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Compressive strength and statistical investigation of concrete made with bituminous sand

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Abstract

Africa is urgently in need of adequate basic infrastructure and housing, and it is one of the continents where massive construction activities are on the rise. There is a vast variety of potentially viable resources for sustainable construction on the continent, and the continent can bring these local resources effectively into practice. This paper reports the results of an experimental study of the compressive strength and statistical analysis of plain concrete made using bituminous sand. Open excavation was used to obtain bituminous sand, which was then crushed with a scoop to sand sizes. 42 specimens underwent casting and testing. The slump test was used to assess the concrete's fresh properties. After the samples were cured for 7, 14, 21, 28, 56, 90, and 150 days, respectively, the concrete strength test was conducted. The findings were statistically analysed using the Excel spreadsheet regression analysis tool (ESRA) and the statistical package and service solution (SPSS). According to the findings, bituminous sand concrete has a better workability/placeability compared to the control. Additionally, the tests demonstrate that samples' compressive strengths rose as curing age increased, albeit at varying rates, with the control concrete achieving the highest strength. Accordingly, bituminous sand concrete may be used for concrete constructions that need grade C15 concrete, according to the trial results. After testing, it was determined that the developed models were sufficient.

Keywords: River Sand; Bituminous Sand; Bituminous Sand Concrete; Compressive Strength; Predictive Model

1. Introduction

The construction aggregate industry is an essential part of most developed economies [1]. Concrete, which comprises more than 70% construction aggregate, is the most versatile building material. Author in [2] described concrete as a composite material that resembles stone and is made by combining aggregates (such as crushed rock or irregularly shaped stones) with cement (which serves as a binding agent) and water, then letting the mixture dry and solidify. These aggregates are the primary ingredients of concrete and have a major role in the development of strength [3].

One of the primary ingredients utilized as a fine aggregate in the manufacturing of concrete is river sand. Authors in [4] reported that the overexploitation of river sand due to an increase in the demand for building materials has had negative effects, including lowering the water table, increasing the depth of the riverbed, and introducing saline into the river. Furthermore, the rising demand has resulted in exorbitant price hikes for obtaining this material, making it extremely challenging to provide the swarming population of a nation like Nigeria with the shelter they need [5]. Authors in [6] observed that urban areas in Africa are experiencing population expansion at a rate that is typically more than twice that of rural areas and [7] concluded that urban construction in Africa is expected to be quintuplicated by 2050, ideally with the use of low-cost beneficial, sustainable, and material-saving technology. One low-cost beneficial material

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explored in this study is bituminous sand which is made up of sand, heavy oil, and clay that are high in water and minerals [8].

According to [9], world-wide reserves of bituminous sands are estimated at 5.6trillion barrels, occurring in over 70 different countries. On the African continent, some sizable quantities of bituminous sands exist in the Dahomey basin. A large portion of the Gulf of Guinea's continental edge is covered by the Dahomey basin. It stretches from the Okitipupa ridge in Nigeria in the east to the volta delta in Ghana in the west. It is a marginal pull-part basin, also known as a marginal sag basin, that formed during the Mesozoic era when the continental margin foundered, and the African and South American lithospheric plates split apart [9, 10-13].

Nigeria has huge quantities of bituminous sands deposits [14-15]. The bituminous sand deposit in the southwestern Nigeria is one of the notable deposits, estimated to be among the largest in the world [16-17], with a belt of 5-8km wide, spanning about 120km in the South-Easterly direction across four states including Lagos, Ogun, Ondo, and Edo states of Nigeria [18-20]. [21] also noted that the Nigeria bituminous sand reserve is about 42billion barrels and ranked 6th in a list of top ten countries [22].

Source: [22]

Figure 1 Top 10 countries with bituminous sand reserves

Despite the abundance of bituminous sand in Nigeria, interest has hardly been directed towards using it to make concrete for the provision of low-cost housing for the teeming population of Nigeria. Thus, this work seeks to investigate the strength of concrete made with Agbabu bituminous sand when subjected to compression.

In statistical analysis of experimental data, including data normality check and concrete property modelling, two of the most powerful tools that have proven their efficacy are the statistical product and service solution (SPSS) and Excel spreadsheet regression analysis (ESRA). The Statistical Product and Service Solution (SPSS) is used to test the normality of experimental data and for the presence of univariate outliers. Research programs generate real numbers, or continuous data, which calls for a normalcy test.

Samples under fifty ($n \leq 50$) are tested for normalcy using the Shapiro-Wilk test; samples over fifty ($n > 50$) are tested using the Kolmogorov-Smirnov test; and univariate outliers are checked using a box plot. If the p-value, or $p \geq \alpha$, is more than or equal to the level of significance, the experimental data is regarded as regularly distributed. Before the models are built using the adjusted data set, the experimental data is first treated using natural log if it shows univariate outliers or is not normally distributed.

According to the authors in [23], regression analysis is a technique for creating empirical models to forecast the values of a dependent response variable in connection to other independent variables. This is due to the fact that it examines the relationships between variables. It is represented mathematically in Eq1 according to [24].

$$Y = Q(X1, X2 \dots \dots \dots .. Xk) \qquad \text{Eq.1}$$

In relation to Eq.1, the independent variables are denoted by X_k and the dependent variable by Y. To make sure that there are no notable differences between experimental and model-generated data, researchers typically perform a model adequacy test. The model of the dependent variable as a function of independent factors, coefficients, and regression analysis includes a random error term, which indicates variation in the dependent variable not explained by the function of the dependent variables and coefficients. These coefficients demonstrate how strongly the variables are related to one another [25].

2. Experimental Works

2.1. Materials

2.1.1. Cement

A 42.5R ordinary Portland cement Dangote brand conforming to [26] and supplied by a retailer in Owerri, Imo state Nigeria was used as the cementitious material in this study.

2.1.2. Fine aggregate

- **River sand:** The river sand used as the control for this study was high-quality, white, crisp sand from Otamiri river in Owerri, Nigeria. It was free of organic elements and trash. The mechanical properties of the river sand are given in table 1.

- **Bituminous sand:** Agbabu in Ondo state, which is in the sedimentary landscape of the Dahomey Basin in southwest Nigeria, provided the bituminous sand used in this study. The bituminous sand was obtained by open excavation from outcrops with the use of pick and or shovel. The bituminous sand sample that was collected was in a solid compact form. With the help of a scoop, the sample was crushed into sand-like pieces because it was challenging to work with in this condition. The mechanical properties of the bituminous sand are given in table 1.

2.1.3. Coarse aggregate

The coarse aggregate was crushed limestone aggregate (Ajali formation) maximum size 20mm obtained from Jingzang quarry km 40 Enugu – Abakaliki highway Okpoto, Ebonyi State, Nigeria. Before being used, the coarse aggregate was cleaned, rinsed with clean, drinkable water, and dried. Table 1 lists the coarse aggregate's mechanical characteristics.

2.1.4. Water

Fresh, drinkable water was used for concreting; this allowed the cement to hydrate, which caused the concrete to set and solidify.

2.2. Batching and mixing of concrete

In compliance with the concrete mix ratio of 1:2.2:3.3, the batching was done by weight. The cement was then evenly distributed over the mixture of crushed stone and sand after the coarse and fine aggregates had been combined and spread out on the laboratory's firm, clean floor. The materials were shoveled repeatedly from one end to another and cut with shovel until the mix appeared uniform. After that, water was injected gradually to prevent cement and water from escaping on their own. After that, the mixing process was repeated as for the dry stage until the mixture's color and consistency seemed consistent.

2.3. Slump test

Utilizing Abram's slump cone apparatus, the slump test was conducted. The purpose of this experiment was to gauge the concretes' fillability. The control concrete and bituminous sand concrete (BSC) were both used in the test. Fresh concrete was poured into the cone in three layers, each containing 25 blows. To allow for concrete distortion on a flat metal plate, the cone was vertically removed. It was measured to determine the new height. The height difference between the cone and the concrete cone upon removal was calculated. See table 2.

Figure 2 Slump test

2.4. Physical tests

2.4.1. Preparation of specimens for strength test

The specimens were prepared firstly by using a brush to grease the inside of the 150-mm x 150-mm x 150-mm molds to facilitate simple de-molding. Secondly, using a mason's trowel, the properly mixed concrete was poured into the cubical molds in three layers. The first, second, and third layers were evenly distributed across the mold's cross section and giving a compaction of 25 blows with a rammer at its own weight in accordance with [27]. The top of each mold was smoothened and leveled, and the outside surfaces cleaned. A total of 42 cubes (21 control and 21 bituminous sand samples) were made for this study. A day later, the firm concrete was removed from the mold and moved to the water-filled curing tank until tested. The laboratory process also considered the precautions noted in [28-29].

2.4.2. Concrete Strength test

The compressive strengths of the bituminous sand concrete and the hardened control concrete were measured at 7, 14, 21, 28, 56, 90, and 150 days after curing using a compressive strength testing machine that met [30]'s requirements. The test was carried out on triplicate samples of concrete cubes that were 150 mm by 150 mm by 150 mm at each curing age in accordance with [31].

2.5. Statistical Analysis

The study's prediction models and normality check were statistically tested using the statistical product and service solution (SPSS) and Microsoft excel spreadsheet regression analysis (ESRA). The Shapiro-Wilks p-value was used to test for normality when the data was less than or equal to 50 (i.e., $n \leq 50$). Skewness, kurtosis, and the existence of univariate outliers were further examined in the data.

The skewness and kurtosis statistics were divided by their corresponding standard errors and compared to a constant value of 1.96 in order to determine whether the data were normal. To look for univariate outliers, box plots were employed. According to [32], empirical predictive models for concrete strength were developed using the conventional linear-iterative approach. Relationships between the variables were established. The empirical models were tested using a 95% accuracy level statistical t-test. Accept the null hypothesis if t Stat is less than t Critical two tails. At a 95% accuracy level, accepting the null hypothesis means that there is no discernible difference between the data produced by the experiment and the model. There must be a substantial difference in order to reject the null hypothesis, which entails accepting the alternative hypothesis.

3. Results and Discussion

3.1. Mechanical properties

The results of the mechanical properties tests of the bituminous sand, river sand, and granite used for the study are shown in table 1.

Table 1 Mechanical properties of materials

Property type	Bituminous sand	River sand	Granite
Physical appearance	Dark-brown	White	Light-colored
Specific gravity	2.60	2.64	2.70
Moisture content (%)	0.60	0.72	0.08
Water absorption (%)	0.70	0.91	0.74
Bulk density (Kg/m^3)	1717	1780	1677
Gradation coefficient, C_c	0.80	0.73	-
Coefficient of uniformity, C_u	2.20	2.50	-
Fineness modulus	3.44	3.79	-

3.2. Slump test

Table 2 displays the results of the slump test. The table shows that, in comparison to the control, the bituminous sand concrete (BSC) had a higher slump and compacting factor value. The presence of bitumen in the bituminous sand concrete (BSC) improved the rheological behavior of the concrete thus making the concrete more workable. Additionally, it is reasonable to believe that bitumen disrupted the cement-water binding interactions, preventing or postponing the cement particles' full hydration [33].

Table 2 Fresh properties of samples

Sample	Slump (mm)	Degree of workability
control	30	Low
BSC	55	Medium

3.3. Compressive strength

Tables 3 and 4 displays the average compressive strength of the concrete samples (control and bituminous sand samples). The bituminous sand concrete's (BSC) compressive strength was significantly impacted. All the samples' compressive strengths rose over time, albeit at varying rates. After seven days of curing, the control concrete's compressive strength was 15.17N/mm2, or 60% of its specified strength. While the bituminous sand sample's values rose with curing age but did not surpass the control at the various testing ages, the control sample consistently maintained the highest compressive strength values with time. The fact that bituminous sand concrete (BSC) gets stronger with time suggests that more calcium silicate hydrate is created during the hydration process, which boosts the concrete's strength. At 28 days, the bituminous sand and control concretes' respective compressive strengths were 15.02N/mm^2 and 24.70N/mm^2, or 60.08% and 98.80% of the design concrete strength, respectively. This indicates that by 28 days, the control concrete's strength has increased by 38.72% compared to the bituminous sand concrete. The control concrete's strength at 150 days of curing was 26.93N/mm^2, while the BSC's was 15.35N/mm^2. In their study, [34] also reported a similar decrease in the strength of concrete containing hydrocarbon when compared to the control.

Table 3 Compressive strength of control concrete

Curing age (days)	Average mass (kg)	Average failure load (kN)	Volume (m^3)	Density (kg/m^3)	Compressive strength (N/mm^2)
7	8.22	341.33	0.003375	2434.57	15.17
14	8.27	385.00	0.003375	2450.37	17.11
21	8.29	465.00	0.003375	2456.30	20.66
28	8.32	555.67	0.003375	2465.19	24.70
56	8.34	579.67	0.003375	2471.11	25.76
90	8.35	582.34	0.003375	2474.07	25.88
150	8.38	606.00	0.003375	2482.96	26.93

Table 4 Compressive strength of Bituminous sand concrete

Curing age (days)	Average mass (kg)	Average failure load (kN)	Volume (m^3)	Density (kg/m^3)	Compressive strength (N/mm^2)
7	7.24	211.00	0.003375	2145.19	9.38
14	7.34	241.67	0.003375	2174.81	10.74
21	7.42	288.67	0.003375	2198.52	12.83
28	7.62	338.00	0.003375	2257.78	15.02
56	7.63	342.33	0.003375	2260.74	15.22
90	7.63	344.67	0.003375	2260.74	15.32
150	7.64	345.33	0.003375	2263.70	15.35

At 56, 90, and 150 days of age, the control concrete increased its compressive strength by 4.24, 4.72, and 8.92%, respectively, over the 28-day compressive strength, while the bituminous sand concrete increased its compressive strength by 0.8, 1.2, and 1.32%, respectively. The low strength development of the concrete cubes may have been caused by the bitumen in the bituminous sand, which is a part of the microstructure of the concrete matrix. This bitumen may have caused the gel to dilate, the cohesive forces in the paste to weaken, and the internal hydraulic pressure to rise as a result of the bitumen's absorption.

Though bituminous sand concrete at 28 days of curing gained a strength of 15.02N/mm^2 which is less than the design strength of 25N/mm2, this strength is among the standard regular strength grades of concrete that is C10, C15, C20 and C25, which is an excellent choice for developing unreinforced foundations for houses, paving, residential flooring, and freestanding retaining walls.

3.4. Statistical Analysis

The experimental findings for bituminous sand concrete (BSC) and control concrete (CC) in terms of compressive strength produced mean and standard deviation of 13.41, 2.48, and 22.39, 4.56, respectively, considering appendices A and B. The distribution curves are all mesokurtic, suggesting that the data are regularly distributed, even though the skewness and kurtosis values of -0.65, 1.62, and -0.92, -0.99 are all less than 1.96, suggesting that the data are not skewed.

The Shapiro-Wilk p-values for the compressive strength of the CC and BSC, which are 0.15 and 0.05, respectively, are all greater than or equal to the level of significance (i.e., $p \geq 0.05$), which further supports the distribution of the data in Appendices A and B. Before the predictive models are developed, the data does not need to be transformed, since the box plot confirms the lack of univariate outliers. The data's normal distribution is confirmed by Appendices A and B, which also show that the compressive strength of the CC and BSC has Shapiro-Wilk p-values of 0.15 and 0.05, respectively. These values are all greater than or equal to the significance level (i.e., $p \geq 0.05$).

The models developed for the CC and BSC are shown in Eq.2 and Eq.3. For the models, Y stands for compressive strength, X_1 stands for curing age (days) and X_2 stands for dry density (kg/m^3).

$$Y = -797 - 0.020X1 + 0.333X2 \quad \text{Eq.2}$$

$$Y = -98.78 - 0.00092X1 + 0.05X2 \quad \text{Eq.3}$$

Appendix C displays the compressive strength predictions derived from models 2 and 3. A high degree of association was indicated by the regression analysis of the data for models 2 and 3, which produced R-square values of 0.95 and 0.98 (see appendices D and E). This implies that the models could account for about 95% and 98% of the variation in the end variable (compressive strength) of the CC and BSC, respectively. The remaining 5% and 2% are due to bias and inaccuracy. Since the models were validated by the t-test analysis of the data, the null hypothesis is accepted for the models. The models are therefore suitable.

4. Conclusion

This study looked at the statistical analysis and compressive strength of concrete made with bituminous sand. As a fine aggregate material, bituminous sand was utilized instead of river sand. Therefore, the following conclusions are drawn from the experimental and statistical data:

- There was an increase in slump of the bituminous sand concrete (BSC) compared to the control.
- The measured compressive strength of bituminous sand concrete (BSC) 15N/mm^2 at 28 days of curing was 39.9% lower than the designed strength of 25N/mm^2.
- This decrease may have been caused by the bitumen in the bituminous sand, which is a part of the microstructure of the concrete matrix. The poor growth of the concrete cubes' strength may have been caused by the gel dilatation, the weakening of the cohesive forces in the paste, and the increase in internal hydraulic pressure caused by the bitumen that was absorbed.
- The C15 grade of BSC at 28 days makes it a great option for creating freestanding retaining walls, paving, residential flooring, and unreinforced foundations for homes.
- Given that all the experimental data's Shapiro-Wilks p-values are greater than or equal to the significance level ($p \geq 0.05$), the data are normally distributed. With a high coefficient of determination, the models were able to predict the control and bituminous sand concrete's compressive strengths with 95% and 98% accuracy, respectively.

Compliance with ethical standards

Disclosure of conflict of interest

The authors state that none of their financial interests or known conflicting personal ties might have appeared to have influenced the work described in this study.

Data availability

The article contains the original contributions made during the study; additional questions can be forwarded to the corresponding author.

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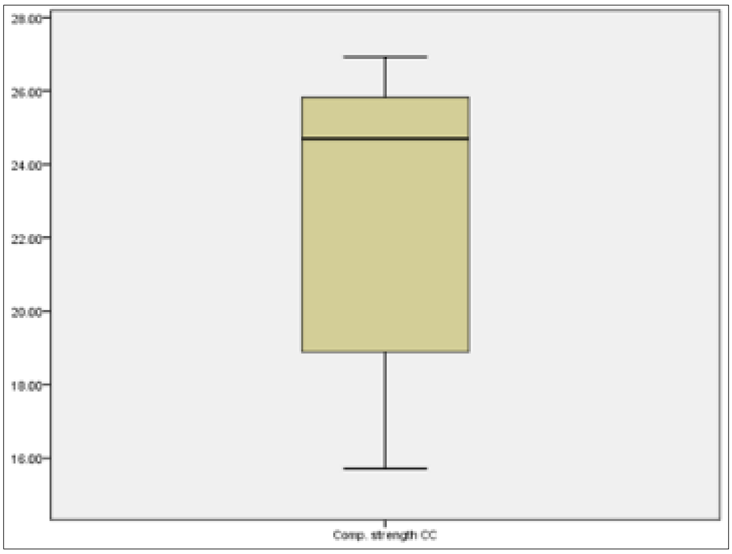
Appendix A

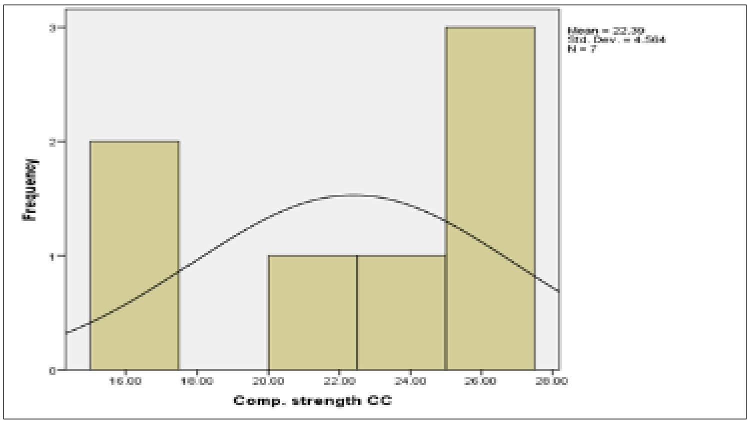
Tests of Normality for Comp. Str. Of Control Concrete (CC)						
	Kolmogorov-Smirnov[a]			**Shapiro-Wilk**		
	Statistic	df	Sig.	Statistic	df	Sig.
Comp. strength CC	.265	7	.148	.860	7	.152
a. Lilliefors Significance Correction						

Descriptives statistics				
			Statistic	Std. Error
Comp. strength CC	Mean		22.3929	1.72501
	95% Confidence Interval for Mean	Lower Bound	18.1719	
		Upper Bound	26.6138	
	5% Trimmed Mean		22.5121	

	Median	24.7000	
	Variance	20.830	
	Std. Deviation	4.56396	
	Minimum	15.71	
	Maximum	26.93	
	Range	11.22	
	Interquartile Range	8.77	
	Skewness	-.650	.794
	Kurtosis	-1.624	1.587



Box plot

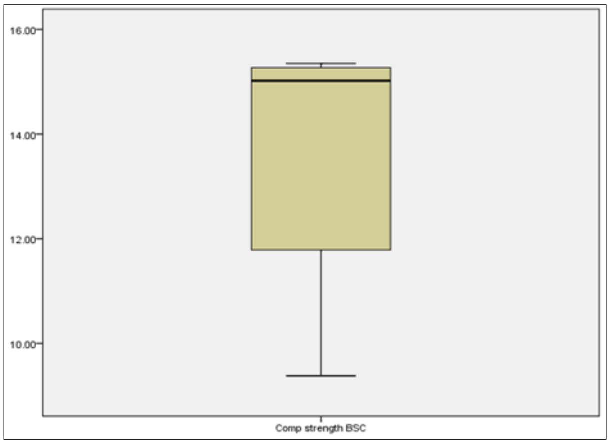


Normal distribution curve

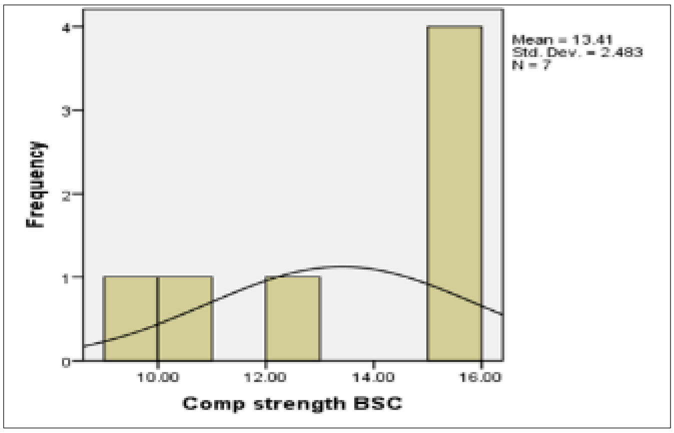
Appendix B

Tests of Normality for Comp. Str. Of Bituminous sand Concrete (BSC)						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Comp strength BSC	.313	7	.037	.802	7	.045
a. Lilliefors Significance Correction						

Descriptives				
			Statistic	Std. Error
Comp strength BSC	Mean		13.4086	.93841
	95% Confidence Interval for Mean	Lower Bound	11.1124	
		Upper Bound	15.7048	
	5% Trimmed Mean		13.5245	
	Median		15.0200	
	Variance		6.164	
	Std. Deviation		2.48281	
	Minimum		9.38	
	Maximum		15.35	
	Range		5.97	
	Interquartile Range		4.58	
	Skewness		-.917	.794
	Kurtosis		-.988	1.587



Box plot



Normal distribution curve

Appendix C

Predicted compressive strength of CC

Observation	Predicted Compressive Strength	Residuals
1	14.06852038	1.10148
2	19.19097338	-2.08097
3	21.02470686	-0.36471
4	23.84472299	0.855277
5	25.24863289	0.511367
6	25.54440540	0.335595
7	27.28803809	-0.35804

Predicted compressive strength of BSC

Observation	Predicted Compressive Strength	Residuals
1	9.518096197	-0.138096197
2	11.0071422	-0.267142197
3	12.19780419	0.632195811
4	15.18331415	-0.16331415
5	15.30712579	-0.087125788
6	15.27600024	0.043999762
7	15.37051724	-0.020517241

Appendix D

Regression statistics for Compressive strength of Control Concrete

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.973562							
R Square	0.947824							
Adjusted R Square	0.921736							
Standard Error	1.314394							
Observations	7							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	2	125.5352	62.76762	36.33159	0.002722			
Residual	4	6.910529	1.727632					
Total	6	132.4458						

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-796.997	154.4557	-5.16003	0.006698	-1225.83	-368.159	-1225.83	-368.159
Curing age	-0.02031	0.019898	-1.02065	0.365125	-0.07556	0.034937	-0.07556	0.034937
Dry density	0.333204	0.063094	5.281088	0.006166	0.158027	0.50838	0.158027	0.50838

Appendix E

Regression statistics for Compressive strength of Bituminous Sand Concrete (BSC)

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.992853864							
R Square	0.985758796							
Adjusted R Square	0.978638193							
Standard Error	0.362879597							
Observations	7							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	2	36.45935931	18.22968	138.43756	0.000202812			
Residual	4	0.526726408	0.1316816					
Total	6	36.98608571						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-98.78182237	9.236792729	-10.694386	0.0004331	-124.4272703	-73.136374	-124.4273	-73.13637
Curing age	-0.000915457	0.004035741	-0.2268375	0.8316713	-0.012120471	0.01028956	-0.01212	0.01029
Dry Density	0.050487988	0.004220878	11.961489	0.0002799	0.038768951	0.06220702	0.038769	0.062207