EVALUATING THE EFFECT OF SUPERPLASTICIZER ON THE PROPERTIES OF ROLLER COMPACTED CONCRETE USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

In this study, the effect of partial replacement of fine aggregate with crumb rubber, and the addition of superplasticizer by weight of cement in roller compacted concrete (RCC) pavement was studied and analyzed using response surface methodology (RSM). Roller compacted rubbercrete (RCR) is used as the terminology for RCC where fine aggregate is partially replaced with crumb rubber. Before testing, the mixes (experimental work) were designed using RSM with the central composite design applied. After executing the experimental works, regression analysis was used to obtain the model equations for Vebe time, compressive strength, and flexural strength. The RSM regression analysis showed that Vebe time decreases addition of crumb rubber and superplasticizer, compressive and flexural strength decreases with increase in crumb rubber and increases with the addition of superplasticizer. Therefore, the addition of superplasticizer can be used to mitigate the negative effect of crumb rubber on the compressive and flexural strength of RCR. The RSM regression analysis also showed that there is a good correlation between the predicted models and the experimental results. Then, multi-objective optimization was achieved when Vebe time is minimized, compressive and flexural strengths maximize. Based on the results of optimization, an optimum mixture can be achieved with a 10% volume replacement of fine aggregate with crumb rubber, and 1.51% addition of superplasticizer by weight.

Keywords: crumb rubber, superplasticizer, roller compacted rubbercrete, compressive strength, flexural strength, response surface methodology.

1. INTRODUCTION

Generation of waste tires keeps increasing annually due to growth in population which leads to increased usage of vehicles (He *et al*., 2016). With the world focusing on environmental sustainability, disposal of waste tires are sometimes difficult and continue to pose threat most especially to the developed countries (WBCSD, 2008, Azevedo *et al*., 2012). According to the estimation made every one person in the highly developed, which cumulatively sums up to, about 1 billion tires annually, and is expected to reach 1.2 billion annually by 2030 (Thomas *et al.*, 2015).Globally, about 4 billion waste tires are disposed of as landfill, with more than half disposed of without pre-treatment(WBCSD, 2008, Azevedo *et al*., 2012). The major challenge with the disposal of the waste tires is they are non-biodegradable in nature and consumes a lot of space due to their large pore volume. They also provide shelter and breeding grounds for harmful insects, reptiles, and rodents, thus increasing the chances for the spread of the epidemic. They also cause environmental, aesthetic and health hazards (Aliabdo *et al*., 2015). Several methods have been adopted to challenge these issues; however, most of the issues affect the environmental sustainability negatively. With the rapid growth and development in the construction industry, with concrete the most readily available and used material and its constituent are all from natural resources, there is high tendency that these natural materials will deplete and become more scarce and expensive, most especially aggregate which constitutes about 70% of concrete constituent materials (Meddah *et al*., 2014). In trying to address these issues in the

construction industry and problems related to waste tire disposal, researchers have been trying to reduce the waste tire to smaller sizes by grinding and removing the steel, threads, and contaminant to form crumb rubber, then it is used as a partial replacement to fine or coarse aggregate. This has helped in reducing the cost of concrete and also too much dependent on natural aggregate (Thomas *et al*., 2016, Thomas and Gupta, 2016, Gupta *et al.*, 2016).

Roller compacted concrete (RCC) is a special type of dry mixed concrete having similar ingredients and properties as conventional concrete but with lower water/cement, lower paste content, higher fine aggregate content and no entrained air (Hesami *et al.*, 2016b, Mehta and Monteiro, 2006). The major advantages of RCC over conventional concrete including high construction speed and reduced construction cost (Mohammed and Loong, 2015).

RCC pavement mix contains water and cementitious materials and large percentage of aggregate with the nominal maximum size of not greater than 19 mm. RCC is mixed to form a relatively stiff mix and is placed in layers not greater than 254 mm (10 inches) compacted thickness. After that properly compacted using steel wheel vibratory roller, and finally, rubber tire rollers used to give a smooth surface to the pavement (Adamu *et al*., 2016). In order to ensure higher performance and specified engineering properties, RCC should be made in such a way that they will be easier to compact and should have adequate properties for the roller compaction. The major factors that influence the compatibility of RCC are the water to cementitious materials ratio, the mineral aggregate gradation and as well as the shape and the

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amount of fine and coarse aggregate in the mix (Hesami *et al.*, 2016a).However, the major problems related to RCC pavement are the rigidity and relative tendency to crack because of plastic shrinkage and low tensile strength (Ghahari *et al.*, 2017). These affect its performance and shorten the RCC pavement design life. Therefore, to tackle this issue, crumb rubber can be added as partial replacement of fine aggregate in RCC. The crumb rubber will increase the ductility of RCC pavement, and will absorb the deformation and strain energy caused by traffic loads due to its high elastic and deformation properties (Moghaddam *et al.*, 2011). However, addition of crumb rubber to RCC pavement will decrease its compressive strength by increasing voids in the hardened matrix. Therefore, in other to reduce this effect, increasing the consistency of RCC will help the paste to fill the excess voids in the hardened matrix caused by crumb rubber. This can be done by addition of water reducing admixtures such as superplasticizer to RCC pavement.

Water-reducing admixtures (superplasticizer) are generally used in concrete to increase strength with lower water to cement ratio (Yoyok Setyo Hadiwidodo, 2009, Oyekan and Oyelade, 2011). These admixtures have been used in RCC to increase its consistency by helping in the distribution of the little paste content, lower its water to cement ratio and improve its strength. Also, its application in RCC can be much higher than in conventional concrete due to the drier nature of RCC (Fuhrman, 2000). However, the dosage of the admixture should be determined in the laboratory prior to the application as its excess might resultin little improvement and sometimes adverse effects on the performance of RCC (Fuhrman, 2000, Gregory E. Halsted, 2009). However, the effect of water reducing admixtures in RCC is mainly dependent on the amount of materials finer than 75 μm which is used to increase the cohesiveness and reduce the pore volume in the paste(ACI 325-10R, 2001).

Therefore, the main objective of this paper is to use response surface methodology (RSM), to study the effect of addition of superplasticizer on the consistency, compressive strength, and flexural strength of roller compacted rubbercrete (RCR). RCR is the terminology given to RCC where fine aggregate is partially replaced with crumb rubber. The Response surface methodology (RSM) is the most suitable and commonly used statistical and mathematical technique used for analyzing and developing models between one or more independent variables and responses. In addition, RSM can be used for model multi-objective optimization by setting defined desirable goals based on either the responses or the variables(Montgomery, 2008).

2. MATERIALS AND MIX PROPORTION

2.1 Materials
Ordinary cement Type I which conforms to ASTM C150M-15, with a specific gravity of 3.15 and having chemical properties as shown in Table-1 was used. Natural sand with nominal maximum size aggregate of 4.75 mm, specific gravity of 2.65, fineness modulus of 2.86, water absorption of 1.24%, and particle size gradation as shown in Figure-1. Two sizes of coarse aggregate which are 19 mm maximum size aggregate having a specific gravity of 2.66 and absorption of 0.48%, and chips of 6.3 mm maximum size with a specific gravity of 2.55 and absorption of 1.05% as shown in Figure-1. Three sizes of crumb rubber were combined so as to achieve gradation similar to fine aggregate. After several series of trial combinations, using sieve analysis according to ASTM D5644, final proportion of 40% of 0.595 mm (mesh 30) size, 40% of 1 - 3 mm size, and 20% of 3 - 5 mm size were used. Their combined particle size curve is shown in Fig. 1. As one of the basic requirement for any RCC pavement is that 2 to 8 % of the aggregate should be materials finer than 75 μm so as to produce a cohesive paste with lower void contents, in this study, fly ash conforming to ASTM C612 and ASTM C311 having properties as shown in Table-1 was used as a filler (material finer than 75 μm). While Polycarboxylate base viscocrete-2044 which conform to the requirements of EN 934-2 was used as water reduction admixture.
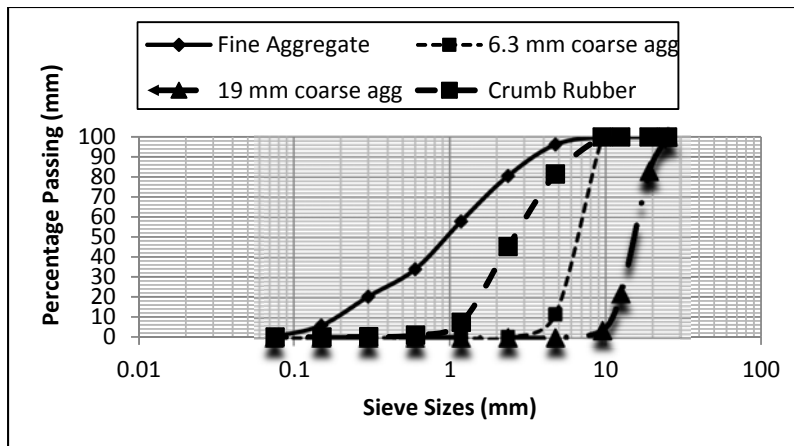

Figure-1. Sieve analysis of aggregate.

Table-1. Properties of cement and fly ash.

| Oxides composition (%)	Cement	Fly ash
SiO_2	20.76	57.06
Al_2O_3	5.54	20.96
Fe_2O_3	3.35	4.15
MnO	-	0.033
CaO	61.4	9.79
MgO	2.48	1.75
Na_2O	0.19	2.23
K_2O	0.78	1.53
TiO_2	-	0.68
Loss of ignition	2.2	1.25
Specific gravity	3.15	2.3
Blaine fineness (m^2/kg)	325	290

2.2 Mix procedure

The mix proportioning has been carried out using the soil compaction geotechnical approach according to ACI 211.3R. It involves a series of stages.

a) The optimal combinations of fine aggregate, coarse aggregate, and mineral filler were determined so that the combined aggregate grading curve falls within the limit recommended by and US army corps of Engineers (CRD-C 161-92, 1992). The combined aggregate gradation curve showed in Figure-2 was obtained using a combination of 55% fine aggregate, 20% of 19 mm coarse aggregate, 20% of 6.3 mm chips coarse aggregate, and 5% of fly ash as a mineral filler.

b) Determination of optimum moisture content (OMC) and maximum dry density (MDD) according to ASTM D 1557-12e (ASTM).

c) The OMC and MDD of four RCC mixes have been produced using different cement contents; 12%, 13%, 14%, and 15% by weight of dry aggregates. For each cement content, five mixes were produced using different water content ranging from 4.5% to 6.5% by weight of dry aggregate, to obtain the moisture content -density relationship. The optimum moisture content for 12%, 13%, 14% and 15% cement contents have been found to be 5.46%, 5.56%, 5.92% and 6.09% respectively.

d) Four RCC mixes have been produced utilizing 12%, 13%, 14% and 15% cement content using their corresponding OMC obtained from step ii as the amount of water for the mix. The 28 days compressive strength and flexural strength of each mix have been determined. Based on target flexural strength of 4.8 MPa, 13% cement content was selected which will be used to derive the proportion for all the mixes in this study.

e) Based on the required flexural strength and calculations of constituent materials, a water to cement ratio of 0.42 has been used.
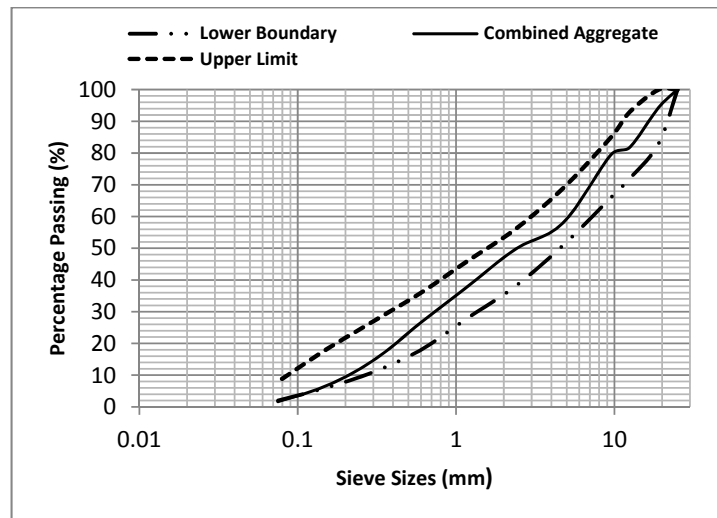
Figure-2. Combined aggregate gradation.

2.3 Samples preparations and test methods

2.3.1 Response surface methodology

The response surface methodology (RSM) is one of the most consistent and suitable mathematical and statistical methods for developing the relationship between more than one variable and responses (Rezaifar *et al.*, 2016). This study is aimed at investigating the effect of two factors namely crumb rubber content (as a partial replacement to fine aggregate), and superplasticizer dosage (as addition by weight of cement) on the Vebe consistency time, compressive strength, and flexural strength of RCR using response surface methodology. The

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independent variables and response were correlated using second order polynomial function shown in Equation (1).

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_i \sum_j \beta_{ij} X_i X_j + \in \quad (1)$$

where y is the modeled response, x_i and x_j are the coded values of the independent variables, i is the linear coefficient, j is the quadratic coefficient, β is the regression coefficient, β_0 is the y-intercept for which $X_i = X_j = 0$, k is the number of factors studied and optimized in the experiment, and ε is error (Douglas, 2008).

The central composited design (CCD) was performed, this is because of its options for selecting the distance from axial run to design center (α) (Douglas,

2008). In this study α=1 was selected. The independent variables are crumb rubber (CR) and superplasticizer (SP), and the measured responses are Vebe consistency time (V), 28 days compressive strength (F_C), and 28 days flexural strength (F_T).

For this study, roller compacted rubbercrete (RCR) were produced by partially replacing fine aggregate with CR in RCC. The replacement levels 0%, 20%, and 30% were chosen for CR, and 0%, 1%, and 2% are the levels chosen for SP. The total runs (based on actual value) and constituent materials for each run are shown in Table-2. The RSM analysis was executed using the design of experiment (DOE) version 11 software.

Table-2. Runs combinations and constituent materials.

Run	Factors		Constituent materials for 1 kg/m³						
	CR (%)	SP (%)	Cement	Filler	Fine aggregate	Coarse aggregate	CR	Water	SP
1	10	2	268.69	103.76	1033.25	831.88	114.89	94.89	5.37
2	30	1	268.69	103.76	803.64	831.88	344.67	98.24	2.69
3	30	0	268.69	103.76	803.64	831.88	344.67	111.64	0
4	20	1	268.69	103.76	918.44	831.88	229.78	98.24	2.69
5	10	1	268.69	103.76	1033.25	831.88	114.89	98.24	2.69
6	20	2	268.69	103.76	918.44	831.88	229.78	94.89	5.37
7	10	0	268.69	103.76	1033.25	831.88	114.89	111.64	0
8	20	1	268.69	103.76	918.44	831.88	229.78	98.24	2.69
9	20	1	268.69	103.76	918.44	831.88	229.78	98.24	2.69
10	20	0	268.69	103.76	918.44	831.88	229.78	111.64	0
11	30	2	268.69	103.76	803.64	831.88	344.67	94.89	5.37

2.3.2 Vebe consistency time

The consistency of fresh roller compacted rubbercrete (RCR) was determined using the modified Vebe test with the use of vibration table according to ASTM C1170 (ASTM C1170, 2014). Additional surcharge of 22.5 kg mass was placed on top of the specimen before testing.

2.3.3 Compressive strength

The compressive strength of RCR mixes was measured after 7 and 28 and days curing period according to BS EN 12390-7:2009 using 100 mm cubes. The specimens were then demoulded after 24 hours and then kept for curing. The compressive strength test was then determined after the duration of curing using the universal

testing machine (UTM) of 3000 kN capacity by applying load gradually at the rate of 3 kN/s until failure.

2.3.4 Flexural strength

The flexural strength was determined after 7 and 28 curing period according to ASTM C293M-10 using prisms of 100 mm x 100 mm x 500 mm sizes. Bosch vibration hammer of 50 Hz frequency was used to simulate the compaction required for the RCC.

3. RESULTS AND DISCUSSIONS

Table-3 shows the results of the responses, which were developed based on the mix design developed by the RSM. These results are used for developing the models and least squares regression analysis.

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Table-3. Run combinations and response results.

Run	Factors		Responses		
	CR (%)	SP (%)	Vebe time (seconds)	28 dayscompressive strength (MPa)	28 days flexural strength(MPa)
1	10	2	26	63.4	5.96
2	30	1	24	40.41	5.73
3	30	0	26	29.62	4.91
4	20	1	25	43.88	6.28
5	10	1	30	60.11	7.81
6	20	2	23	39.87	5.04
7	10	0	32	48.79	6.92
8	20	1	26	43.28	6.18
9	20	1	27	45.02	5.93
10	20	0	28	36.06	5.71
11	30	2	22	33.09	4.75

The relationships between the independent variables (CR and SP) and responses; Vebe time, compressive strength, and flexural strength were developed as shown in Equations 2(a-c), and the summary of the analysis of variance (ANOVA) shown in Table-4. The 5% significance level (P<0.05) is used to check if a model is significant. The P-values for all the response models were less than 0.05, this implies they are all significant at 95% confidence level, and there is only 0.01% chance that the models F-value of this size could occur due to noise. Similarly, the statistical significance of each term in the model was checked at 0.05 significance level (P<0.05). As presented in Table-4 andEquation2(a-c), all the response models were the quadratic type. For Vebe time, model terms (CR, SP) were the only significant terms, all other terms were insignificant. For compressive strength response, all model terms were significant. For flexural strength response, all model terms were significant except CR*SP. Furthermore, the lack of fit for all the responses was not significant implying that their experimental data accurately fit into the model. The relationship between the variables (CR and SP) and the responses (Vebe time, compressive strength, and flexural strength) developed is shown in Equations 2(a-c).

$$V = 38.33 - 0.717CR - 2.5SP + 0.05CR*SP + 0.01CR^2 - 0.5SP^2 \tag{2a}$$

$$F_C = 75.54 - 3.262CR + 21.871SP - 0.279CR*SP + 0.06CR^2 - 6.327SP^2 \tag{2b}$$

$$F_T = 9.48 - 0.284CR + 1.212SP + 0.02CR*SP + 0.0044CR^2 - 0.955SP^2 \tag{2c}$$

where V=Vebe time (seconds), FC=compressive strength (MPa), FT=flexural strength (MPa), CR=crumb rubber (% replacement of fine aggregate), SP=Superplasticizer=(% addition by weight of cement).

However, the insignificant terms in the models can be removed so as to shorten the model equations and reduces noise. Eqn 3a and 3b Vebe time and flexural strength models respectively with the insignificant terms removed hierarchically.

$$V = 37.1 - 0.613CR - 2.5SP + 0.0087CR^2 \tag{3a}$$

$$F_T = 9.08 - 0.264CR + 1.612SP + 0.0044CR^2 - 0.955SP^2 \tag{3b}$$

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Table-4. ANOVA summary.

Variable	Factors	Sum of square	Mean square	F -Values	P-Values	Significant
Vebe time (seconds)	Model	83.85	16.77	35.94	0.0006	Yes
	CR	42.67	42.67	91.43	0.0002	Yes
	SP	37.50	37.50	80.36	0.0003	Yes
	CR*SP	1	1	2.14	0.2031	No
	CR^2	2.53	2.53	5.43	0.0672	No
	SP^2	0.63	0.63	1.36	0.2966	No
	Lack of Fit	4.02	0.67	0.67	0.7026	No
Compressive strength (MPa)	Model	1059.92	211.98	55.01	0.0002	Yes
	CR	797.65	797.65	206.97	<0.0001	Yes
	SP	79.86	79.86	20.72	0.0061	Yes
	CR*SP	31.02	31.02	8.05	0.0364	Yes
	CR^2	90.24	90.24	23.42	0.0047	Yes
	SP^2	101.40	101.40	26.31	0.0037	Yes
	Lack of Fit	17.71	5.90	7.56	0.1191	No
Flexural (MPa)	Model	7.78	1.56	33.27	0.0008	Yes
	CR	4.68	4.68	100.09	0.0002	Yes
	SP	0.53	0.53	11.42	0.0197	Yes
	CR*SP	0.16	0.16	3.42	0.1236	Yes
	CR^2	0.49	0.49	10.49	0.023	Yes
	SP^2	2.31	2.31	49.40	0.0009	Yes
	Lack of Fit	0.17	0.056	1.73	0.3864	No

Table-5 shows the coefficient of determination for all the developed response models. A good correlation exists between the predicted and the measured responses. The developed model accounts for 97%, 98%, and 97% of the variation of Vebe time, compressive strength, and flexural strength respectively. Only about 3%, 2% and 3% of the variations of Vebe time, compressive strength, and flexural strength respectively cannot be accounted by the fitted models. In addition, as shown in Table-5, the adjusted R^2 and predicted R^2 for all the response models were in agreement with each other, as their difference is less than 0.2(Montgomery, 2008). The coefficient of variations (CoV) is also used to measure the variability of the experimental data points to the overall mean. All the response models have a low CoV; therefore, the data points fitted the overall mean. The adequate precision for all the response models is greater than 4, therefore the predicted models can be used to navigate the design space as defined by the central composite design.

Removing the insignificant terms Vebe time and flexural strength responses reduce their R^2, adjusted R^2 and predicted R^2 as shown in Table-5, this is because removing the insignificant terms reduces the number of data points which is also included in the calculation of the R^2.

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Table-5. Coefficient of determinations for developed models.

Response	With insignificant terms			Without insignificant terms	
	Vebe time (seconds)	Compressive strength (MPa)	Flexural strength (MPa)	Vebe time (seconds)	Flexural strength (MPa)
R^2	0.97	0.98	0.97	0.95	0.95
Adjusted R^2	0.95	0.96	0.94	0.93	0.92
Predicted R^2	0.92	0.82	0.81	0.89	0.80
SD	0.87	1.96	0.22	0.75	0.26
Mean	26.27	43.96	5.93	26.27	5.93
CoV (%)	2.60	4.47	3.65	2.87	4.32
PRESS	7.22	190.22	1.56	9.65	1.57
Adequate precision	20.48	20.94	17.66	22.76	17.48

*SD=standard deviation, PRESS=predicted residual error sum of squares, CoV=coefficient of variation

3.1 Multi-objective optimization

An optimization was carried out using RSM by minimizing the Vebetime and maximizing compressive strength and flexural strength. The summary of the optimization criteria is shown in Table-6. The result of the optimization process shows that 10% volume replacement of fine aggregate with CR and 1.51% addition of superplasticizer by weight of cement yielded the optimized responses as shown in Table-6.

Table-6. Optimization criteria and optimization result.

Variables & Responses	Goal	Lower limit	Upper limit	Optimum ratio and predicted responses
Crumb rubber (%)	In range	10	30	10
Superplasticizer	In Range	0	2	1.51
Vebe Time (seconds)	Minimize	22	32	28.1
Compressive strength (MPa)	Maximize	29.62	63.4	63.29
Flexural strength (MPa)	Maximize	4.75	7.81	7.04
Desirability (%)				66.4

3.2 Effect superplasticizer on the Vebe consistency of RCR

The effect of partial replacement of fine aggregate with crumb rubber and the addition of superplasticizer by weight of cement on the Vebe consistency of RCR was analyzed using RSM. The result is presented in form of 3D response surface plot shown in Figure-3.TheVebe consistency of RCR decreases with increase in partial replacement of fine aggregate with crumb rubber. It also increases with increase in the addition of superplasticizer. However, superplasticizer has more effect on Vebe consistency of RCR compared to crumb rubber.This result is in agreement with the findings of Mohammed and Azmi (2014) for rubbercrete. The lower absorption of crumb rubber compared to fine aggregate is partially replaced is the main reason causing a decrease in Vebe time, as the amount of free water during mixing is increased thus increasing the consistency (Meddah *et al*., 2014).While the decrease in Vebe consistency with the addition of superplasticizer is attributed to the ability of superplasticizer to disperse and distribute the paste in RCR thereby reducing the compaction effort needed to achieve consistency (Xu *et al*., 2016).
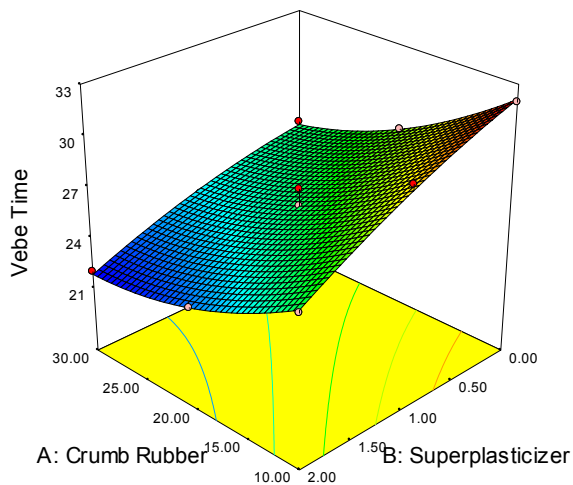
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Figure-3. 3D response surface plot for vebe time.

Figure-4. 3D response surface plot for compressive strength.

3.3 Effect of superplasticizer on compressive Strength of RCR

The effect of partial replacement of fine aggregate with crumb rubber and the addition of superplasticizer by weight of cement was analyzed using RSM. The result of the RSM is shown by the 3D response surface plot in Figure-4. The compressive strength decreases with increase in partial replacement of fine aggregate with crumb rubber, and increases with addition of superplasticizer, with the optimum compressive strength achieved at 10% crumb rubber and 1% superplasticizer as shown by the reddish region in Figure-4. The reduction in compressive strength as the crumb rubber replacement increases is caused by the poor bonding between hardened cement matrix and rubber particles, and increased pore volume in the hardened RCR mix, which leads to microcrack formation with applied loads and consequently premature failure (Mohammed *et al*., 2016, Mahamood *et al*., 2016). Another reason is due to increased porosity in the hardened RCR caused by entrapped air on crumb rubber surface during mixing (Mohammed *et al*., 2012, Mohammed *et al*., 2011). While the increase in compressive strength with the addition of superplasticizer is due to proper distribution and dispersion of paste which leads to better compaction and reduction in voids in the hardened RCR.
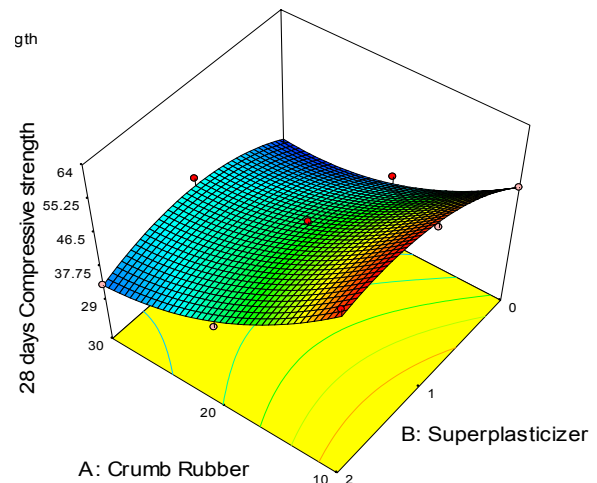
3.4 Effect of superplasticizer on the flexural strength of RCR

RSM is used to analyze the effect of partial replacement of fine aggregate with crumb rubber, and the addition of superplasticizer by weight of cement. The result is shown as 3D response surface plot in Figure-5. The flexural strength of RCR decreases with increase in percentage replacement of fine aggregate with crumb rubber, and increases with the addition of 1% superplasticizer, as shown by the reddish region on Figure-6. However, the addition of 2% superplasticizer decreases the flexural strength of RCR as shown by the bluish regions in Figure-6. Therefore in this study, the highest flexural strength was achieved by incorporating 10% crumb rubber as are placement to fine aggregate and addition of 1% superplasticizer by weight of cement in RCR. The decrease in flexural strength with the incorporation of crumb rubber is due to poor bonding between crumb rubber particles and hardened cement paste which is causing premature flexural failure(Mohammed and Azmi, 2014). While the increase in flexural strength with the addition of superplasticizer is due to increased paste distribution and dispersion resulting in proper compaction, and denser RCR matrix, thus increasing its bending resistance. The decrease in flexural strength with the addition of 2% superplasticizer is attributed to excess water available after consistency has been achieved, which occupied the pore volume, and later dried up leaving pores in the hardened RCR matrix, therefore micro cracks develop through the pores during loading and causes premature failure and reduced bending resistance.
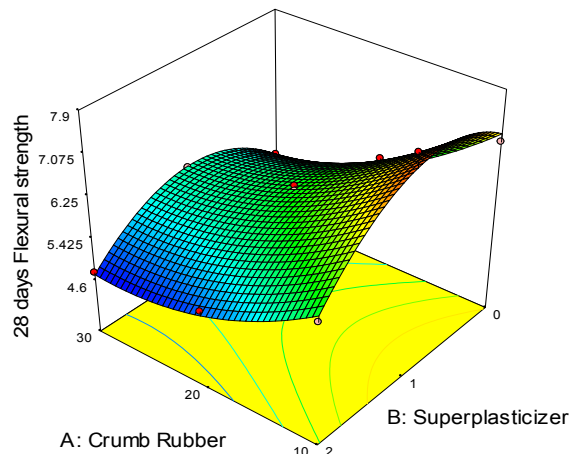
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Figure-5. 3D response surface plot for flexural strength.

4. CONCLUSIONS

In this study, the following conclusions can be drawn based on experimental works and RSM analysis.

- The fitted quadratic model developed explains over 97%, 98%, and 97% of the variability in Vebe time, compressive strength and flexural strength over 97%, 98%, and 97% respectively.
- Vebe consistency time of RCR decreases with increase in crumb rubber and superplasticizer contents.
- Compressive and flexural strengths decrease with increase in crumb rubber content, and increases with the addition of superplasticizer, with the optimum dosage been 1%. However, flexural strength decreases for 2% superplasticizer addition.
- The multi-objective optimization results showed that a combination of 10% crumb rubber as are placement to fine aggregate, and 1.51% superplasticizer as addition by weight of cement yielded the best results as the Vebe time was minimized, compressive and flexural strengths maximized.

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