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RESPONSE SURFACES FOR PROPERTIES OF CONCRETE WITH CLAY BRICK POWDER AS SUBSTITUTE FOR CEMENT

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This study examined the application of pulverize clay brick wastes as alternative constituent for Portland cement replacement in green concrete production using the response surface methodology (RSM). The adopted response surface approach is central composite design (CCD). The statistical models were developed between the concrete constituents (clay brick powder and water cement ratio) and their response variables (slump, compressive and split tensile strength). Relationships were established and mathematical models in terms of actual factors from predicted responses were developed. The influence of the considered factors on the properties of response were visually observed from the contour and response surface plots. The statistical models of experimental values clearly depict that the obtained experimental values are in close agreement with the predicted values, which validates the response surface models with desirability value of 1. The results show that pulverized clay brick waste have significant influence on the properties of concrete than the water cement (w/c) ratio, however, a declining trend was seen for all analyzed concrete properties. In addition, this study showed that the pulverized waste brick can be used as alternative substitute for Portland cement up to 20% in the production of sustainable concrete.

Keywords: Mathematical modeling, Waste clay brick, Cement, Sustainable concrete.

1 INTRODUCTION

Sustainability is a key issue for the construction industry because the industry relies more on nonrenewable resources for construction materials (Calkins 2009). Moreover, these materials constitute major components for the construction of engineering infrastructures; hence, limiting the impact of these materials on the environment is now very crucial. Concrete is one of the commonly used construction materials and finding ways to reduce its production impact on the environment is important (Akinwumi *et al.* 2016, Olofinnade *et al*. 2018b). Moya *et al*. (2010) reported that the process of producing concrete demands a considerable amount of raw materials and energy thus resulting in the emission of significant quantity of greenhouse gases (GHG) into the atmosphere. Previous studies emphasized on the impact of CO_2 emission on the environment (Shakir *et al*. 2014, Olofinnade *et al*. 2016). Meanwhile, studies also depicted that the impact of cement on the environment can be limited through the use of supplementary cementitious materials such as metakaolin, fly ash and slag used as alternative material to partially replace cement (Bektas *et al.* 2008, Schneider *et al*. 2011). Moreso, additional benefits include energy and cost saving (Olofinnade *et al*. 2016, 2017, 2018a). With the continuous advancement in knowledge, new materials are being researched upon as alternative materials for cement replacement. One of such materials is clay brick wastes generated mostly from brick and ceramic industry or as construction and demolition (C&D) wastes (Bektas *et al*. 2008, Olofinnade *et al*. 2018a). The clay bricks are produced from natural clay by calcination at very high temperature not less than 900°C (Olofinnade *et al*. 2018a). The clay brick contains relevant chemical compositions used to classified pozzolanic materials and exhibit amorphousness due to the high temperature exposure (Olofinnade *et al*. 2018a). Consequently, when the clay brick waste is finely ground into powder, it can be deployed as pozzolana to partially replace cement in concrete or mortar production instead of discriminate disposing as reported by (Olofinnade *et al*. 2018a). Previous studies by researchers have focused on using clay brick wastes as partial replacement for cement (Bektas *et al*. 2008, Olofinnade *et al*. 2016, 2018a) and natural aggregates (Aliabdo *et al*. 2014) in concrete composites. This study aims at developing mathematical models using the response surface methodology (RSM) to model the response of concrete properties containing pulverize clay brick wastes as alternative constituent for Portland cement replacement in green concrete.

2 MATERIALS

In this study, the pulverized clay brick wastes were sourced as generated wastes from brick factory in Lagos Metropolis, and used to partially replace Portland cement in concrete at dosage percentages of 0%, 10%, 20%, 30%, and 40%. The Portland cement (Grade 42.5) with specific gravity of 3.15 was used in all the concrete mixes in accordance to NIS 444 (2003). The natural gravel with a maximum size of 19 mm and specific gravity of 2.70, while the sand with a particles size ranging from 0.075 to 4.75 mm and specific gravity of 2.62 were used in this study. The chemical compositions of the clay brick powder and cement are presented in Table 1. Example of the concrete mix proportioning is presented in Table 2. Tests were carried out in accordance with BS EN 12350-2 (2009) and BS EN 12390 (2002) respectively.

Table 1. Chemical composition of cement and clay brick powder.

Composition%	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**K_2O**	**Na_2O**	**TiO_2**	**P_2O_5**
Cement	24.08	19.40	6.28	74.25	3.96	0.85	1.74	0.62	1.21
Clay brick	60.64	14.23	4.93	0.27	1.72	1.44	1.94	0.98	0.90

2.1 Experimental Design

The RSM comprises of statistical and mathematical procedures of analyzing and modelling problems involving a response influenced by several factors. In this study, RSM was used to the analyzed and developed relationship for fresh and hardened properties of concrete at 28 days as the response of interest. The response surface design approach used is the face-centred central composite design (CCD) with α = 1 and full quadratic model for each response. The dosage percentage of clay brick (%) is represented as A and water-cement ratio (w/c) is coded as B; both considered as factors. The Eq. (1) depicts the full quadratic model used in this study.

$$Y=\beta_0+\beta_1A+\beta_2B+\beta_{12}AB+\beta_{11}A^2+\beta_{22}B^2 \quad (1)$$

where Y is predicted response, β_0 is the intercept, β_1 and β_2 are linear influence coefficients, β_{11} and β_{22} are quadratic influence coefficients, and β_{12} is interaction coefficient.

Table 2. Concrete mix proportion.

Mixture	Control Mix	CB10%	CB20%	CB30%	CB40%
w/b ratio	0.5	0.5	0.5	0.5	0.5
Water, kg/m^3	197	197	197	197	197
Cement, kg/m^3	385	347	308	269.5	231
Sand, kg/m^3	790	790	790	790	790
Gravel, kg/m^3	1073	1073	1073	1073	1073
Clay brick, kg/m^3	0	38	77	115.5	154
Target strength, MPa	25	25	25	25	25

3 RESULTS AND DISCUSSION

3.1 Response Surface for Fresh Properties: Slump

The obtained values from the experiment show that the slump shows a reduction trend as the percentage of the clay brick content increases. The obtained values were used to evaluate the influence of w/c ratio and clay brick (%) in fresh concrete mixes using RSM. Table 3 depicts the results of the analysis of variance (ANOVA) carried out for slump response surface quadratic model. The results show that the clay brick content % effect ($P < 0.0001$) and the quadratic clay brick content% effect ($P < 0.0001$) were statistically significant. The mathematical model for the slump is presented in Eq. (2). Furthermore, Table 4 shows the actual and predicted values of slump (mm) of fresh concrete.

$$\text{Slump (mm)(Y)} = 7185.81990 + 0.26998\ A - 28794.78610\ B - 0.056409\ AB - 0.024390A^2 + 29085.26267\ B^2 \tag{2}$$

Table 3. ANOVA for slump (mm) response surface quadratic model.

Source	Sum of Squares	Degree of freedom	Mean Square	F Value	p-value Prob > F
Model	1653.08	5	330.62	115.75	< 0.0001
Clay Brick, A (%)	1374.13	1	1374.13	481.08	< 0.0001
w/c ratio, B	3.817E-004	1	3.817E-004	1.336E-004	0.9911
AB	1.328E-004	1	1.328E-004	4.649E-005	0.9948
A^2	254.62	1	254.62	89.14	< 0.0001
B^2	1.56	1	1.56	0.55	0.4839
Residual	19.99	7	2.86		
Lack of Fit	19.99	5	4.00		
Pure Error	0.000	2	0.000		
Cor Total	1673.08	12			

3.2 Response Surface for Compressive and Split Tensile Strength

The obtained values from the experiment show that the compressive strength and the split tensile strength of the hardened concrete measured reduce as the percentage of the clay brick content increases. However, the results show a significant compressive strength increase at lower dosage level of cement replacement with clay brick powder (%). The obtained values were used to evaluate the influence of w/c ratio and clay brick (%) in fresh concrete mixes using RSM.

Table 4. Actual and predicted values of slump, compressive and split tensile strength (MPa) at 28 days.

Run	**Slump (mm)**		**Compressive Strength (MPa)**		**Split tensile strength (MPa)**	
	Actual Value	Predicted Value	Actual Value	Predicted Value	Actual Value	Predicted Value
1	55.00	54.84	23.00	23.44	3.80	3.78
2	55.00	59.00	24.89	24.02	3.66	3.63
3	60.00	59.74	20.00	20.02	3.34	3.35
4	30.00	29.68	20.00	20.02	3.34	3.27
5	55.00	54.10	20.00	19.83	2.55	2.51
6	55.00	54.10	23.56	23.58	3.34	3.35
7	30.00	30.42	23.00	23.44	3.34	3.35
8	30.00	30.39	23.67	23.63	3.80	3.80
9	55.00	54.82	23.00	22.96	3.80	3.83
10	55.00	54.10	22.00	22.04	3.34	3.35
11	45.00	45.05	23.00	23.02	3.34	3.35
12	60.00	59.02	23.50	23.79	2.80	2.87
13	60.00	59.75	23.60	23.44	2.55	2.56

Table 4 also shows the actual and predicted values of compressive and split tensile strength of concrete. Table 5 depict the results of the ANOVA carried out for strength response surface quadratic model respectively. The results show that for compressive strength, the quadratic clay brick content % effect ($P < 0.0036$), were statistically significant. Similarly, for split tensile strength, the quadratic clay brick content % effect ($P < 0.0005$), were statistically significant. The mathematical model in terms of actual factors for the compressive strength and split tensile strength are presented in Eqs. (3) and (4) respectively.

Compressive Strength,

$$\text{Y (MPa)} = -4755.32581 + 164.46331\,\mathbf{A} + 19253.54710\,\mathbf{B} - 666.74000\,\mathbf{AB} + 0.044192\,\mathbf{A^2} - 19391.46172\,\mathbf{B^2} - 0.097500\,\mathbf{A^2B} + 676.00000\,\mathbf{AB^2} \tag{3}$$

Split Tensile Strength,

$$\text{Y (MPa)} = -390.89076 + 0.23793\,\mathbf{A} + 1592.56093\,\mathbf{B} - 0.51178\,\mathbf{AB} - 4.4137\text{E-}004\,\mathbf{A^2} - 1606.34270\,\mathbf{B^2} \tag{4}$$

Furthermore, the contour and response for strength properties are depicted in Figures 1 and 2.

Table 5. ANOVA for split tensile strength (STS) and compressive strength (CS) MPa quadratic model.

Source	**Sum of Squares**		**Degree of freedom**		**Mean Square**		**F Value**		**p-value Prob > F**	
	STS	**CS**	**STS**	**CS**	**STS**	**CS**	**STS**	**CS**	**STS**	**CS**
Model	2.25	29.09	5	7	0.45	4.16	227.06	16.16	< 0.0001	0.0037
Clay brick, A (%)	2.14	9.78	1	1	2.14	9.78	1079.39	38.04	< 0.0001	0.0016
w/c ratio, B	8.686E-003	0.22	1	1	8.686E-003	0.22	4.38	0.87	0.0746	0.3931

Table 5 (contd). ANOVA for STS and CS MPa quadratic model.

Source	Sum of Squares		Degree of freedom		Mean Square		F Value		p-value Prob > F	
	STS	CS	STS	CS	STS	CS	STS	CS	STS	CS
AB	7.338E-003	0.078	1	1	7.338E-003	0.078	3.70	0.30	0.0957	0.6046
A^2	0.071	6.80	1	1	0.071	6.80	35.89	26.44	0.0005	0.0036
B^2	4.902E-003	0.062	1	1	4.902E-003	0.062	2.47	0.24	0.1598	0.6439
Residual	0.014	1.29	7	5	1.981E-003	0.26				
Lack of Fit	0.014	1.05	4	3	3.468E-003	0.35		2.90		0.2665
Pure Error	0.000	0.24	3	2	0.000	0.12				
Cor Total	2.26	30.37	12	12						

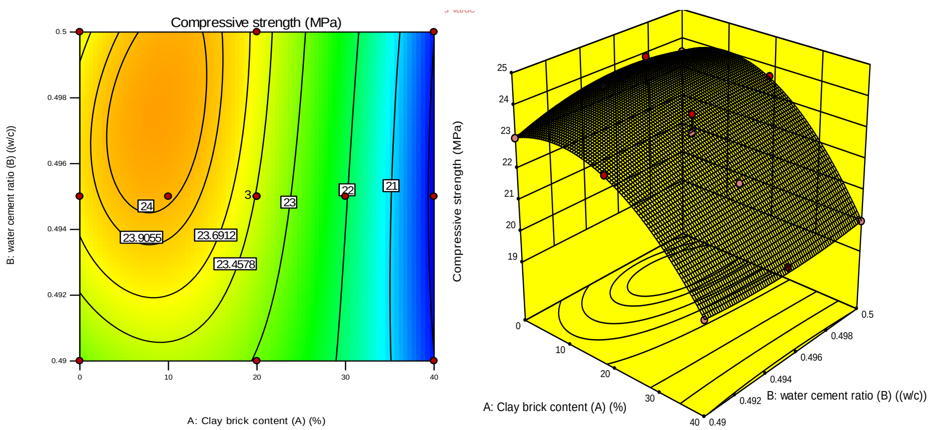

Figure 1. Contour plot and response surface of compressive strength.

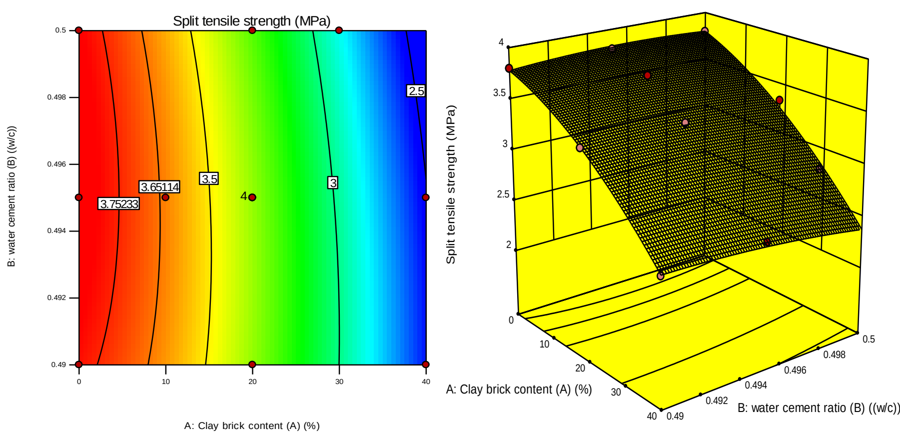

Figure 2. Contour plot and response surface of split tensile strength.

4 CONCLUSION

In this study, pulverized clay brick waste was used as partial substitute for cement in concrete of moderate strength. The experimental study clearly indicated a significant decrease in the slump with increasing clay brick powder content. Moreover, the compressive and split tensile strength of the hardened concrete specimens were found to decrease as the replacement quantity of clay brick increases compared to control. Using the response surface method, the measured values were analyzed by the face-centered composite surface design (CCD) employing the full quadratic model to determine the effect of clay brick and water-cement variables on the response, it was found that the models were significant. The results showed that pulverized clay brick waste had significant effect on the properties of concrete compared to water-cement (w/c) ratio, however, a declining trend was seen for all analyzed concrete properties. However, linear influence of clay brick content (%) was noticed to be more significant in the models.

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References

Akinwumi, I. I., Awoyera, P. O., Olofinnade, O. M., Busari, A. A., and Okotie, M, Rice Husk as A Concrete Constituent: Workability, Water Absorption and Strength of The Concrete, *Asian Journal of Civil Engineering*, 17, 887–898, 2016.

Aliabdo, A. A., Abd-Elmoaty, A. M., and Hassan, H. H., Utilization of Crushed Clay Brick in Concrete Industry, *Alexandria Engineering Journal,* 53(1), 151–168, 2014.

Bektas, F., Kejin, W., and Ceylan, H., Use of Ground Clay Bricks as A Pozzolanic Materials in Concrete, *Journal of ASTM International,* 5, ISSN 1546-962X, 2008.

BS EN 12350-2. *Testing of Fresh concrete,* European Committee for Standardization, 2009.

BS EN 12390. *Testing Hardened concrete,* European Committee for Standardization, 2002.

Calkins, M., *Materials for Sustainable Sites: A Complete Guide to The Evaluation, Selection, and Use of Sustainable Construction Materials.* Hoboken: Wiley, 2009.

Moya, J. A., Pardo, N., and Mercier, A., *Energy Efficiency and CO_2 Emissions: Prospective Scenarios for The Cement Industry,* JRC Scientific and Technical Report, 2010.

NIS 444: Part 1, *Composition, Specifications and Conformity Criteria for Common Cements*, Nigeria Industrial Standards Center, Standard Organisation of Nigeria (SON), Abuja, 2003.

Olofinnade, O. M, Ndambuki, J. M, Ede, A. N., and Booth, C, Application of Waste Glass Powder as a Partial Cement Substitute Towards More Sustainable Concrete Production, *International Journal of Engineering Research in Africa*, 31, 77–93, 2017.

Olofinnade, O. M., Ede, A. N., and Booth, C. A., *Sustainability of Waste Glass Powder and Clay Brick Powder as Cement Substitute in Green Concrete*, Handbook of Environmental Materials Management, Springer, 2018a.

Olofinnade, O. M., Ede, A. N., Ndambuki, J. M, and Bamigboye, G. O., Structural Properties of Concrete Containing Ground Waste Clay Brick Powder as Partial Substitute for Cement, *Materials Science Forum,* 866, 63–67, 2016.

Olofinnade, O. M., Ede, A. N., Ndambuki, J. M., Ngene, B. U., Akinwumi, I. I., and Ofuyatan, O., Strength and Microstructure of Eco-Concrete Produced Using Waste Glass as Partial And Complete Replacement for Sand, *Cogent Engineering*, 5, 1483860, 1-19, 2018b.

Schneider, M., Romer, M., Tschudin, M., and Bolio, H, Sustainable Cement Production –Present and Future, *Cement and Concrete Research,* 43, 642–650, 2011.

Shakir, A. A., Naganathan, S., and Mustapha, K. N, Effect of Quarry Dust and Billet Scale Additions on The Properties of Fly Ash Bricks, *Iranian Journal of Science and Technology. Transactions of Civil Engineering*, 38(C1), 51–60, 2014.