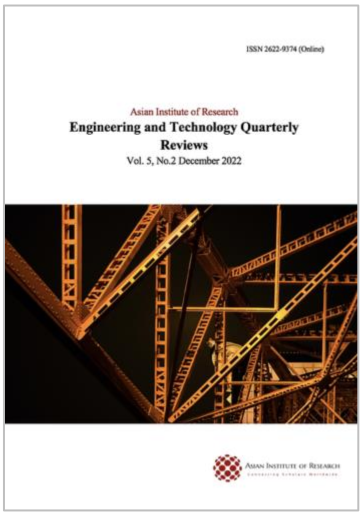

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Statistical Evaluation of the Mechanical Properties of Cow Dung Ash Concrete

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Abstract

Cement is the main binder in the production of concrete for construction activities. Unfortunately, the continuous use of cement results in severe environmental and energy concerns. An established way of reducing carbon footprints and the energy demands associated with cement production is the use of supplementary cementitious material (SCMs). Most supplementary cementitious materials are processed from agro-wastes and bye-products like cow dung. Although cow dung has been utilized as manure, for heating and so on, its use is yet to match the level of production. In this study, the authors propose to investigate the strength performance of cow dung ash as SCMs. Cow dung ash is the product of controlled burning of dried cow dung. Concrete beams and cubes containing 0% to 30% cow dung ash as cement replacement were cured by complete immersion in water for 7,14,28,60 and 90 days. Compressive and flexural strengths decreased as CDA increases; and increased with curing age. Concrete made with 5%, 10%, and 15% CDA and cured for at least 60 days achieved the 28days target compressive strength of 20N/mm^2. The strength test results were analysed by analysis of variance (ANOVA) and regression analysis. Proposed regression models showed a strong relationship between the strengths, CDA content and curing age. The proposed models were examined and found to be permissible

Keywords: Compressive Strength, Flexural Strength, Cow Dung Ash, Regression, ANOVA

1. Introduction

Concrete is a ubiquitous construction material owing to its many properties, which include excellent compressive strength, fire resistance, ability to be molded into any desired shape and size (Mahdikhani & Ali, 2015). Concrete essentially contains cement, coarse aggregates, fine aggregates, water and sometimes, additive or admixtures in the required proportion to improve certain properties. Cement is the main binder in the production of concrete and sandcrete blocks for the construction of public and private infrastructure. According to the US Statistica (2021), global cement production grew from 1.39 billion tons in 1995 to 4.4 billion tons in 2021, and that number is expected to rise to 5.5 billion tons by 2050 (Garside, 2022). There are few concerns associated with the production and consumption of cement. First is the exorbitant cost of cement especially in developing countries. For instance, between 2017 and 2022, the price of a 50kg bag of ordinary Portland cement (OPC) in Nigeria went up by 58% (Ugochukwu et al., 2017). Some of the ripple effects of this are the high cost of constructing public and private buildings, bridges, roads etc. Nigeria needs $ 1.5 trillion to bridge infrastructure gap over a period of 10 years (Michael, 2022).

The second concern is that cement production process requires enormous thermal energy and reportedly contributes between 5-6% of global CO_2 emission (Worrel et al., 2001. The effect of CO_2 emission and global climate change on the environment, human and animal health, and plant life cannot be over-emphasized (De Sario et al., 2017). Therefore, there is a huge challenge to reduce carbon footprint and make concrete or sandcrete block cheaper, eco-friendly and sustainable. To achieve the goal of reducing the global carbon footprint, agro waste and bye products have been proposed as supplementary cementitious materials (SCMs), which are materials that can partially replace cement in concrete production (Adebakin, et al., 2012). Some studied materials as SCMs with viability for large-scale usage include sawdust ash (Elinwa & Mahmood, 2002; Elinwa & Ejeh, 2004), Groundnut husk ash (Buari et al., 2013; Ikumapayi, 2018), Rice hush ash (Godwin et al., 2012; Seyed et al., 2017). These SCMs have proven ability to partially replace cement, improve mechanical and durability properties of concrete. The overall benefits are lower cost of production and durable concrete is produced; significantly lower CO_2 is emitted into the environment (low carbon footprint); and cleaner environment from recycling these by-products (Mehta & Monterio, 2006).

Cow dung is the undigested residue of plant matter, which has passed through the cow's gut. Globally, an estimated 1.3 billion tons of cow dung is produced annually (FAO, 2010). Although cow dung is used in many areas such as manure in farming, biogas for electricity, and heat generation, some quantities are left as waste in the grazing field, cowshed, and at times washed away into waste pipes in abattoirs (Olusegun & Sam, 2012; Marek, 2012). The result of using dried cow dung in place of wood for domestic firing is the production of ash that now constitutes a nuisance to the environment (Szymajda et al., 2021). Kumar and Raju (2012) studied the effect of using cow dung ash as partial cement replacement material in concrete. Cow dung ash replaced cement by weight at 10%, 20% and 30% and the engineering properties of fresh and hardened concrete were investigated. There was a continuous decrease in compressive strength as CDA contents increased and strength gained with increasing curing time. Setting times and workability increased as CDA content increased. Ojedokun et al. (2014) reported similar findings from another independent work. The increased setting times are an indication of the potential of cow dung ash as to serve as a set retarder which is beneficial in hot weather concreting (Eren et al., 1995). Furthermore, the decrease in density as CDA increases reveals that CDA/cement results in the production of lightweight concrete (Agrawal et al., 2021). Omoniyi *et al.* (2014) investigated the possibility of using cow dung ash as a pozzolanic material in concrete production. The chemical composition of cow dung ash meets the ASTM C618-2012 criteria for use as pozzolana in mortar and concrete production. Further test results also showed that it slowed down hydration, prolonged setting times, reduced the risk of delayed expansion and increased the standard consistency. Duna and Omoniyi (2014) examined the effect of cement replacement with cow dung ash (CDA) replacement at 5%, 10%, 15%, 20%, 25% and 30% on the compressive strength of concrete and observed that concrete made with no more than 15% CDA is as equally good as the plain concrete. There is a dearth of information on the flexural strength of cow dung ash concrete. In this study, the mechanical properties of cow dung ash (CDA) and cement-blended concrete were investigated and statistical approaches were employed to draw inferences.

2 Materials and Methods

2.1 Materials

2.1.1 Cow dung ash

Cow dung used for this study was collected from a cattle farm located in Bauchi, North–East Nigeria. The cow dung was air-dried, pulverized and calcined at a temperature of about 500°C. The resultant ash was passed through sieve size 212μm and the chemical composition was determined through XRF (X-ray fluorescence) technique.

Figure 1: Sample of cow dung ash used for the study.

2.1.2 Cement

The study used Ordinary Portland cement (OPC) which conforms to BS 12:1978 and the Nigerian Industrial standards NIS 444-1:2003 Specification.

2.1.3 Fine aggregates

Fine aggregate used for the study was sourced from a flowing stream close to the cattle farm location. The fine aggregate was air-dried under a shed until all the water was virtually removed.

2.1.4 Water

Potable water from public source within the yelwa campus of the Abubakar Tafawa Balewa University as used for concrete production.

2.2 Methodology

2.2.1 Experimental Program.

2.2.1.1 Concrete Production, casting and curing

The first phase of the study includes concrete production; curing and testing. The reference concrete (control) was designed to achieve a 28 days target strength of 20N/mm^2.The other six mixes were designed to replace cement with cow dung ash (CDA) at, 5%, 10%, 15%, 20%, 25%, and 30%. After batching of the constituent materials for the concrete, the materials were mixed thoroughly until a consistent mix was achieved. The fresh concrete was poured into well-oiled molds, and removed twenty-four hours later. Hardened concrete cubes and beams were cured by complete immersion in curing tank filled with water at a temperature and relative humidity of 20℃ and 56°H. The curing ages were 7,14,28,60 and 90 days. The long-term curing of up to 90 days is to enable the pozzolanic potentials of the cow dung ash to participate maximally in strength gain with time. The mix proportion is presented in Table 1.

Table 1: Concrete mix proportions

Cement replacement level. DA (%)	Cement (kg/m^3)	CDA (kg/m^3)	Fine Aggregate(kg/m^3)	Coarse Aggregate(kg/m^3)	Water (kg)
0	300	0	776	1164	165
5	285	15	776	1164	165
10	270	30	776	1164	165
15	255	45	776	1164	165
20	240	60	776	1164	165
25	225	75	776	1164	165
30	210	90	776	1164	165

2.2.1.2 Compressive strength

The compressive strength of the cubes was determined using the ELE digital compression machine in accordance with BS 1881: Part 116:1983 specification. The dimension of the concrete cube used for the study is 150mmx150mmx150mm. For each mix design (Mix ID) and curing age, three samples were cast and crushed to failure. The compressive strength of the CDA/OPC concrete was determined using equation (1).

$$f_{cu} = \frac{failure\ load\ in\ KN}{Area\ of\ test\ specimen.} \text{..........} (1).$$

2.2.1.3 Flexural Strength

Flexural strength test was conducted on the hardened concrete beams of size 100mm x100mm x 500mm after curing for at 7,14,28,60 and 90 days. The test was conducted in accordance with ASTM C 78-2002 specification. The testing apparatuses and loading arrangement for the flexural strength test are shown in Fig. 2 and 3 respectively. The flexural strength is expressed as modulus of rupture (MR) in (N/mm^2), and determined using Eq. 2.

$$f_{ct} = \frac{PL}{bd^2} \text{..........} (2).$$

Where
P= maximum load in kN
L= span of the beam. (i.e. 500mm)
d= depth of the beam (i.e 100mm)
b= breath of the beam. (i.e. 100mm)

(a) Compressive strength test set up (b) Flexural strength test set up

Figure 2: Compressive and flexural strength test set up.

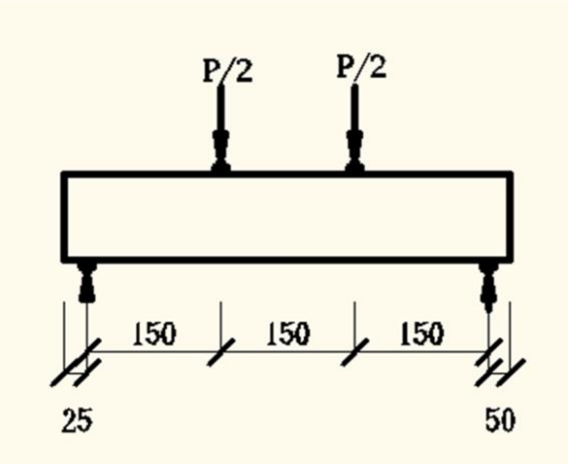


Figure 3: Testing set up for flexural strength

2.3 Data Analysis, model develop

The second phase includes data validation, analysis, model development and model testing. The compressive and flexural strength test results formed the basis for the analysis. Basic descriptive statistics of the strength data are considered in this study. This provides basic and useful information about the variables and highlight potential relationships between the variables. The statistics considered are the mean, standard deviation, standard error of the mean, variation and coefficient of variation. They were first determined along the row, that is, for same mix but with varying curing age (within-test) and then determined along the column, which batch-batch test involves different mixes cured at the same age.

Analysis of variance (ANOVA) is a collection of statistical tools used to ascertain the difference between the means of the reference concrete and those containing cow dung ash. ANOVA is a strong indicator beyond the normal graph because of the deeper insight it provides for informed, reliable and accurate conclusion on the study. Regression analysis is another statistical method, which seeks to explore the relationships between the dependent variable (compressive and flexural strength) and the independent variable (cow dung content, curing age). The regression models were validated by checking for the basic assumptions of constant variation of the residuals and the normality of the probability plot.

3 Results and Discussion

3.1 Material testing and characterization.

The chemical composition of cow dung ash (CDA) and ordinary Portland cement determined through X-ray fluorescence are presented in Table 2. Cow dung ash (CDA) had similar oxides to cement and other pozzolana. The sum of the oxides of silicon (SiO_2), iron (Fe_2O_3) and aluminum (Al_2O_3) is 77.63%, which exceeds the 70% minimum specified by ASTM C618-12 for raw or calcined pozzolana (class N). These oxides determine the amount of tricalcium silicate (C_3S), tricalcium aluminates (C_2S) and tetra calcium Aluminoferraite (C_3AF) (Shim et al., 2021). These compounds contribute to early and later strength as well as the setting characteristics of concrete (Neville, 2012). The silica content in CDA is one important factor because, when added $Ca(OH)_2$ (product of cement hydration), will form additional calcium silicate hydrates (C-S-H) in the hydrated cement matrix, which increases the density of the matrix, and refines the pore structure. The combined sodium oxide and potassium oxide of cow dung ash (CDA) i.e. Na_2O+ K_2O is low (3.5%) and thus reduces the possibility of the destructive aggregate alkali reaction, which causes disintegration of concrete (Falade et al., 2012). In addition, high alkalis percentage delayed final setting time and decreased compressive strength (Zhengqi et al., 2016). One other interesting chemical present is Sulphur trioxide (SO_3). The SO_3 of 0.94% present is below the 4% maximum specified by ASTM C618-12 and thus has the potential to improve the durability of concrete or mortar and prevent unsoundness of the cement paste (Neville, 2012).

The comparison of the physical properties of OPC and CDA is shown in Table 3. The specific gravity of CDA is about 20% less than that of PC. This implies that more volume of CDA will be required to replace an equal weight of Cement. CDA is observed to be finer than OPC and will certainly increase the surface area of cementitious material available for hydration. The loss on ignition of 12.28% for cow dung ash exceeds the maximum LOI of 10% specified by ASTM C-618 for pozzolans. This high value can be attributed to the presence of impurities and are expected to be found in the raw cow dung. This may affect the reactivity of the CDA and thus increase the water requirement due to the presence of impurities (Falade et al., 2012). The pH of CDA indicates neutrality and thus will have no adverse effect on the durability of the cement matrix. Some properties of the fine and coarse aggregate are presented in Table 4 while Fig 4 shows the particle size distribution of the coarse aggregate.

Table 2: XRF results of Cow dung Ash and Ordinary Portland Cement

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O
CDA (%)	69.76	4.74	3.18	13.25	2.12	0.89	2.71	0.611
Cement (%)	19.68	6.44	3.22	60.92	0.97	2.28	0.85	0.12

Note. Test results for the CDA are means of five (5) separate determination.

Table 3 Physical Properties of Ordinary Portland Cement and Cow dung ash.

Property	Cement	CDA
Specific gravity	3.15	2.55
Blaine Fineness(m^2/kg)	370	338
pH	-	9.5
Loss on Ignition (%)	1.0	12.28

Table 4: Properties of Fine and Coarse Aggregates

Property	Fine aggregate	Coarse aggregate
Specific Gravity	2.62	2.65
Bulk density(Kg/m^3)	1528	1410
Aggregate crushing value (%)	N.A	22.27*
Silt content.	4.26	N.A

Test results are means of three determinations

** Aggregate crushing value less than 45% maximum specified for concrete works.*

N.A means not applicable

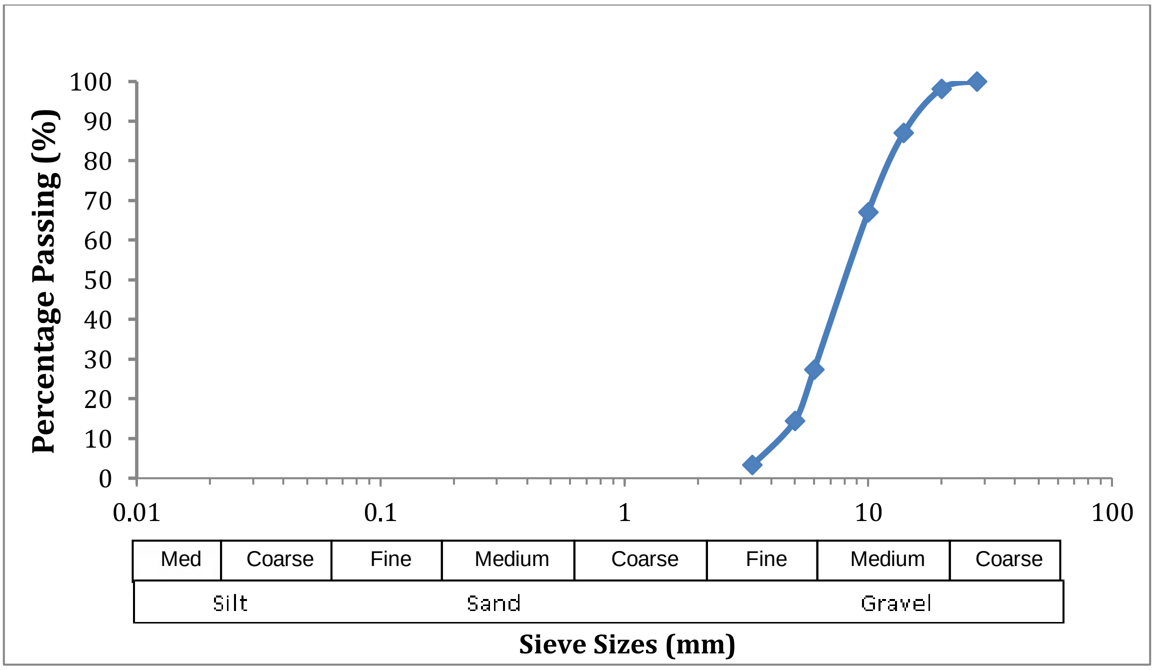


Figure 4: Particle size distribution of coarse aggregate.

3.2 Compressive and flexural Strength of cow dung ash concrete.

The variations of compressive strength and flexural strength with are shown in Fig 5, 6 respectively. Generally, both compressive and flexural strengths decreased with increasing CDA content and increased with curing age. The 3D plots of the model variables in Figs. 7a and 7b for compressive and flexural strength respectively reveal similar trend. With respect to strength reduction as CDA increases, 5% CDA resulted in strength reduction of 7.04%, 19.3%, 22.9%, 10.63% and 3.90% when compared to the strength of control specimen (0% CDA) at 7,14,28,60 and 90days of curing respectively days. The percentage of strength reduction increased with increasing CDA content for both compressive and flexural strengths. The strength reduction with increasing CDA content could be attributed to the reduction in strength forming compounds of tricalcium silicate (C_3S) and di-calcium silicate (C_2S) through partial replacement of cement with CDA (Manasseh, 2010). The amorphous silica (SiO_2) that forms the dominant oxide in CDA enters into a secondary reaction with the hydration product of calcium hydroxide ($Ca(OH)_2$) to form more stable calcium silicate hydrate, which is responsible for strength gain overtime (Ikponwosa et al., 2012; Elinwa & Mbadike, 2011; Malhotra et al., 2000). The results also revealed that all concrete made with 5-15% CDA and cured for at least 60 days exceeds the 28 days target compressive strength of 20N/mm^2. Thus, concrete made within these replacement levels and curing ages are adjudged good for structural use.

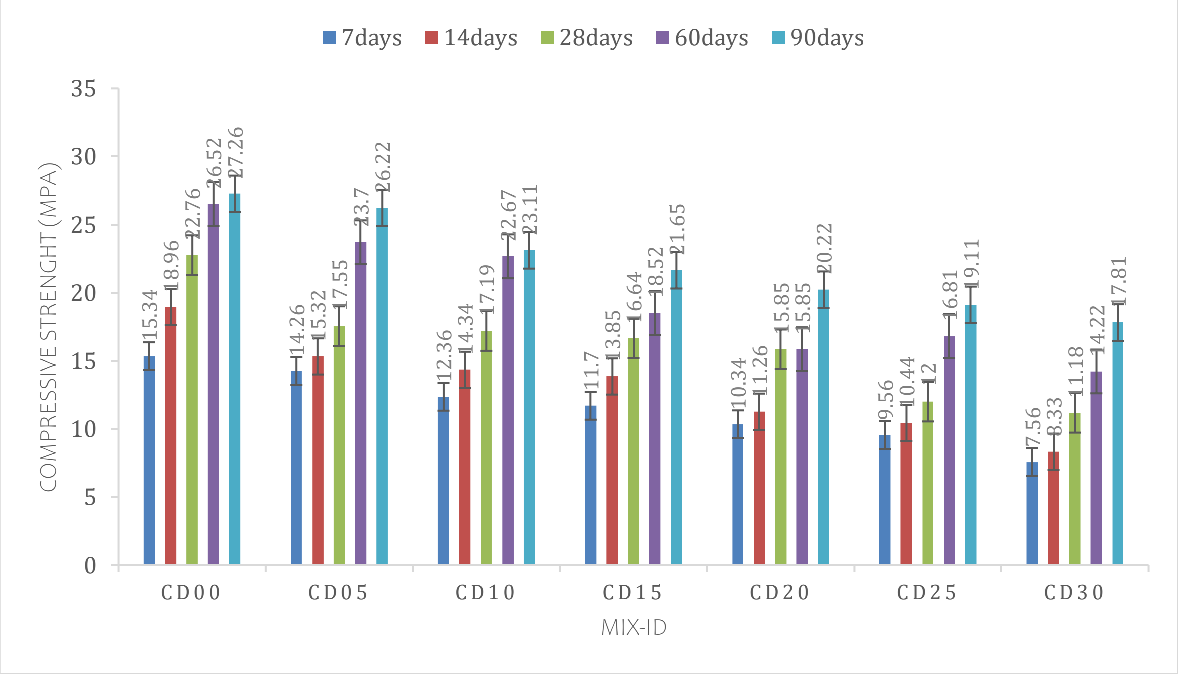


Figure 5: Comparison of compressive strength different mixes.

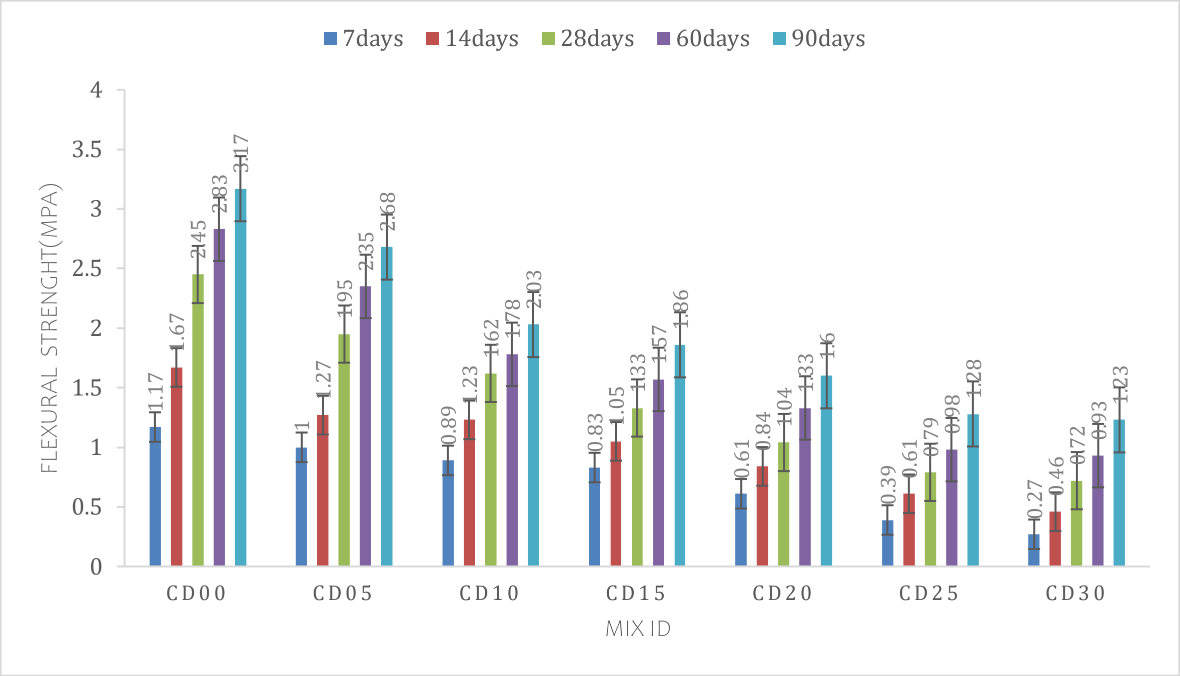
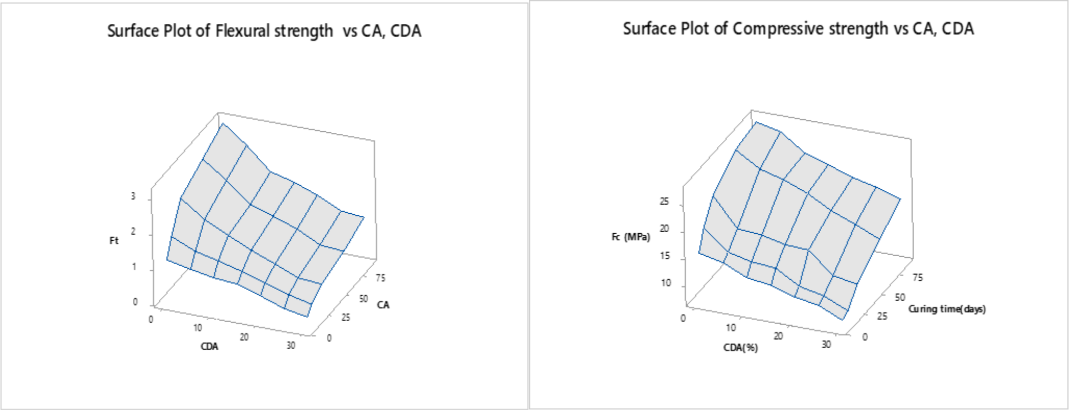


Figure 6: Comparison of flexural strength different mixes.



(a) (b)

Figure 7: (a) 3D surface plot of flexural strength. (b) 3D Surface plot of compressive strength.

3.3 Descriptive statistics of the strength results

The descriptive statistics for inside test and outside test data are presented in Tables 5 and 6 respectively. The corresponding flexural strength statistics are presented in the brackets. The mean value measures the central tendency of the data. The ranges of the mean value for the inside and outside test are (11.82-22.17) and (11.59-22.19) respectively. Standard deviation is a measure of dispersion of the data around the mean. Low standard deviations values indicate data spread around the mean while high values indicates greater data spread. The ranges for standard deviation for the inside and outside test data are (3.89-5.28) and (2.70-4.25) respectively. The standard error gives a measure of how well a sample represents the population. When the sample is representative, the standard error will be small. The standard error of the mean for inside and outside test data ranged from (1.74-2.36) and (1.02-1.61) respectively. These values are expectedly low and represented as bars on corresponding bar charts for compressive and flexural strength in Figs 5 and 6 respectively. The coefficient of variation is the ratio of the standard deviation to the mean expressed as a percentage and the higher the value, the greater the level of dispersion around the mean. The within-test value ranged from (22.79 to 35.99) while the between-test was from (15.98 to 26.66).

The box plots for the flexural and compressive strength are shown in Fig. 8 and 9 respectively. Box plots are used to visualize the overall patterns of response for a group, inspect the data for skewness, and to check for unusual observations (outliers). The median lines of all the box plots are not exactly at the center. This is an indication that the data are not normally distributed (i.e. mean is not equal to median), as some are negatively skewed while others are positively skewed. There are also no outliers as no observations fell outside the whiskers of the box plot. The interquartile ranges (the box lengths) in most cases are not short and that is an indication of a dispersed data. The box plot for varying cow dung ash has longer box lengths, which is an indication that cow dung ash caused more variation in compressive and flexural strength than curing age. In other words, cow dung ash has more significant effect on the strength than curing age.

Table 5: Statistics inside test data of same mix with varying curing age for compressive/flexural strength

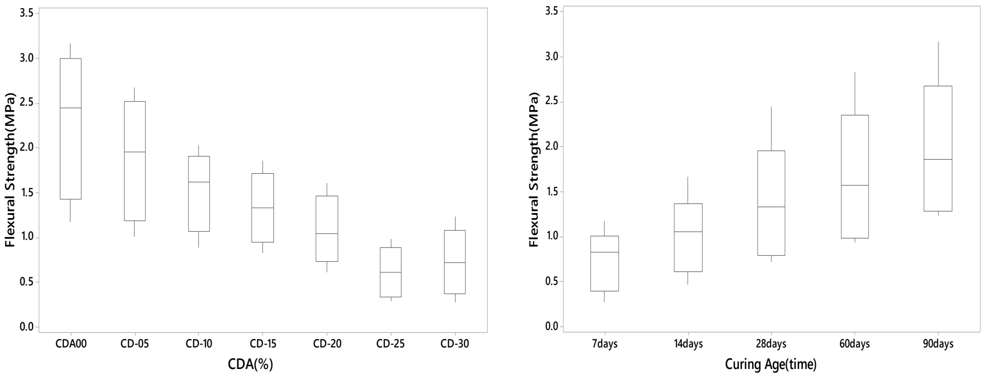
Variable	Mean	SE Mean	StDev	Variance	CoeffVar
CDA00	22.17(2.258)	2.26(0.369)	5.05(0.825)	25.53(0.681)	22.79(36.56)
CDA05	19.41(1.870)	2.36(0.308)	5.28(0.689)	27.87(0.475)	27.20(36.85)
CDA10	17.93(1.510)	2.17(0.202)	4.84(0.452)	23.44(0.205)	27.00(29.95)
CDA15	16.47(1.328)	1.74(0.183)	3.89(0.408)	15.17(0.167)	23.65(30.75)
CDA 20	15.24(1.084)	1.95(0.175)	4.35(0.391)	18.95(0.153)	28.56(36.11)
CDA 25	13.58(0.610)	1.86(0.128)	4.17(0.286)	17.38(0.082)	30.69(46.84)
CDA30	11.82(0.722)	1.90(0.169)	4.25(0.379)	18.09(0.144)	35.99(52.48)

SE=Standard Error. StDev= Standard deviation. CoeffVar= Coefficient of Variation. Flexural strength values in brackets.

Table 6: Descriptive Statistics for batch-batch test for compressive/flexural strength.

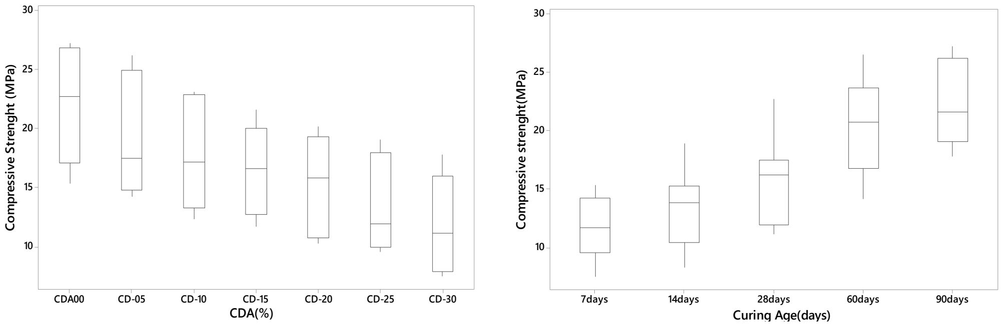
Variable	Mean	SE Mean	StDev	Variance	CoeffVar
7Days	11.59(0.737)	1.02(0.124)	2.70(0.327)	7.29(0.107)	23.29(44.42)
14Days	13.21(1.033)	1.33(0.162)	3.52(0.429)	12.42(0.184)	26.66(41.51)
28Days	16.11(1.414)	1.45(0.240)	3.85(0.635)	14.79(0.403)	23.88(44.91)
60Days	20.46(1.681)	1.61(0.266)	4.25(0.703)	18.04(0.495)	20.76(41.83)
90Days	22.19(1.979)	1.34(0.273)	3.55(0.721)	12.58(0.520)	15.98(36.45)

SE=Standard Error. StDev= Standard deviation. CoeffVar= Coefficient of Variation. Flexural strength values in brackets



(a) **(b)**

Figure 8: (a) Box plot for flexural strength with varying CDA content. (b) Box Plot for flexural strength with varying curing age.



(a) **(b)**

Figure 9: (a) Box plot for compressive strength with varying CDA content. (b) Box Plot for compressive strength with varying curing age.

3.4 Analysis of Variance (ANOVA)

The results of a one-way analysis of variance at 5% level of significance for the compressive and flexural strengths results are presented in Tables 7 and 8 respectively. The P-values are indicators to check whether the difference between group means is statistically significant or not. In other words, the difference between a group like the reference concrete (0% CDA) and other groups containing CDA such as 5% and so on. The least square difference (P-values) in Table 7 at 5%, 10% and 15% CDA is 0.42N/mm^2,0.21N/mm^2 and 0.11N/mm^2 respectively. These values are greater than the selected level of significance (α=0.05N/mm^2) and implies that there is no statistically significant difference between the group mean of the compressive strength of plain concrete and those containing up to 15% CDA ($p > 0.05$). Similarly, the least square difference at 5% level of significance showed that no statistically significant difference exist between the mean of the flexural strength of the plain concrete and those containing up to 10% CDA($p > 0.05$). The summary is that the compressive strength of concrete containing 5-15% CDA is not statistically significantly different from that of the reference concrete.

Table 7: ANOVA for the Compressive strength results.

Mix- ID	Mean Strength	Variance	P
CDA-00	22.168	-	-
CDA-05	19.398	27.908	0.4216*
CDA-10	17.930	23.447	0.2123*
CDA-15	16.840	18.600	0.1107*
CDA-20	15.238	18.945	0.0485**
CDA-25	13.584	17.382	0.0190
CDA-30	11.924	18.772	0.0081

** Means are significant at 5% level.*

***Means are significant at 1% level.*

Table 8: ANOVA for the Flexural strength results.

Mix- ID	Mean Strength	Variance	P
CDA-00	2.26	0.5019	-
CDA-05	1.87	0.4750	0.4033*
CDA-10	1.51	0.2046	0.0811*
CDA-15	1.328	0.1668	0.0342**
CDA-20	1.084	0.1523	0.0117**
CDA-25	0.81	0.1165	0.0033
CDA-30	0.722	0.1436	0.0027

** Means are significant at 5% level.*

***Means are significant at 1% level.*

3.5 Regression analysis

Regression model that expresses the influence of cow dung ash and curing age on compressive and flexural strength are represented as equations 3 and 4 respectively. The analysis of variance (ANOVA) that measures which of the independent parameters are statistically significant are presented in Tables 9 and 10 respectively for compressive and flexural strengths

$f_c = 16.44 + 0.1285CA - 0.32196CDA$…………………………………………………… (3)

$\sqrt[3]{f_t} = 1.138 + 0.00381CA - 0.001419CDA$……………………………………………...... (4)

Where f_c, f_t, CDA and CA are compressive strength, flexural strength, CDA and curing age respectively.

The compressive strength model (Equation 3) reveals that a linear model fitted the compressive strength data well as there was no necessity for data transformation as is the case with Eq. 4. The coefficient of variation (R^2) for the proposed linear model for the compressive strength reveals a high correlation among the compressive strength, CDA and curing age. The R^2=94.78% indicates that 94.78% of the variation in compressive strength is caused by the CDA contents and curing age. Unlike the regression model for compressive strength, a linear regression model did not fit the flexural strength data well as the residual versus fits plots shows that the residuals suffered from heteroscedasticity. In other words, the residual had no constant variance at every level of the predictor variables and thus the estimates for the model coefficient are not reliable. A solution was arrived at using the cube-root transformation of the original flexural strength data. The standard deviations (σ) are low for both models, which is a strong indication of the goodness of fit of the proposed models (Karen, 2012). The P-values in Table 9 and 10 respectively are used to check the significance of each coefficient (independent variables). The P-values of 0.00 indicates that the regression model and all independent variable are highly significant at 5% level of significance. The p-values are all less than 5 % (α= 0.05).

Table 9: ANOVA Results and Model Summary for Compressive strength

Source	DF	SS	MS	F	P
Regression	2	918.44	459.22	290.79	0.00*
CDA	1	555.74	555.740	351.91	0.00
CA	1	362.70	362.701	229.67	0.00
Error	32	50.53	1.579		
Total	34	968.97			

** Significant at 5% level Regression model summary gives σ = 1.260* R^2*=.94.78%* R^2*(adj) 94.46%*

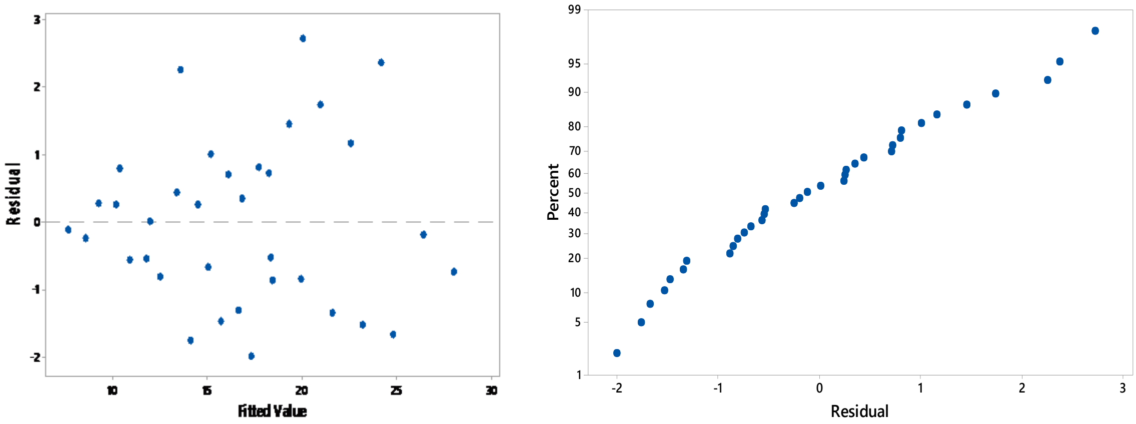
Table 10: ANOVA Results and Model Summary for Flexural strength.

Source	DF	SS	MS	F	P
Regression	2	2.8817	1.4408	205.71	0.00*
CDA	1	1.1794	1.1794	168.39	0.00
CA	1	1.7023	1.7023	243.03	0.00
Error	32	0.2241	0.0070		
Total	34	3.1058			

** Significant at 5% level, Regression model summary gives* $\sigma = 0.084$ R^2*=92.78%* R^2 *(adj) 92.33%*

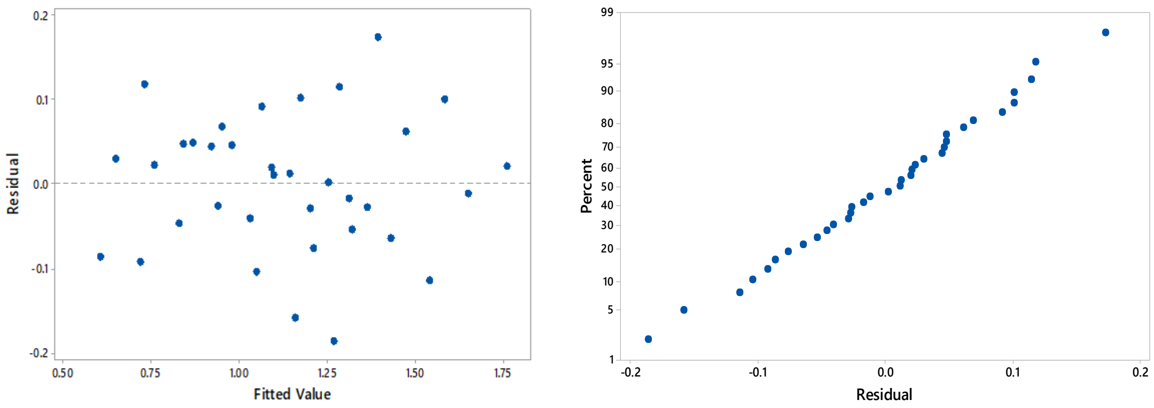
3.6 Regression Model validations

The high coefficient of variation (R^2) and low standard deviation does not determine satisfactorily the permissibility of the model, as these are not indicators of a residual with constant variance (Guowei, 2009). Hence, model diagnostic plots were examined to check that the assumption of constant variance and normal distribution of the data was not violated. The plots are presented in figures 10 and 11 for compressive and flexural strength respectively. The residual versus fits plots (10a and 11a) does not reveal any definite pattern; the residuals (noise) are randomly distributed along the zero-error line with just a few outliers observed. Therefore, the constant variance criterion is adequately satisfied for both models. The normal probability plots in Figures 10b, 11b approximately follow a straight line and consequently, the regression models satisfied the normal probability assumptions and are permissible (Muche, 2008; John, 2011; UVA Library, 2015; Dunn & Smyth, 2018).



(a) **(b)**

Figure 10: (a) Residual versus fits plot of compressive strength. (b) Normal probability plot of compressive strength.



(a) *(b)*

Figure 11: (a) Residual versus fits plot of flexural strength. (b) Normal probability plot of flexural strength.

4. Conclusion

This study focused on the properties of cow dung ash blended cement concrete especially statistical evaluation of the strength of this type of concrete. The following conclusions can be drawn:

- Cow dung ash possess the required amount of oxides stipulated by ASTM C618-12 for pozzolana. Therefore, CDA are applicable as cement replacement in concrete production.
- There is no statistically significant difference between the means of compressive strength of up to 15% CDA concrete and those of the reference concrete (without CDA). Therefore, 15% CDA is recommended when compressive strength governs, and 10% CDA where flexural strength governs.
- There is a strong mathematical relationship between the compressive/flexural strength and other variants (i.e. curing age and CDA). R^2>97 for both strengths models.
- The proposed mathematical models are capable of predicting the mechanical strengths to a high degree of accuracy.
- All proposed models passed the model diagnostics test and thus are permissible.

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