Modelling the Slump, Compressive Strength and Density of Concrete Containing Coconut Shell as Partial Replacement for Crushed Granite

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Abstract
In this research, crushed coconut shell was used to partially replace crushed granite as coarse aggregate in the production of concrete. Tests were conducted on the physical properties of crushed coconut shell and crushed granite. Thirty one random mixes were generated using Mini Tab 14 statistical software package. A total of 108 cubes were cast and cured for 28 days and then crushed to determine their compressive strength. The results were used to develop empirical models for the slump, compressive strength and density of the concrete. The concrete developed in this work has slump ranging from 0 – 135 mm, compressive strength ranging from 8.94 N/mm^2 – 27.11 N/mm^2 and density ranging from 1757.04 kg/m^3 to 2198.52 kg/m^3 respectively. This implies that concrete made using coconut shell as partial replacement for crushed granite can be used for structural application such as in the construction of reinforced concrete slabs, beams, columns and foundations. Polynomial model was developed with the capability of explaining the under-laying relationship of 93.8%, 83.6% and 72.3% for slump, compressive strength and density respectively.

Keywords
Coconut shell, slump, compressive strength, density, models

1. Introduction

Concrete has wide area of application in Civil Engineering and building works. Due to urbanisation, especially in developing countries like Nigeria, the use concrete product has continued to be on its increase. This has led to increased depletion of natural resources and thereby distorting the ecological balance. This has necessitate researchers to consider waste materials in the production of concrete, since it has additional advantage of sanitising the environment (Mohammed et al. 2014a, Mohammed et al. 2014b, Mohammed et al 2013, Mohammed et al 2011a, Mohammed et al. 2011b, Abdullahi et al. 2010, Abdullahi 2016, Oyetola and Abdullahi 2006, Abdullahi et al. 2009, Abdullahi et al. 2008). Inclusion of such unconventional materials in concrete does not easily give workable mix and requires trial mixes to come up with the desired mix compositions. A comprehensive and rational design of concrete mixes is influenced by numerous factors which depend upon the sources of materials and their properties, method of preparation, placement, compaction, curing of concrete and the requirements of a construction job. The optimum design of concrete mix involves selection of proportions of ingredients that yield concrete of the desired workability, strength and durability at minimum cost. The most important factors which influence such a mix design are the water-cement ratio (w/c), aggregate-cement ratio (TA/C) and coarse-total aggregate ratio (CA/TA) (Abbasi et al. 1987). Since these factors are inter-dependent, proper and analysis of experiments for studying their influences on the mix proportions is necessary.

Several researches have been conducted to develop new materials relying on renewable resources. These include the use of by-products and waste products such as periwinkle shell, rice husk, palm kernel, coconut shell, just to mention but a few. According to (Adewuyi and Adegoke 2008), many of these by-products are used as aggregate for the production of lightweight concrete. Due to the economic situation in developing countries like Nigeria conventional concrete materials needs substitution with more sustainable ones. Therefore, it may be beneficial to carry out research on the available local waste materials that will partially or fully substitute costly conventional materials. Numerous results have been achieved in these regards, and the subject is attracting attention due to the benefits of recycling and suitability in concrete work. Reduction in construction costs and the ability to produce lightweight structures are added advantages. In Nigeria, particularly in the south-south region and the eastern zone of Nigeria, coconut shells are available in abundance as waste. In this regard, development modelling of properties of concrete containing coconut shell as partial replacement for crushed granite is timely and justifiable.

2. Materials and Method

2.1 Materials

The materials used for this research work were sourced locally and they are as follows:

i. Natural sand (fine aggregate) obtained from River Kpakungu in Minna, Nigeria.
ii. Crushed coconut shell and granite as coarse aggregate. The coconut shell used was obtained from Bosso in Minna, Nigeria; dried and crushed to a particular size of about 20mm.
iii. Ordinary Portland cement, being the commonly used cement in Minna, Nigeria.
iv. Clean water: The water used for mixing and curing was potable drinking water from tap which is suitable for concrete work (BS 3148, 1980).

2.2 Methods

2.2.1 Aggregate Characterisation

The following tests were carried out on the aggregates: Sieve analysis, moisture content, specific gravity and bulk densities in accordance to (BS 812: part 1 ,1975 and BS 812: part 109, 1990, BS 812: part 2, 1975).

2.2.2 Experimental Design

Central composite design was used to select 31 candidate points for the experiment. These points include the centre point, factorial points, axial points and repetitions to allow for pure errors arising from the experimental process. The variable factors considered in the mix design are the water-cement ratio (W/C), total aggregate-cement ratio (TA/C) and coarse-total aggregate ratio (CA/TA). Absolute volume method was used for the mix design. Three mixes were also developed for model validation. In this work x_1 is the water-cement ratio (W/C), x_2 is the total aggregate-cement ratio (TA/C), x_3 is the coarse-total aggregate ratio (CA/TA) and x_4 is the percentage replacement of coconut shell with crushed granite.

2.2.3 Production and Testing of Concrete

For each of the mixes three cubes (150mm x 150mm x 150mm) were cast, cured and crushed at 28 days according to (BS 1881 Part 116, 1983). Slump test was conducted before casting in accordance (BS 1881: Part 102, 1983).

2.2.4 Modelling

The results of the slump, compressive strength and density of the concrete were used to develop statistical models in Minitab environment. Possible models are linear, interaction, pure quadratic, full quadratic and reduced version of all the aforementioned models.

2.2.5 Validation

The developed models were used to compute the slump, compressive strength and density of concrete and compared with experimental data reserved for model validation.

3. Results and Discussion

3.1 Aggregate Characterisation

The specific gravity, moisture content, bulk density, fineness modulus, void ratio and porosity of sand, crushed granite and coconut shell are shown in Table 1. The specific gravity of sand and crushed granite are 2.61 and 2.74 which lies within the range for natural aggregate given as 2.5 and 3.0 (Neville, 2000). Also the specific gravity of coconut shell obtained is 1.32. This value is very low compared with that of natural aggregate. This is an indication that coconut shell is much lighter than most natural aggregate. The uncompacted bulk density of coconut shell is 476.99Kg/m^3 which is close to the result obtained by (Aguwa and Amadi, 2010), who reported that coconut shell has a bulk density of 489 kg/m^3 and can be used as a lightweight aggregate in concrete production.

The uncompacted bulk density was used in this research work because in practice, the material is not likely to be compacted before use in mixing. The porosity of coconut shell is 19.58% as shown in Table 1. This value is very high compared with most natural aggregate, which have their porosities in the range of 6 – 10%. Hence less strength is expected, because the higher the porosity of aggregate, the lower the strength and durability of concrete. The value of porosity also indicates that the coconut shell may absorb higher amount of water and cement paste during mixing compared to normal aggregates. Table 1 also shows the moisture content for the coconut shell aggregate to be 5%. This indicates that the aggregate is not too dry but at the same time will absorb some amount of water from concrete and additional water has to be added to compensate for this absorption. The same applied to the fine aggregate having a moisture content of 4.1%. However, the moisture content for granite (coarse aggregate) is 0.5% indicating that the aggregate would only absorb little water from the concrete.

Table 1 Physical properties of constituent materials

Parameter	Sand	Crushed granite	Coconut shell
Specific gravity	2.61	2.74	1.32
Moisture content (%)	4.0	0.5	5.2
Uncompacted bulk density (kg/m^3)	1468.46	1370.17	476.99
Compacted bulk density (kg/m^3)	1602.54	1500.29	593.18
Fineness modulus	4.58	6.6	5.5
Void ratio	0.44	0.5	0.64
Porosity (%)	8.4	8.67	19.58

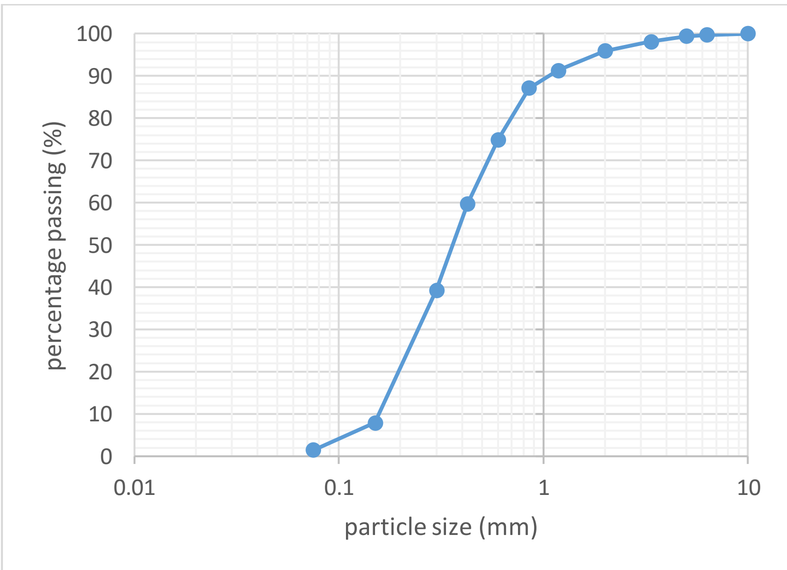


Figure 1 Sieve analysis of fine aggregate

Figures 1 to 3 shows the particle size distribution curve for the aggregates. The result of percentage passing BS sieves shows that the sand satisfies the grading requirement for overall and medium grading as specified in (BS 882, 1992). This implies that the sand can conveniently be used for concrete work without much mixture proportioning adjustment. Figure 1 shows a smooth curve which indicates that the aggregate contain particle of different sizes in good proportion. The soil is considered to be well graded.

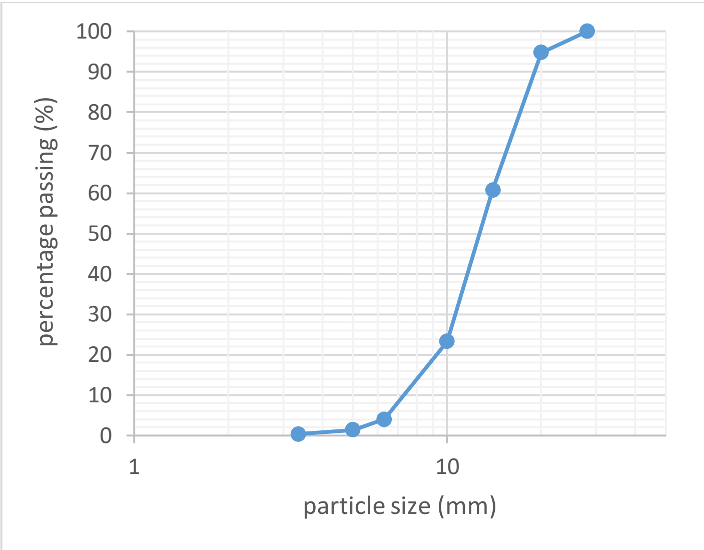


Figure 2 Sieve analysis of crushed coconut shell

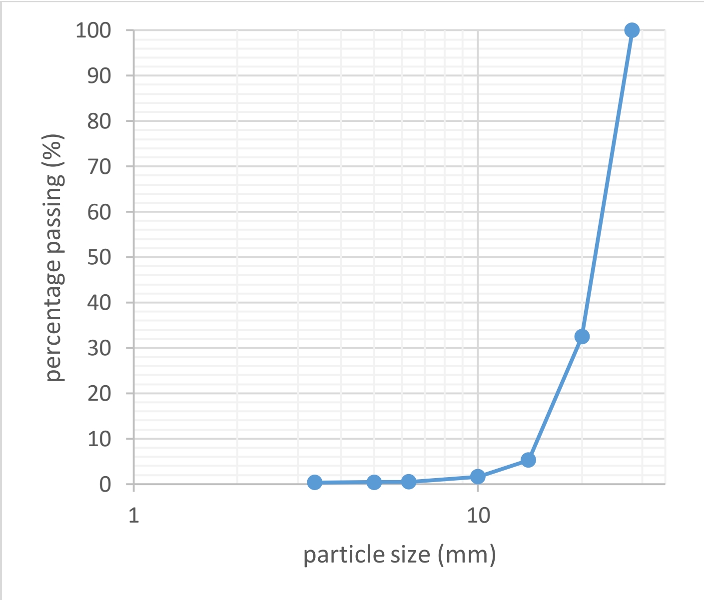


Figure 3 Sieve analysis for crushed granite

3.2 Concrete Properties

The result of the slump, compressive strength and density are shown in Table 2. The result shows that the concrete properties are in the range for normal weight concrete and can be used for structural purposes such as reinforced concrete slabs, beams, columns and foundations.

3.3 Model Development

Several models were generated with the use of statistical software called Minitab 14. The statistical package generated and analysed several models for slump, compressive strength and density of the concrete cubes. The models are expected to reasonably explain the variability in the experimental data. These developed include slump model, compressive strength model and density model.

Table 2 - Slump, compressive strength and density of concrete cubes

Mix No.	X_1	X_2	X_3	X_4	Slump (mm)	Compressive strength at 28 days (N/mm^2)	Density (kg/m^3)
1	0.36	0.60	4.00	0.24	0	10.05	1979.3
2	0.40	0.65	3.00	0.36	20	17.2	1961.3
3	0.50	0.67	4.00	0.24	5	15.91	2038.5
4	0.40	0.55	3.00	0.36	10	15.78	1997
5	0.40	0.65	5.00	0.12	0	11.29	2094.8
6	0.50	0.60	5.41	0.24	0	6.28	1970.4
7	0.60	0.65	5.00	0.12	20	12.65	2154.1
8	0.60	0.55	5.00	0.36	10	9.33	1982.22
9	0.40	0.55	3.00	0.12	20	20.88	2198.52
10	0.60	0.65	3.00	0.36	120	8.95	1896.3
11	0.50	0.60	4.00	0.41	0	11.61	1917.04
12	0.50	0.60	4.00	0.24	10	19.7	2091.85
13	0.60	0.55	5.00	0.12	10	15.2	2106.07
14	0.50	0.60	4.00	0.24	0	17.17	1985.19
15	0.60	0.65	5.00	0.36	0	10.8	1920
16	0.40	0.55	5.00	0.12	0	8.79	1982.19
17	0.50	0.60	4.00	0.24	10	16.71	1991.11
18	0.50	0.53	4.00	0.24	10	18.03	2071.11
19	0.40	0.65	5.00	0.36	0	3.51	1757.04
20	0.60	0.55	3.00	0.12	125	15.35	2080
21	0.50	0.60	4.00	0.24	5	13.75	1914.07
22	0.50	0.60	4.00	0.24	15	12.74	2071.11
23	0.40	0.65	3.00	0.12	20	27.11	2225.19
24	0.50	0.60	2.59	0.24	70	18.8	2044.44
25	0.60	0.65	3.00	0.12	135	16.71	2109.63
26	0.50	0.60	4.00	0.07	25	23.63	2198.52
27	0.60	0.55	3.00	0.36	90	11.64	1994.07
28	0.50	0.60	4.00	0.24	20	19.64	2145.19
29	0.50	0.60	4.00	0.24	10	18.4	2005.19
30	0.40	0.55	5.00	0.36	0	4.3	1851.85
31	0.64	0.60	4.00	0.24	60	11.54	2035.55
32	0.5	0.55	3.50	0.24	10	12.8	2133.33
33	0.45	0.60	4.50	0.30	0	4.84	1917.04
34	0.6	0.65	5.00	0.18	10	11.47	2162.96

3.3.1 Slump model

A reduced full quadratic model was found to be most appropriate for the slump model. Its residual values were reasonable when compared with other models generated for slump. The slump model generated is as follows:

$$Y_1 = 79.46 - 71.87X_1 - 29.55X_3 + 1236.85{X_1}^2 + 14.14{X_3}^2 - 225.86X_1X_3$$

$$R_SQ = 94.5\%\,,\ \ R_SQ(ADJ) = 93.5\%$$

3.3.2 Compressive strength model

A full quadratic model was found to be most adequate for explaining the experimental data for compressive strength. The model is as follows:

$$Y_2 = -17.75 + 201.8X_1 - 5.58X_2 - 0.21X_3 - 47.59X_4 - 248.56{X_1}^2 + 124.82{X_2}^2 - 1.71{X_3}^2 + 69.79{X_4}^2 - 151.63X_1X_2 + 30.95X_1X_3 - 50.7X_1X_4 - 10.17X_2X_3 - 82.81X_2X_4 + 2.71X_3X_4$$

$$R_SQ = 85.6\%\,, \qquad R_SQ(ADJ) = 75\%$$

3.3.3 Density model

A full quadratic model was also considered appropriate for the density model. The model is as follows:

$$Y_3 = 4615.71 + 235.91X_1 - 6682.83X_2 - 283.89X_3 + 1857.5X_4 - 1683.64{X_1}^2 + 6136.89{X_2}^2 - 14.76{X_3}^2 + 293.84{X_4}^2 - 537.89X_1X_2 + 519.29X_1X_3 + 1336.17X_1X_4 + 196.83X_2X_3 - 5536.19X_2X_4 - 46.72X_3X_4$$

$$Rsq = 87.1\%\,, \qquad Rsq(adj) = 77.6\%$$

3.3.4 Response Surface Plot

The response surface plot for slump, compressive strength and density models are shown in Figures 4, 5, and 6 respectively.

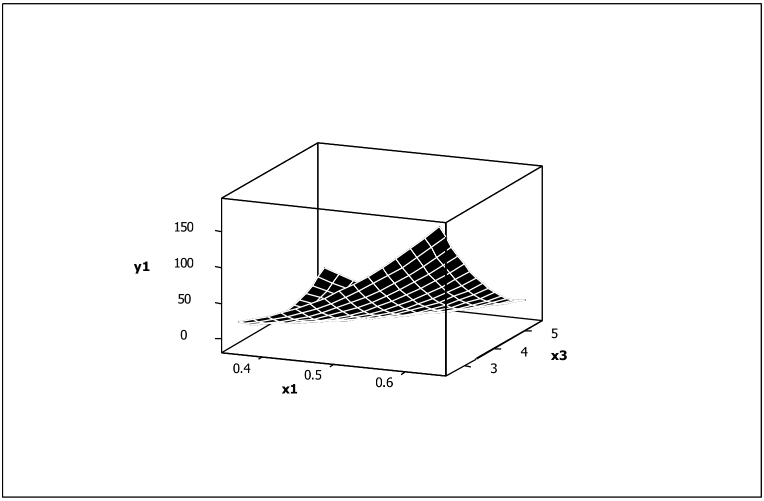
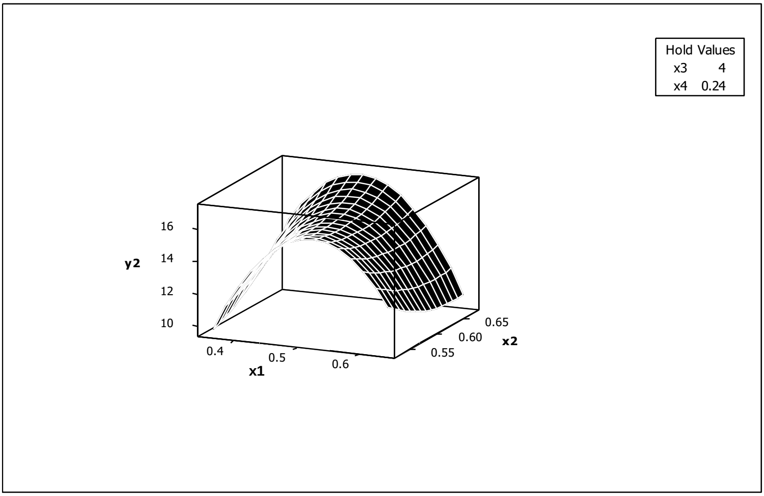
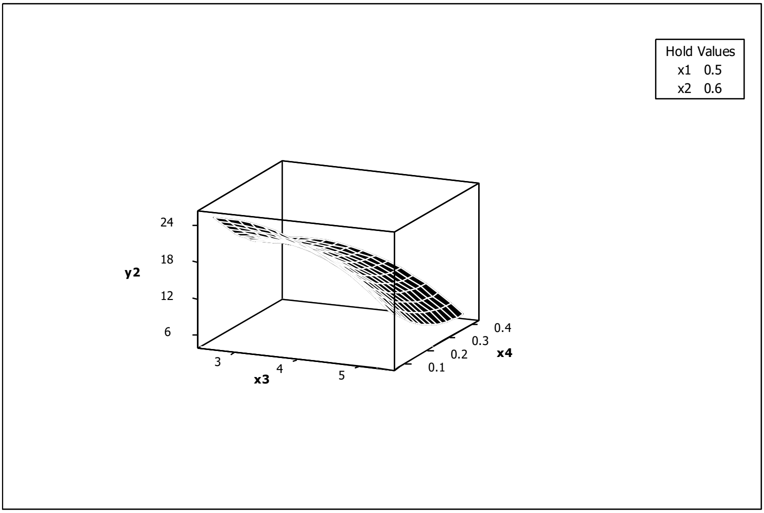


Figure 4: Response Surface Plot for Slump

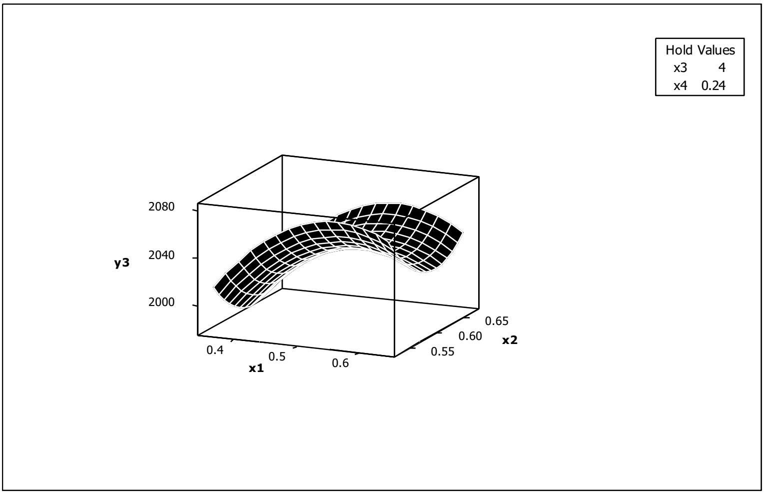


(a)

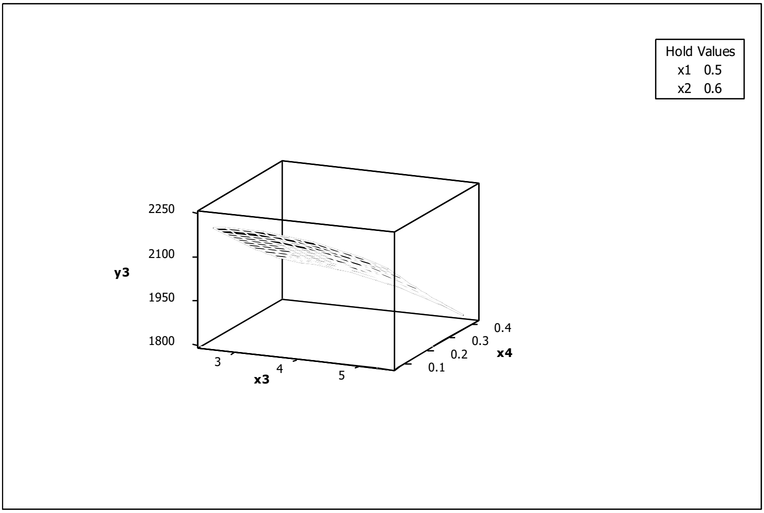
Figure 5: Response surface plot for compressive strength



(b)
Figure 5: Response surface plot for compressive strength



(a)
Figure 6 Response Surface Plot for Density



(b)

Figure 6 Response Surface Plot for Density

3.4 Model validation

To validate the adequacy of the fitted models, the mix compositions in the three mixes employed for this purpose were used to compute the slump, compressive strength and density using the models. The experimental and model data are shown in Table 3. The result shows that the polynomial models are capable of computing the properties of the concrete.

Table 3: Comparison of experimental data with model data

	Factors				Experimental Data			Model Data		
S/No	X1	X2	X3	X4	Y1 (mm)	Y2 (N/mm^2)	Y3 (kg/m^3)	Y1 (mm)	Y2 (N/mm^2)	Y3 (kg/m^3)
1	0.50	0.55	3.50	0.24	10	12.80	2133.3	30	18.00	2068.14
2	0.45	0.60	4.50	0.30	0	4.84	1917	0	11.61	1941.00
3	0.60	0.65	5.0	0.18	10	11.47	2163	10	11.95	2091.43

4. Conclusion

From the results obtained on the tests conducted on the concrete developed Using crushed coconut shell as partial replacement for crushed granite, the following conclusions are hereby made:

(i) The specific gravity, uncompacted bulk density, compacted bulk density for coconut shell were found to be 1.32, 476.99 kg/m^3 and 593.18 kg/m respectively.
(ii) The slump, compressive strength and density of concrete containing crushed coconut shell ranges from 0 mm to 135 mm, 3.51 N/mm^2 to 27.11 N/mm^2 and 1757.04 kg/m^3 to 2198.52 kg/m^3 respectively.
(i) Polynomial models were obtained for slump, compressive strength and density for concrete containing crushed coconut shell as partial replacement for crushed granite with predictive capabilities of 93.5%, 75% and 77.6% respectively.

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