (30-50%) on the compressive strength response. The accuracy of the mathematical model created by CCD was tested using ANOVA. The RSM evaluation results show that the empirical findings suit linear and quadratic models for cost response and compressive strength. A coefficient of determination greater than 0.85 for all reactions indicates that the model can explain response variability. The optimization results show that the input variables PET particle and epoxy resin ratio have an average optimum value of 40% epoxy resin, each with a PET size of 3 mm. This optimal combination produces a maximum compressive strength of 13.37 MPa. The study and application of a mixture of PET particles and epoxy resin in making sustainable bricks has shown that these materials have great potential to increase the compressive strength of sustainable bricks.*

Keywords:

Sustainable brick, CCD, Epoxy, PET, RSM

1. Introduction

Currently, environmental problems, especially waste, are one of the urgent problems to be solved worldwide [1], [2], [3]. Population growth and economic development are directly proportional to the increase in waste, resulting in significant waste generation. This increase in waste creates various challenges for the environment. This increase in waste occurs not only in developed countries but also in developing countries. One of the main challenges related to this increase in waste is the problem of effective waste management. Utilizing waste efficiently reduces the amount of waste in the environment [4], [5].

The use of PET (Polyethylene Terephthalate) has now increased significantly. PET is widely used to make beverage bottles, cosmetics, food, and other products [6], [7]. This is because PET is light, solid, and easy to recycle. Appropriate handling is needed to handle PET waste to prevent environmental pollution. Recycling is one of the best ways to reduce the negative impact of increasing PET waste. This recycling process can reduce the amount of waste that currently ends up in landfills.

PET plastic waste is used to create brick composites or permeable bricks [8]. Apart from that, the use of PET is an innovation in reducing the amount of plastic waste and reusing it in development. Making permeable bricks using PET has the potential to be a sustainable solution in waste management. The construction industry generally uses large quantities of clay bricks in most buildings [9]. The use of bricks in building construction requires a lot of clay, which will have an impact on land degradation. Based on data from one brick Micro, Small, and Medium Enterprises (MSMEs) in West Java, it is stated that the demand for bricks reaches 6000 per day. If this number is multiplied by the number of brick MSMEs in Indonesia, it can undoubtedly exceed 1,000,000 bricks produced daily. To reduce this problem, it is necessary to substitute brick making with another material. PET plastic can be used as a substitute for making bricks. PET substitution is one way of reusing PET waste to protect existing natural resources. This permeable brick has several advantages that can reduce the effects of heat, absorb noise, and increase anti-skid performance [10]. Plastic waste has the potential to be utilized as an ingredient in brick production, with Polyethylene Terephthalate (PET), Low Density Polyethylene (LDPE), and High Density Polyethylene (HDPE) being the commonly employed types for this purpose [11], [12], [13], [14], [15].

When making bricks, a binding agent, such as water, is also needed to bond the clay. One of alternative to using adhesive is epoxy resin. Epoxy resin is a polymer that has excellent tensile strength. The use of epoxy resin in buildings has become a topic of research. Epoxy resin, known initially as a strong and long-lasting adhesive, is now widely used in various building and construction applications. Epoxy resin has high strength, weather resistance, and flexibility, making it an alternative building material.

Post-use polymer waste is the main component of solid waste, creating a substantial environmental burden because it is not easily damaged. Plastic waste can pollute the environment because of carbon bonds; primary and secondary carbon are in the plastic packaging. Therefore, it is necessary to turn plastic waste into new products that can be useful. High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), and Polyethylene (PET) are the materials most widely used for plastic packaging and plastic bottles. One method to decrease the community's waste is by recycling plastic materials. In China, Most PET bottle waste is recycled into fiber using a deposit refund system (DRS), which has great potential to reduce greenhouse gas emissions and significant pollutants [16].

On the other hand, the demand for construction and building materials is increasing along with the increasing population worldwide. One of the raw materials used for building materials is brick. The increase in brick production in the world occurred in several regions, such as China, India, Canada, and Indonesia [17], [18]. An increase in brickmaking will cause a reduction in natural resources of fertile clay that are only for use in brick production in the world. Adding natural materials to buildings will cause rapid depletion of natural resources. In addition, approximately 7% of total global energy is consumed in extracting, processing, and handling raw materials used for making concrete [19]. Therefore, using various wastes to produce bricks is vital for a sustainable product.

Mixing plastic waste with clay to make bricks is an alternative to recycling plastic waste. The utilization of plastic waste in construction has sparked a recent movement toward achieving sustainability. In addition, adding plastic to the concrete mixture can improve the product's characteristics [20], [21], [22], [23], [24]. One way to recycle plastic waste is by making eco-bricks. This eco-brick is an innovative form of recycling plastic waste into building materials.

In materials, epoxy is used as an adhesive between one brick and another [25]. Apart from being an adhesive, epoxy is also used as a substitute for some binders with glycolate obtained from Poly (ethylene terephthalate) waste [26]. In research, [27] epoxy resin can be used to improve the manufacture of Portland cement. In other research, epoxy resin was used as a material derived from PET bottle waste [15], [28]. Plastic waste can be used as a binding material for brick-making mixtures. This plastic waste can increase compressive strength and durability [29], [30], [31]. The results of the porosity test show an increase in the percentage of porosity, so the addition of PET produces a more porous surface than HDPE and LDPE. PET is more porous than HDPE and LDPE [32].

The use of sustainable brick has been widely done this is because sustainable brick is easy to produce and has a relatively good and strong compressive strength. The compressive strength of bricks is one of the most important parameters in construction and building material applications. This research is focused on producing suggestions for predicting compressive strength results in making permeable bricks using the Response Surface Method (RSM) approach. This RSM is one part of the Design of Experiment (DoE), which is widely used for optimization in the industry [33], [34], [35], [36]. The procedures in RSM include designing experiments, developing mathematical models, measuring optimal experimental parameters, and showing interconnected parameters [37]. RSM can also describe the influence of interactions between variables with 3D images [38]. This research can be used to select the characteristics of experimental specimens based on maximum compressive strength. The variable parameters in this study are ratio (%) and PET size (mm).

2. Research Method

2.1. Materials

The material chosen and used in this research was PET-based beverage bottles cut into small pieces. Meanwhile, the clay is sourced from areas with local brick producers. For the binder, epoxy resin is used, which is found in chemical companies, as shown in Fig 1. This research was carried out using more than 85% epoxy resin, bisphenol a diglycidyl ether (E-44 and E-51), produced using bisphenol A (BPA) and epichlorohydrin (ECH). In this experiment, hardener was used as a mixing ingredient for epoxy resin. A hardener is usually used to cure epoxy resin. Epoxy resin will cause a reaction if combined with hardener. The result of this reaction is a strong, durable, and often stiff material. The epoxy resin hardener in the experiment was 1:1. The hardener acted as a catalyst, starting the cross-linking reaction between the epoxy resin molecules.

Fig 1. Epoxy Resin Material

2.2. Experimental Design

The mix design in this research was carried out using Central Composite Design (CCD). Central Composite Design (CCD) is one of the experimental design parts of Response Surface Methodology (RSM) [39]. The CCD method can evaluate the number of experiments determining response optimization and variables. This CCD method has three points: factorial, axial points (star points), and central points [40]. Based of Design Expert experimental manufacturing using CCD resulted in 9 processes. Mix design with nine experiments with two factors: ratio (%) and size (mm). The variables determined for this experiment are shown in Table 1.

Table 1 The Level of Factors

Ratio (X1; Epoxy resin)	Size Particles (X2, mm)
10 (minimal)	1 (minimal)
50 (maximal)	5 (maximal)

The manufacture of experimental materials is carried out by mixing epoxy resin and hardener in a ratio of 50: 50 and then mixed with clay and PET particles so cure the sustainable brick. The schematic of preparation steps can be seen in Fig 2.

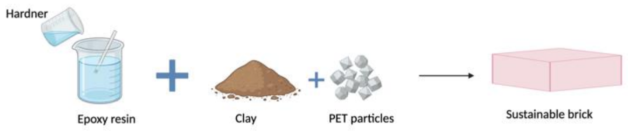

Fig 2. Schematic diagram for sustainable bricks preparation steps

2.3. Measurement of Compression Test

Compressive strength measurements were performed using ASTM C109-11 standards with a sample cube measuring 100x100x100 mm. The test was carried out after the drying process for seven days and continued with the burning process. Compression tests are carried out using a universal testing machine. Sample of a sustainable brick shape combined with PET and epoxy can see in Fig 3.

Fig 3. Sample of Sustainable Brick

2.4. Response Surface Method (SRM)

The Response Surface Method (RSM) is efficient for determining the relationship between parameters and response while estimating the influence of the ratio and size of PET particles [41],[42]. This RSM also includes optimization aspects by obtaining optimum compressive strength values. There are three main stages in developing the RSM model: collecting experimental data from the desired response, building the RSM model and validating its accuracy, and finally, optimizing the parameters used to meet the desired response variables [43]. This research optimizes the combined results of factors to minimize or maximize the desired output. Equation (1) describes a linear function:

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum\sum \beta_{ij} x_i x_j + \varepsilon \quad (1)$$

According to the equations, Y represents the response, β_0 is a constant, β_i, β_{ii}, and β_{ij} are coefficients of linear influence and double interactions, x_i,x_j are the independent factors, and ϵ is the error.

2.5. Optimization and Validation Procedures

The optimization aims to obtain optimal values for two independent parameters to produce the desired response variable. Visualization of the response model using graphical optimization shows the influence of epoxy resin ratio and PET particle size on the compressive strength of porous brick. The overall goal of this numerical optimization is to maximize the compressive strength. Verification of experimental data and predicted values was carried out to evaluate the efficiency and suitability of the predicted RSM model.

3. Results and Discussion

The influence of independent parameters in ratio (epoxy : clay) and PET size on compressive strength has been assessed. Computations of polynomial coefficients from experimental data predicted both response variables. ANOVA (Analysis of Variance) is characterized as a linear model. The resulting regression equation for all response surface methods can be illustrated in Equation 2:

$$y\ (\text{compression}) = 15.22 + 3.42X_1 - 1.46X_2 \quad (2)$$

Table 2 Coefficient Estimate of The Model

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	15.22	1	0.9246	12.96	17.48	-
A-Ratio (x1)	3.42	1	0.4811	2.24	4.60	1.0000
B-size (x2)	-1.46	1	0.9523	-1.82	0.8722	1.0000

This research created nine sets of data points using the RSM model. The set point design in this study includes two variables and one response. In planning the experiment, use the design expert application 11. Design-Expert is a software that provides a statistical method approach quickly developed by the state. Initially introduced in 1996, this software aids in executing experimental designs, including the determination of the most effective formula for a dosage form. Apart from optimization, this software can also interpret the factors in the experiment [44]. This software is divided into three research direction options depending on the design of the experiment to be carried out. There are screening, characterization, and optimization options [45]. The entire set of experimental data and predicted experiments after the compression test can be seen in Table 3 below:

Table 3 Experimental Results

Run Order	Factors		Response Compression Test (MPa)		Residual
	1 (Ratio)	2 (Size)	Experiment	Predicted	
1	10	1	10.42	12.16	-1.74
2	10	2.5	8.20	10.34	-2.14
3	10	5	17.47	19.00	-1.53
4	30	1	17.67	17.18	0.43
5	30	2.5	3.88	6.41	-2.53
6	30	5	5.68	3.50	2.18
7	50	1	7.33	5.32	2.01
8	50	2.5	13.81	13.26	0.55
9	50	5	22.86	20.10	2.77

This study considered the epoxy resin ratio and the PET intermediate particles' size to develop the RSM model. Ratio and particle size are helpful factors for optimizing polymer concrete aggregate [46], [47]. The response seen from this research is the compression test, which is one of the primary responses that is widely used to determine the relationship between factors in research related to materials [23], [38], [48], [49]. After collecting the experimental data, a polynomial model is calculated for the existing responses. Analysis of variance (ANOVA), primarily used to determine P-value and F-value, was performed to verify the adequacy of the model. F-value and P-value are essential parameters in evaluating the significance of the model. The results of the ANOVA model are presented in Table 4.

Table 4 ANOVA Analysis Results

Source	Sum of Squares	df	Mean Square	F_{value}	P_{value}	$P_{value} < 0.05$ = Significant
Model	293.91	2	146.95	26.46	0.0011	Significant
A-PET	13.02	1	13.02	2.34	0.1766	-
B-Ratio	280.89	1	280.89	50.57	0.0004	-
Residual	33.33	6	5.55	-	-	-
Cor Total	327.24	8	-	-	-	-

The adequacy of this model is carried out to describe the actual phenomenon accurately. Residuals were evaluated using the ANOVA value hypothesis for the satisfaction model. Standard deviation is calculated based on empirical values using standard residuals. The relationship between values and external residuals is shown in Fig 4, Based on Fig 4, it shows a linear relationship between residuals and expected probability. Each residual approaches the fit line associated with the model so that the model is normally distributed so that it can predict empirical observations. Specific optimization studies show that a good model should have a normal distribution [50], [51], [52].

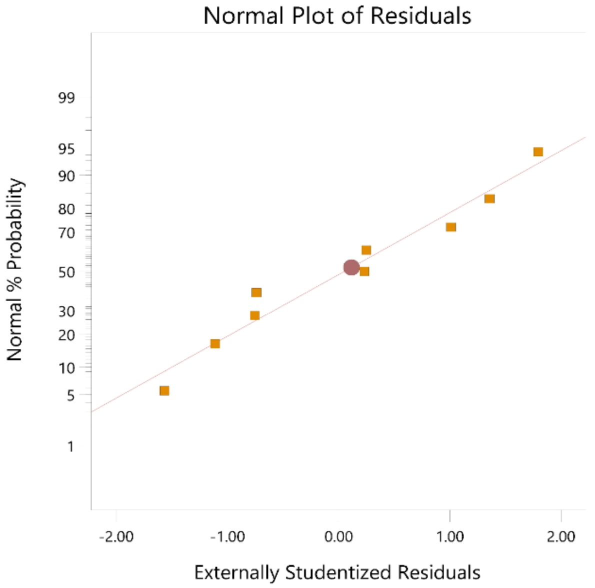

Fig 4. Expected Probability vs External Residual Plot

In Fig 5, the predicted and actual values are in agreement. This can be seen in the data points scattered near the line, and the model can estimate the value accurately. The diagnostic residual vs projected graph shows no outliers in the mode. The data points are scattered near the line, indicating that the model estimates the values correctly. Hassan, Mohammad Zaki, et al. [53] show that higher proximity of data points to the reference line indicates high accuracy.

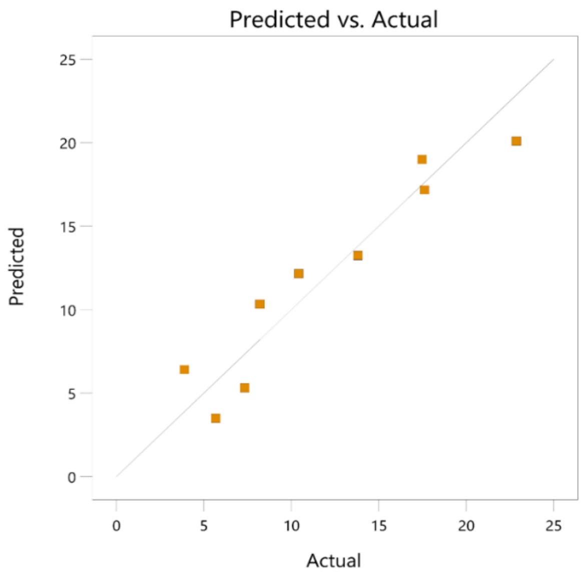

Fig 5. Predicted vs Actual Values

Fig 6 depicts residuals and estimated data points, which shows that residuals experiencing stunting have a random distribution in a specific range around the zero point. This indicates a lack of indicative patterns to confirm constant variance. The residual vs. predicted diagnostic graph also shows that the model has no outliers. [54] Sinkhonde's work was used to conclude that an ideal residual graph indicates that the model has no outliers.

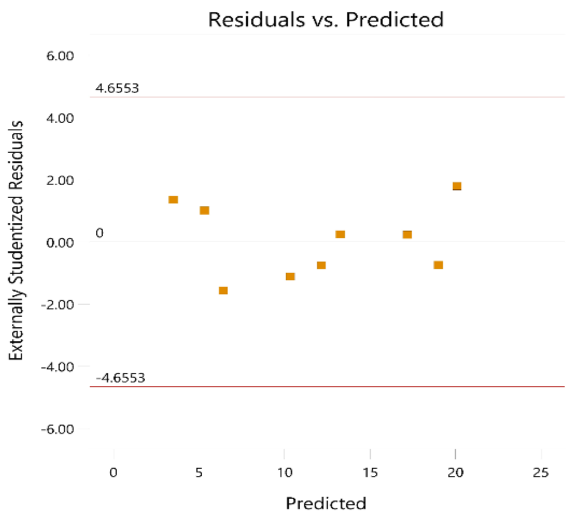

Fig 6. Residual vs Predictable Values

The contour graph also illustrates the interaction between size and ratio variables on the compression test response. The graph shows that the greater the compressive strength response value, the smaller the value of the size variable and the greater the value of the ratio variable. Fig 7 shows that larger PET particles have lower compressive properties. Therefore, eco-friendly bricks must be made with tiny particles for greater compressive strength. Increasing the epoxy resin content is associated with a higher ratio, increasing the compressive strength. The job of epoxy resin is to create a better bond between PET particles [55].

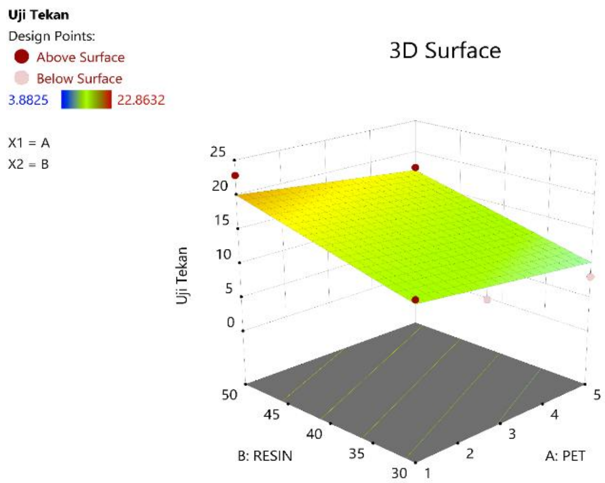

Fig 7. 3D Response Surface Plot of Compressive Strength Response

The optimization strategies recommended by the DOE software are tabulated in Table 5. Based on Table 5, factors are optimized to obtain maximum compressive strength. The optimization target was set to be in the range for PET particles' ratio and size parameters. Meanwhile, the response parameter is compressive strength at the maximum setting. Based on the optimization results in Fig 8, it was found that the chosen solution was 40% ratio and 3 mm for the PET particle size. The optimum compressive strength is 13.37 MPa. The desirability results also approach the unity value of one, which means that all the factors analyzed are entirely significant.

Table 5. Optimization Results of RSM on Sustainable Brick

Parameters	Goals	Level		Optimization Result
		Lower	Upper	
Ratio	in Range	30	50	40
Size	in Range	1	5	3
Compressive Strength	Maximize	3.8	22.8	13.37

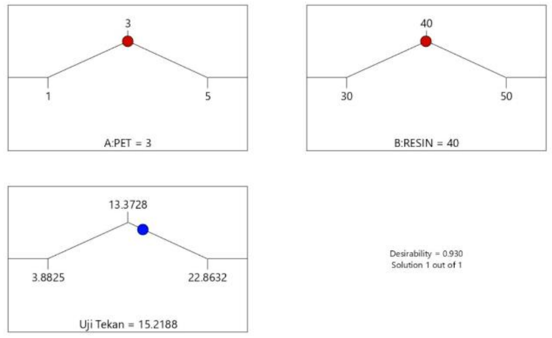

Fig 8. Optimization Result in Ramps Graphical View

The desirability results in histogram display in the Fig 9. The histogram indicates that each factor and response is individual. Combining all aspects with the recommended solution of 40% ratio and particle size of 3 mm can produce maximum values, thus showing the interaction between factors.

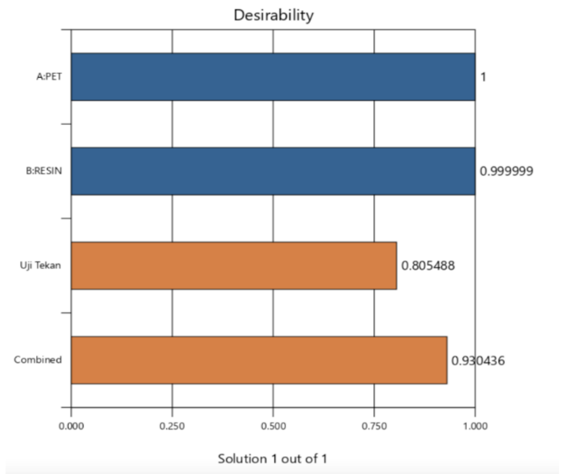

Fig 9. Optimization Result in Histogram Graphical View

4. Conclusions

The response surface method using central composite design has been proven to be a reliable tool for modeling, analyzing, and optimizing interactive effects to obtain a formulation that produces a product with the desired properties. Research shows that the use of epoxy resin has a more significant role. Parameters for optimal process capability regarding compressive strength are achieved with a composition of 40% epoxy resin with a PET size of 3 mm. In addition, the R2 value is close to one (1.00), which adequately represents the proposed linear regression model in predicting the optimal interaction parameters for the compressive strength response. This research also shows that CCD are an economical way to collect optimal values for mechanical behavior over short periods. The suggestions for further research are to include modifications to the epoxy resin that are more environmentally friendly and to calculate the temperature when burning the bricks.

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References

[1] M. Haqq and others, “Implementation of waste banks for reduction of solid waste in South Surabaya,” in *MATEC Web of Conferences*, 2019, p. 6021.

[2] C. Mukherjee, J. Denney, E. G. Mbonimpa, J. Slagley, and R. Bhowmik, “A review on municipal solid waste-to-energy trends in the USA,” *Renewable and Sustainable Energy Reviews*, vol. 119, p. 109512, 2020.

[3] D. Wulandari, S. H. Utomo, and B. S. Narmaditya, “Waste bank: Waste management model in improving local economy,” *International Journal of Energy Economics and Policy*, vol. 7, no. 3, pp. 36–41, 2017.

[4] A. Kholil, M. Budiaman, and A. A. Jumhur, “Waste management based on 3R in mutiara waste banks Bekasi City Indonesia,” *World Environment*, vol. 8, no. 3, pp. 71–76, 2018.

[5] W. Xue, K. Cao, and W. Li, “Municipal solid waste collection optimization in Singapore,” *Applied Geography*, vol. 62, pp. 182–190, 2015.

[6] M. Frigione, “Recycling of PET bottles as fine aggregate in concrete,” *Waste management*, vol. 30, no. 6, pp. 1101–1106, 2010.

[7] S. Perera, A. Arulrajah, Y. C. Wong, S. Horpibulsuk, and F. Maghool, “Utilizing recycled PET blends with demolition wastes as construction materials,” *Construction and building materials*, vol. 221, pp. 200–209, 2019.

[8] N. Fatchurrohman, G. W. Kang, and M. I. Adelino, “Product Development And Performance of Reinforced Metal Matrix Composite Brake Disc: Modelling, Simulation And Multi-Criteria Decision Making Technique,” *Spektrum Industri*, vol. 19, no. 2, p. 105, Oct. 2021, doi: 10.12928/si.v19i2.21951.

[9] M. Ijaz, S. R. Ahmad, M. Akram, W. U. Khan, N. A. Yasin, and F. A. Nadeem, “Quantitative and qualitative assessment of musculoskeletal disorders and socioeconomic issues of workers of brick industry in Pakistan,” *International Journal of Industrial Ergonomics*, vol. 76, p. 102933, 2020.

[10] S. Tighe, T. Smith, and R. Fung, “Concrete Pavements in Canada: A Review of their Usage and Performance,” in *Paper for Transportation Association of Canada Annual Conference*, 2001.

[11] I. I. Akinwumi, A. H. Domo-Spiff, and A. Salami, “Marine plastic pollution and affordable housing challenge: Shredded waste plastic stabilized soil for producing compressed earth bricks,” *Case Studies in Construction Materials*, vol. 11, p. e00241, 2019.

[12] R. Bhushaiah, S. Mohammad, and D. S. Rao, “Study of plastic bricks made from waste plastic,” *International Research Journal of Engineering and Technology*, vol. 6, no. 4, p. 6, 2019.

[13] S. Dinesh, A. Dinesh, and K. Kirubakaran, “Utilisation of waste plastic in manufacturing of bricks and paver blocks,” *International journal of applied engineering research*, vol. 2, no. 4, pp. 364–368, 2016.

[14] S. K. Intan and S. Santosa, “Utilization of PTE and LDPE plastic waste and building material waste as bricks,” *Korean Journal of Materials Research*, vol. 29, no. 10, pp. 603–608, 2019.

[15] H. Limami, I. Manssouri, K. Cherkaoui, and A. Khaldoun, “Study of the suitability of unfired clay bricks with polymeric HDPE \& PET wastes additives as a construction material,” *Journal of Building Engineering*, vol. 27, p. 100956, 2020.

[16] K. Zhou, Q. Liu, J. Feng, T. Chang, and J. Liu, “Comprehensive environmental performance of bottle-to-bottle recycling of PET bottles based on deposit-refund system in China,” *Waste Management*, vol. 172, pp. 90–100, 2023.

[17] M. U. Hossain, S. T. Ng, P. Antwi-Afari, and B. Amor, “Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction,” *Renewable and Sustainable Energy Reviews*, vol. 130, p. 109948, 2020.

[18] K. Rashid, E. U. Haq, M. S. Kamran, N. Munir, A. Shahid, and I. Hanif, “Experimental and finite element analysis on thermal conductivity of burnt clay bricks reinforced with fibers,” *Construction and Building Materials*, vol. 221, pp. 190–199, 2019.

[19] M. Mahdaoui *et al.*, “Building bricks with phase change material (PCM): Thermal performances,” *Construction and Building Materials*, vol. 269, p. 121315, 2021.

[20] J. O. Akinyele, U. T. Igba, T. O. Ayorinde, and P. O. Jimoh, “Structural efficiency of burnt clay bricks containing waste crushed glass and polypropylene granules, Case Stud,” *Const. Mater*, vol. 13, pp. 1–11, 2020.

[21] B. Debska and L. Lichołai, “The selected mechanical properties of epoxy mortar containing PET waste,” *Construction and Building materials*, vol. 94, pp. 579–588, 2015.

[22] A. Gregori, M. Mercuri, M. Angiolilli, and M. Pathirage, “Simulating defects in brick masonry panels subjected to compressive loads,” *Engineering Structures*, vol. 263, p. 114333, 2022.

[23] P. Munoz, M. A. Mend\'\ivil, V. Letelier, and M. P. Morales, “Thermal and mechanical properties of fired clay bricks made by using grapevine shoots as pore forming agent. Influence of particle size and percentage of replacement,” *Construction and Building Materials*, vol. 224, pp. 639–658, 2019.

[24] P. R. Pati, “Characterization of glass-epoxy composites using red brick dust particles,” *Materials Today: Proceedings*, vol. 18, pp. 3775–3779, 2019.

[25] S.-Y. Guo *et al.*, “Mechanical and interface bonding properties of epoxy resin reinforced Portland cement repairing mortar,” *Construction and Building Materials*, vol. 264, p. 120715, 2020.

[26] N. George, T. K. B. Sharmila, and T. Kurian, “Preparation of a one-component epoxy adhesive using PET bottle waste derived terephthalic dihydrazide as latent curing agent,” *International Journal of Adhesion and Adhesives*, vol. 98, p. 102524, 2020.

[27] A. Deriszadeh, F. Shahraki, D. M. Kalhori, and O. M. Jazani, "Epoxy/GO nanocomposite adhesives reinforced with waste blends of PET/GTR: Evaluation of mechanical properties," *Progress in Organic Coatings*, vol. 136, p. 105292, 2019.

[28] P. L. Paihte, A. C. Lalngaihawma, and G. Saini, "Recycled Aggregate filled waste plastic bottles as a replacement of bricks," *Materials Today: Proceedings*, vol. 15, pp. 663–668, 2019.

[29] O. Adiyanto, E. Mohamad, R. Jaafar, and M. Faishal, "Identification of Musculoskeletal Disorder among Eco-Brick Workers in Indonesia," *International Journal of Occupational Safety and Health*, vol. 13, no. 1, pp. 29–40, 2023.

[30] S. N. Amir and N. Z. Yusof, "Plastic in brick application," *Trends in Civil Engineering and its Architecture*, vol. 3, no. 1, p. 4, 2018.

[31] M.-H. Wu, C.-L. Lin, W.-C. Huang, and J.-W. Chen, "Characteristics of pervious concrete using incineration bottom ash in place of sandstone graded material," *Construction and Building Materials*, vol. 111, pp. 618–624, 2016.

[32] O. Adiyanto, E. Mohamad, Irianto, R. Jaafar, M. Faishal, and M. I. Rasyid, "Optimization of PET Particle-Reinforced Epoxy Resin Composite for Eco-Brick Application Using the Response Surface Methodology," *Sustainability*, vol. 15, no. 5, p. 4271, 2023.

[33] M. Abdulgader, Q. J. Yu, A. A. Zinatizadeh, P. Williams, and Z. Rahimi, "Application of response surface methodology (RSM) for process analysis and optimization of milk processing wastewater treatment using multistage flexible fiber biofilm reactor," *Journal of Environmental Chemical Engineering*, vol. 8, no. 3, p. 103797, 2020.

[34] K. E. Alyamac, E. Ghafari, and R. Ince, "Development of eco-efficient self-compacting concrete with waste marble powder using the response surface method," *Journal of cleaner production*, vol. 144, pp. 192–202, 2017.

[35] M. A. Bezerra, R. E. Santelli, E. P. Oliveira, L. S. Villar, and L. A. Escaleira, "Response surface methodology (RSM) as a tool for optimization in analytical chemistry," *Talanta*, vol. 76, no. 5, pp. 965–977, 2008.

[36] N. Mohamad Yatim, A. Shaaban, M. F. Dimin, F. Yusof, J. Abd Razak, and others, "Application of response surface methodology for optimization of urea grafted multiwalled carbon nanotubes in enhancing nitrogen use efficiency and nitrogen uptake by paddy plants," *Journal of Nanotechnology*, vol. 2016, 2016.

[37] U. A. Toor, T. T. Duong, S.-Y. Ko, F. Hussain, and S.-E. Oh, "Optimization of Fenton process for removing TOC and color from swine wastewater using response surface method (RSM)," *Journal of Environmental Management*, vol. 279, p. 111625, 2021.

[38] A. Habibi, A. M. Ramezanianpour, M. Mahdikhani, and O. Bamshad, "RSM-based evaluation of mechanical and durability properties of recycled aggregate concrete containing GGBFS and silica fume," *Construction and Building Materials*, vol. 270, p. 121431, 2021.

[39] E. W. Elsayed and M. F. Emam, "Application of Response Surface Methodology Using Face-centered Central Composite Design for Studying Long-Term Stability of Gliclazide-Loaded Multiparticulate Systems," *Journal of Pharmaceutical Sciences*, 2024.

[40] H. Karyab, M. Ghasemi, F. Ghotbinia, and N. Nazeri, "Efficiency of chitosan nanoparticle with polyaluminum chloride in dye removal from aqueous solutions: Optimization through response surface methodology (RSM) and central composite design (CCD)," *International Journal of Biological Macromolecules*, vol. 249, p. 125977, 2023.

[41] M. Yan *et al.*, "Design and evaluation of a novel heliostat-based combined cooling, heating, and power (CCHP) system: 3E analysis and multi-criteria optimization by response surface methodology (RSM)," *Energy*, vol. 285, Dec. 2023, doi: 10.1016/j.energy.2023.129389.

[42] R. T. Mushtaq *et al.*, "Multi-objective optimization of laser polishing parameters for enhanced mechanical properties, sustainability, and surface finish of 3D-Printed industrial ABS polymers using response surface methodology (RSM)," *Journal of Materials Research and Technology*, vol. 29, pp. 3168–3184, Mar. 2024, doi: 10.1016/j.jmrt.2024.02.023.

[43] P. Zafari and A. Ghaemi, "Mixed MDEA-PZ amine solutions for CO2 capture: Modeling and optimization using RSM and ANN approaches," *Case Studies in Chemical and Environmental Engineering*, vol. 8, Dec. 2023, doi: 10.1016/j.cscee.2023.100509.

[44] Y. Luo, P. Guo, J. Gao, J. Meng, and Y. Dai, "Application of Design-Expert response surface methodology for the prediction of rejuvenated asphalt fatigue life," *Journal of Cleaner Production*, vol. 379, p. 134427, 2022.

[45] R. Chikati, T. A. Mpandanyama, D. Nkazi, P. Khangale, and J. Gorimbo, "Optimization and evaluation of the distribution of Fischer-Tropsch products over a cobalt-based catalyst utilising design expert software," *Heliyon*, vol. 10, no. 1, 2024.

[46] W. Ferdous *et al.*, "Optimal design for epoxy polymer concrete based on mechanical properties and durability aspects," *Constr Build Mater*, vol. 232, p. 117229, 2020.

[47] W. Boransan, T. Kerdphol, and V. Phunpeng, "Experimental Manufacturing Methods of Glass Fiber Composites Considering Flexural Behaviour," *Spektrum Industri*, vol. 19, no. 2, p. 87, Oct. 2021, doi: 10.12928/si.v19i2.21658.

[48] X. Kang, Y. Gan, R. Chen, and C. Zhang, "Sustainable eco-friendly bricks from slate tailings through geopolymerization: synthesis and characterization analysis," *Construction and Building Materials*, vol. 278, p. 122337, 2021.

[49] K. Suresh, "Recycling of fly ash for development of value added products," *Materials Today: Proceedings*, vol. 46, pp. 5666–5674, 2021.

[50] S. Dixit and V. L. Yadav, "Optimization of polyethylene/polypropylene/alkali modified wheat straw composites for packaging application using RSM," *Journal of Cleaner Production*, vol. 240, p. 118228, 2019.

[51] H. Fang *et al.*, "Ultra-sensitive nanoprobe modified with tumor cell membrane for UCL/MRI/PET multimodality precise imaging of triple-negative breast cancer," *Nano-micro letters*, vol. 12, pp. 1–14, 2020.

[52] M. E. Imanian and F. R. Biglari, "Modeling and prediction of surface roughness and dimensional accuracy in SLS 3D printing of PVA/CB composite using the central composite design," *Journal of Manufacturing Processes*, vol. 75, pp. 154–169, 2022.

[53] M. Z. Hassan, S. M. Sapuan, S. A. Roslan, S. Sarip, and others, "Optimization of tensile behavior of banana pseudo-stem (Musa acuminate) fiber reinforced epoxy composites using response surface methodology," *Journal of Materials Research and Technology*, vol. 8, no. 4, pp. 3517–3528, 2019.

[54] D. Sinkhonde, R. O. Onchiri, W. O. Oyawa, and J. N. Mwero, "Response surface methodology-based optimisation of cost and compressive strength of rubberised concrete incorporating burnt clay brick powder," *Heliyon*, vol. 7, no. 12, 2021.

[55] A. P. King, "225Ac-MACROPATATE: a novel $α$-particle peptide receptor radionuclide therapy for neuroendocrine tumors," *Journal of Nuclear Medicine*, vol. 64, no. 4, pp. 549–554, 2023.