Properties of cow-dung ash blended cement concretes in fresh and hardened states

Adekunle Adewuyi* & Gabalaiwe L. Ramahobo

Department of Civil Engineering
Faculty of Engineering and Technology
University of Botswana, Gaborone, Botswana

*Corresponding Author: AdewuyiA@ub.ac.bw

Abstract*—The paper reports the investigation thee properties of cow dung ash and its influence on the fresh and hardened properties of concrete. The utilization of cow dung ash was meant to achieve purposes of waste management, reduction of greenhouse gases and its unhealthy effects on global warming and indiscriminate depletion of natural resources for the production cement. The colour of the sundried cow dung was light grey and while the pulverised CDA was dark grey/black at 900°C in 2 hours. The loose bulk density of CDA was 810 kg/m^3. The pH of the CDA was 6.9, and the specific gravity was 2.48 g/cm^3. The CDA was well graded with coefficients of uniformity and curvature of 12.5 and 1.62 respectively. Both the consistency and slump of CDA-blended cement concrete were quadratic and it increased with CDA content up to 20% beyond which it dropped. For a concrete mix of target strength 30 N/mm^2, 10% CDA content was above the threshold which gave 7.8%, 5.4%, 5.2% and 2.8% strength decline at 7, 14, 21 and 28 days curing ages respectively. The tensile strength of concrete increased by 26.5% and 17.7% for 10% and 20% CDA contents respectively, while 30% CDA content recorded 26.5% tensile strength loss. A gradual increase of water absorption of concrete cubes was recorded from 0% to 10% CDA replacement for all the curing days. Beyond 20% CDA content, water absorption of concrete slowly decreased for all the four curing ages, namely 7, 14, 21 and 28 days. It can be concluded that up to 20% CDA replacement of cement is ideal for acceptable concrete performance in plastic and hardened states.

***Keywords*—concrete, consistency, workability, compressive strength, tensile strength, water absorption, durability.**

I. Introduction

Building and civil construction industry is one of the leading contributors to the depletion of natural resources and production of greenhouse effects. During the production of concrete, the emissions which cause greatest concern and need to be dealt with are carbon dioxide (CO_2) and other air emissions such as nitrogen oxides and sulphur dioxides. Approximately, one ton of CO_2, a greenhouse gas, is delivered into the atmosphere for each ton of cement production. Worldwide, the cement industry is responsible for about 1.4 billion tons in 1995, which caused the emission of as much CO_2 gas as 300 million automobiles statistically for almost 7% of the total world production of CO_2 [1].

The construction industry is a great resources and materials consuming sector with an enormous potential for the use of waste materials generated by its own activities [2]. The use of such waste materials allows decrease the energy consumption, to preserve non-renewable natural resources, and to reduce the high amount of material that goes to landfills. However, in the cement industry, which has always been among the largest CO_2 emission sources, technical, economic and legal challenges still play as remarkable obstacles against the widespread implementation of procedures to help mitigate this situation [3]. Thus, the increase in demand for construction materials in the recent years as a result of development has called for an alternative way to develop or derive construction materials from different sources.

The exorbitant cost of building and construction materials is the greatest challenge confronting housing delivery in low-and-income countries [4]. Unlike the aggregates and water that are locally sourced, the price of cement determines the overall cost of building. Cement is an indispensable material in building and construction works. It is primarily utilized as a binder in the production of sandcrete blocks, concrete and as a stabilizing admixture in soils. In order to ameliorate this problem, alternative materials from a range of widely abundant local materials have been sought to replace the expensive conventional ones, most especially cement. To achieve sustainable development in cement manufacture and building industry, pozzolans such as fly ash, silica fume, rice husk ash and blast furnace slag have been discovered to be viable alternative binders in partial replacement to cement [5, 6]. Other alternatives include recycled crushed glass waste [7-9], recycled aggregate concrete [10] and agricultural wastes such as corn-cob ash [11], rice husk ash [5, 12] cow bone ash, saw dust ash, palm-kernel shell ash and periwinkle shell [13] have been incorporated as pozzolans in partial replacement of regular cement in concrete or mortar structures. Sewage sludge ash (SSA) is the by-product produced during the combustion of dewatered sewage sludge in an incinerator. The residues after thermal conversion of sludge are among other things the fly ashes captured from flue gases in electrofilters. These residues are primarily a silty material with some sand-size particles [14, 15]. More recently, reported a study on the use of Sugar Cane Bagasse Ash (SCBA) as a supplement to the cementitious material [16].

The Statistics Botswana in 2015 recorded 2,072,683 cattle in the year of severe drought which might have negatively impacted on the population of cattle and other livestock. Thus, it is reasonable that the current population of cattle in Botswana could be far more than that and by extension, much higher than the population of people currently living in the country. The cow dung is obtained from cow excreta, which is dried in sunlight in the form of cake. In many parts of the developing world, caked and dried cow dung is used as fuel. The fuel ash is obtained in the form of black colour [17]. However, farmers in Botswana have resorted to artificial or inorganic ways of providing nutrients for their crops since they deemed to be faster, more effective and required in less amounts than the use of organic matter. This in turn has led to the increase in amount of unused cow dung in farms and in the society. Recycling or reuse of CDA serves the purpose of waste management and environmental protection, and its industrial re-utilization causes reduction in depletion of natural resources and greenhouse energy reduction. Nowadays, it is relatively uncommon to use cow dung as source of fuel and manure for agricultural purposes. A significant population has resorted to using electricity which is produced by solar, and some by fossil fuels. Cow dung has also been used as a source of nutrients for plants and crop, especially in the agricultural industry. It is, therefore, imperative to investigate other industrial benefits of cow dung.

This paper reports the investigation on the suitability of cow-dung ash (CDA) as admixture for cement for concrete and mortar in building and civil construction works. It studied the applicability of CDA as an alternative pozzolanic cementitious admixture to enhance the workability, compressive strength and overall durability of concrete.

II. Experimental Programme

A. *Processing of cow dung*

Cow dung was collected in and around the city of Gaborone, Botswana. The surrounding villages where the cow dung was sourced were Tlokweng, Mmopane and Kopong. The cow dung was then exposed to sunlight to dry in order to have dung cakes (in case of fresh dung) which was then subjected to controlled pulverization up to a maximum temperature of 900°C. The final product of the cow dung ash which was blackish in colour. A Dual Laser Infra-red thermometer was used to monitor the temperature at intervals of 5 minutes during burning, for 2 hours. It was later allowed to cool at room temperature in a vacuum desiccator to exclude absorbed water. The CDA was ground in a miller and sieved through 150 µm sieve prior to analyses.

B. *Analysis of CDA samples*

The specific gravity of CDA was determined by pycnometer. The particle size distribution was analyzed by laser diffraction over the size range 0.4–900 µm using Beckman Coulter LS-100. The specific surface area and pore size distribution of sludge ash was determined by a single port Gas Sorption Analyzer Coulter Omnisorp 100 using the Brunauer–Emmett–Teller (BET) test method. The pH was determined by preparing a 1:5 sludge ash to liquid ratio suspension using deionized water. The mixture was shaken for 5 min and left for 3 hours to equilibrate before measuring the pH in accordance with BS 7755 [18].

C. *Tests on fresh concrete*

Consistency limit

The test performed to determine the water content required to produce a cement paste of standard consistency as specified by the BS 1881 [19] procedure. The procedure was repeated three times for each concrete batch of 0, 10, 20 and 30% CDA contents as fractions of cementitious materials.

Slump test

The test was carried out on fresh concrete according to BS 1881 [19] using equipment recommended in the standard. A sample of freshly mixed concrete was placed and compacted by rodding in a mould shaped as the frustum of a cone. The mould was then raised, and the concrete allowed to compact. The vertical distance between the original and displaced position of the centre of the top surface of the concrete was measured using a steel rule and reported as the slump of the concrete. The slump test was performed three times for each concrete batch of 0, 10, 20 and 30% CDA contents as fractions of ordinary Portland cement.

D. *Tests on hardened concrete*

Compressive strength

Standard cubes of size 100 mm were used in preparation of the concrete for testing [20]. The target strength of concrete adopted for the mix design was 30 N/mm^2. The compression testing machine was used for this experiment. The cross-sectional area of the cube was calculated from the measured dimensions. The compressive strength of the cube was then calculated by dividing the maximum load by the cross-sectional area. The result shall be expressed to the nearest 0.01 MPa. The density of the specimen was calculated prior to crushing of specimens. The mixing water was potable water supplied by the WUC.

The cubes were cleaned of excess concrete by passing an iron in a sawing motion over the top of the cubes. The free surface was finished using hand trowel. The cubes were then stored 24 hours undisturbed temperatures between 18º C and 22ºC and relative humidity of not less than 90 percent. The mould was stripped off after 24 hours and the cubes were fully immersed in water for curing in a tank at a temperature range 19-21ºC. After setting for 24 hours, the cubes were labelled and taken into the curing tank for their respective curing ages being 7, 14, 21 and 28 curing days. A compressive load was then applied to the concrete cubes after curing to test for the compressive strength at a constant rate of 60000 kN/s. The strength at failure was then reported to the nearest 0.5 N/mm. The compressive strength was determined by dividing the load at failure by the area of the cube and recorded it in N/mm^2.

Split tensile strength

Concrete cylinders of 100 mm dia × 200 mm lengths of CDA contents 0, 10, 20 and 30% in partial replacement of ordinary Portland cement were cast for the split tensile strength of the concrete. After casting, the cylinders were left to set for 24 hours, ensuring no loss of moisture. The cylinders were then removed from their moulds, labelled and cured for 28 days. A load was applied at a constant rate of 0.94 kN/s. The strength at failure was recorded to the nearest 0.5 N/mm^2.

Water absorption

The 100 mm cubes were removed from the curing tank and placed in an oven for drying. The dry masses of the cubes were noted after 24 hours of drying. The cubes were subsequently fully immersed in water for another 24 hours after which the wet masses of the cubes were noted and the water absorption of the concrete was calculated as follows:

$$\text{Water absorption (\%)} = \frac{\text{wet mass} - \text{dry mass}}{\text{dry mass}} \times 100$$

III. RESULTS AND DISCUSSION

A. *Physical Properties of CDA*

The texture of sun-dried sludge was rough, while the smoothness of the sieved CDA was comparable to cement as shown in Fig. 1. The colour of the sundried cow dung was light grey and changed to dark grey/black after incineration to a temperature of 900°C in 2 hours. The loose bulk density of CDA was 810 kg/m^3.

The pH of the CDA was 6.9, the specific gravity was 2.48 g/cm^3 and the BET surface area was 6.9 m^2/g. The results agreed with the findings of Donatello et al. [20]. It is obvious from the particle size distribution of the CDA, in Fig. 2, that over 60% of the material was finer than 150 µm. The diameter of particle corresponding to 10%, 30% and 60% were D_{10}=10 µm, D_{30}=45 µm and D_{60}=125 µm respectively. The coefficients of uniformity and curvature were 12.5 and 1.62 respectively. It is evident from the particle size distribution curve that the CDA was well graded.

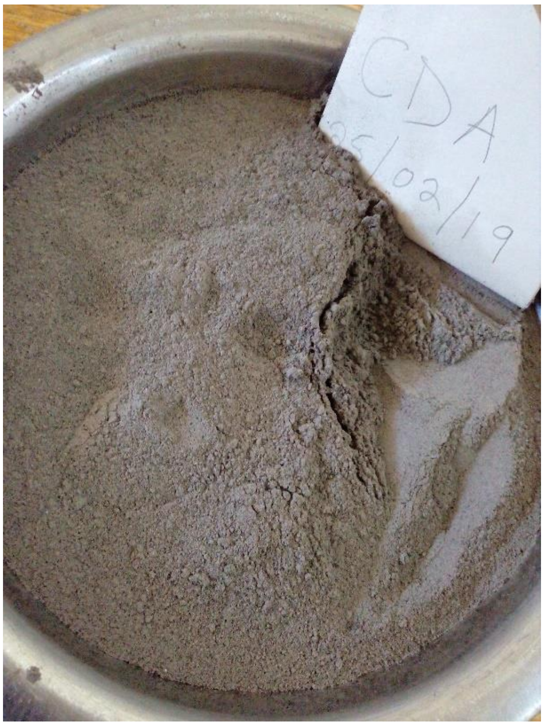

Fig. 1: The texture of cow sludge ash passing through 150 µm sieve

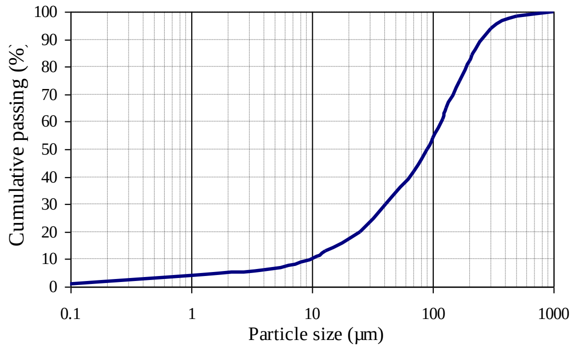

Fig. 2: Cumulative particle size distribution of CDA

B. *Concrete constituent materials*

Grade 42.5 ordinary Portland cement conforming to BS 12 [21] was used in this study. The properties of cement such as consistency, setting times, soundness and compressive strength are summarized in Table 1. The properties of cement such as consistency, setting times, soundness and compressive strength are summarized in Table 1. Coarse aggregate was crushed granite of maximum nominal size of 19 mm sourced from quarry sites within Gaborone. Fine aggregates were crusher dusts of maximum nominal size of 2.00 mm. The particle size distribution curve of the crusher dusts is plotted in Fig. 3. The coefficients of uniformity and curvature of the particles were 10.3 and 1.73 respectively. The aggregates were free from deleterious materials and the physical properties were carried out in accordance with BS 812 [22].

Table 1. Physical properties of cement

Standard consistency (%)	30
Specific gravity	3.15
Initial setting time (mins)	118
Final setting time (mins)	215
Soundness (mm)	1.0
Compressive strength (N/mm^2)	
3 days	24.5
7 days	30.8

The properties of fine and coarse aggregates are presented in Table 2. The fine and coarse aggregates employed as constituents of the concrete in the study were well-graded. Drinking tap water supplied by the Water Utility Corporation of pH of 7.1 which conformed to the requirements of BS 3148 [23] was used in mixing the aggregates and cement. The water absorption of the coarse aggregate was found to be 0.41%.

Table 2. Properties of aggregates

	Crusher dust	Crushed granite
Specific gravity	2.64	2.70
Bulk density (kg/m^3)	1240	1464
Moisture content	4.09	0.6
Fineness modulus	3.00	6.15
Aggregate crushing value (%)		12.9
Impact value (%)		7.13

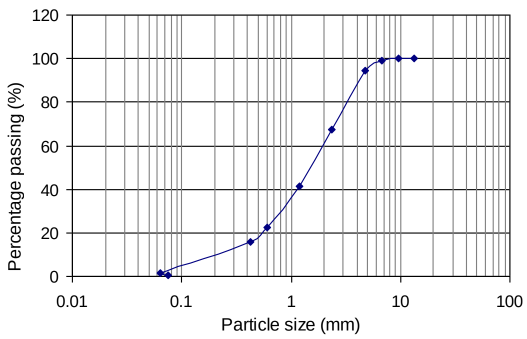

Fig. 3: Particle size distribution of crusher dust

C. Influence of CDA on fresh concrete

Consistency limit

The consistency of OPC blended with CDA is quadratic as shown in Fig. 4. It increased with CDA content up to 20% beyond which it dropped. The best line of fit has a relationship Consistency, $C = -0.0175c_d^2 + 0.835c_d + 34.85$ (coefficient of correlation, R^2= 0.993).

This decline may be due to the accumulation of the smaller particles of CDA which may have formed clusters inside the mix. Hence, the optimum percentage of CDA that can be added to cement was 20%.This shows that more water is needed to achieve the same level of consistency in all the pastes. This increase may be attributed to the porosity and fineness of cow dung ash (Kumar et al., 2015). Increase in water demand was also evident when wood ash blended cement was used relative to OPC mainly due to a higher specific surface area of porous wood waste ash particles in comparison to OPC particles [24].

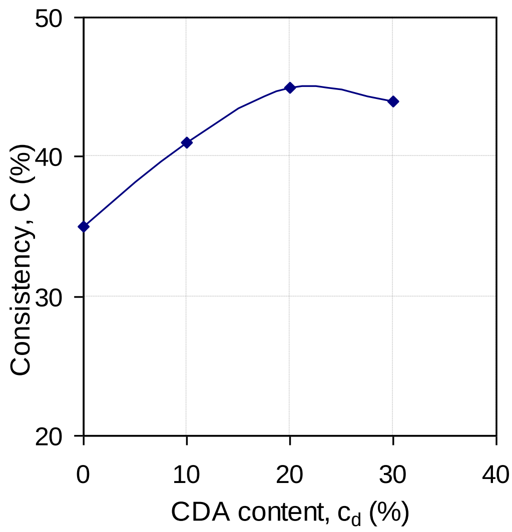

Fig. 4: Consistency limit with varying CDA contents

Slump tests

The relations between slump and CDA contents is quadratic having an expression
$S = -0.14c_d^2 + 5.5c_d + 69.5$ (R^2 = 0.973).

The optimum CDA was 19.64% corresponding to a slump of 123.5 mm. Fig. 5 shows an increase in workability from the control up to about 20% CDA addition beyond which there was a gradual decline.

The workability decreased by 7.56% at 30% CDA content. This shows as CDA content increased beyond 30% the workability of the concrete decreased because CDA could not fill in the voids concrete mix which made it relatively difficult for concrete to flow easily. A higher water/cement ratio also results in higher workability. To maintain same workability of fresh concrete, the water-cement ratio must increase, but at the expense of the compressive strength of concrete. Similar trends of increase in workability of concrete produced from cow dung ash were also reported by Ojedokun et al. [25] who attempted to produce concrete mixes containing a similar range of cement replacement (10–30%) of cement using CDA. This was however not the case with the report by Omoniyi et al. [26] who found that slump decreased with increase in the amount of CDA, which implies that more water is required to maintain the same consistency as CDA absorbed more water than OPC.

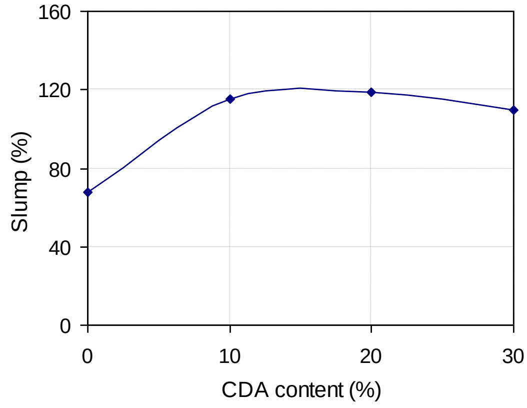

Fig. 5. Slump value of fresh concrete with varying CDA contents

D. Influence of CDA on hardened concrete

Compressive strength

The compressive strength of concrete cubes of varying CDA contents at different curing ages is plotted in Fig. 6. The compressive strength of concrete specimens of different curing ages decreased with increasing CDA contents. However, the decline in strength varied with the CDA content. It is obvious from the plots that the compressive strength-CDA content trends are linear with negative slopes. The magnitude of the slope decreased with the age of concrete.

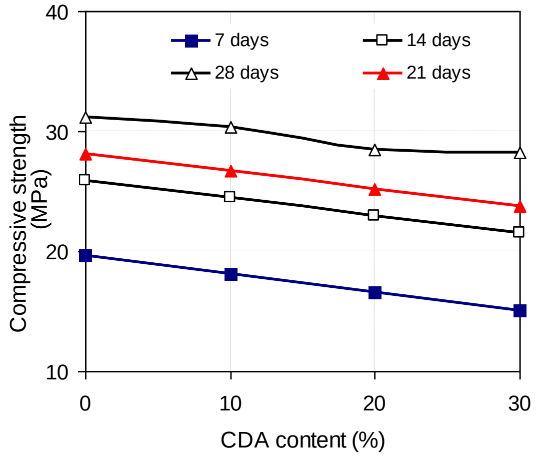

Fig. 6. Compressive strength of concrete of varying CDA contents

For a 30 N/mm^2 target strength adopted for the concrete mix, it is evident from the 28th day plot that 10% CDA content is above the threshold. The 10% CDA gave 7.8%, 5.4%, 5.2% and 2.8% strength decline at 7, 14, 21 and 28 days curing ages respectively. Further assessment of concrete behaviour in compression for longer curing days could give better information on the hydration pattern and variation of compressive strength with age of concrete. There is high likelihood that CDA-blended OPC concrete could be more durable over a longer monitoring period.

A comparative assessment of the results was made with SCBA-blended and RHA-blended cement concrete conducted by Bahurudeen & Santhanam [27] and Venkatanarayanan & Rangaraju [28] respectively showed that the present study gave a better compressive stregth than the previous study. The differences in the results could be as a result of the different species of cattle, the livestock feeds, and the processing of the cow dung for the production of CDA.

Split tensile strength

The 28-day split tensile strength tests of various concrete cylinders are shown in Fig. 7. The tensile strength exhibited a quadratic relation with the CDA contents in replacement of cement. With respect to the control specimen, the tensile strength of concrete increased by 26.5% and 17.7% for 10% and 20% CDA contents respectively. However, there was a loss of 26.5% tensile strength for the 30% CDA replacement of OPC. Such higher strengths were also observed for ground RHA concrete [28]. However, split tensile strength of concrete mixes at 7 and 28 days was observed to decline with increasing level of cement replacement with wood waste ash [24].

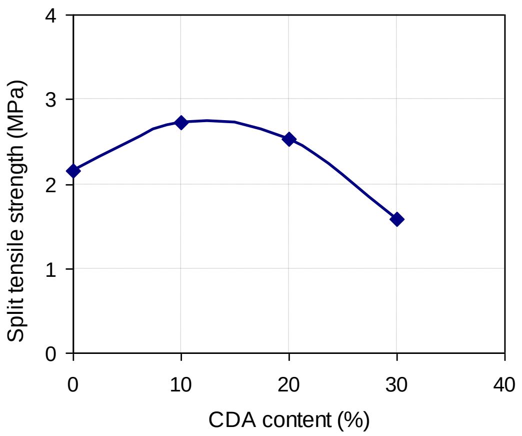

Fig. 7: Split tensile of concrete cylinders of varying CDA contents

E. Water absorption of CDA-blended cement concrete

Water absorption of concrete has been used to assess the durability of concrete. This was tested by immersion of the cube in water and measuring the difference of dry weight to wet weight and expressing it as a percentage. The water absorption has a quadratic relation with CDA replacement contents for different test days. However, water absorption of control specimens were generally lower than the measured values for concretes with 10% and 20% CDA replacement of OPC in hardened concrete cubes. A gradual increase of water absorption of concrete cubes was recorded from 0% to 10% CDA replacement for all the curing days. Water absorption also increased for concretes with 20% CDA replacement at 7 and 14 test days, though at a decreasing rate; but reduced for 21 and 28 test days. Beyond 20% CDA replacement, water absorption of concrete slowly decreased for all the four curing ages, namely 7, 14, 21 and 28 days.

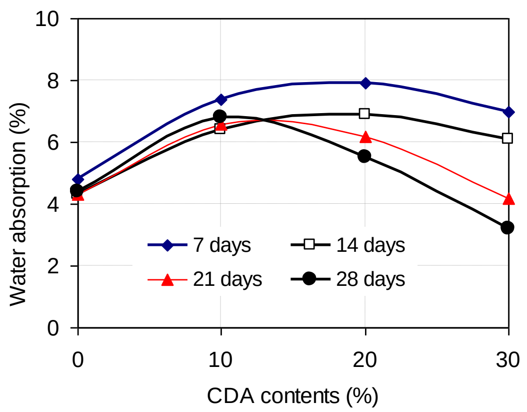

Fig. 8: Water absorption of concrete specimens at varying CDA contents

IV. Conclusions

The paper presents the applicability of cow dung ash as partial replacement of cement for concrete works in building and civil construction works. The properties of cow dung ash and its influence on the fresh and hardened properties of concrete was investigated in this study. The utilization of cow dung ash was meant to achieve purposes of waste management, reduction of greenhouse gases and its unhealthy effects on global warming and indiscriminate depletion of natural resources for the production cement. The following conclusions can be drawn from the study.

1. The colour of the sundried cow dung was light grey and while the pulverised CDA was dark grey/black at 900°C in 2 hours. The loose bulk density of CDA was 810 kg/m^3. The pH of the CDA was 6.9, the specific gravity was 2.48 g/cm^3 and the BET surface area was 6.9 m^2/g.

2. The particle size distribution parameters of the CDA finer than 150 µm were D_{10}=10 µm, D_{30}=45 µm and D_{60}=125 µm while the coefficients of uniformity C_u=12.5 and curvature C_c=1.62. It is evident from the particle size distribution curve that the CDA was well graded.

3. The consistency of CDA-blended cement concrete was quadratic and it increased with CDA content up to 20% beyond which it dropped.

4. The relation between slump and CDA contents is quadratic and the optimum CDA was 19.64% corresponding to a slump of 123.5 mm. The workability increased from the control up to about 20% CDA addition beyond which there was a gradual decline.

5. For a concrete mix of target strength 30 N/mm^2, 10% CDA content was above the 30 MPa threshold which gave 7.8%, 5.4%, 5.2% and 2.8% strength decline at 7, 14, 21 and 28 days curing ages respectively.

6. The tensile strength exhibited a quadratic relation with the CDA contents in replacement of cement. The tensile strength of concrete increased by 26.5% and 17.7% for 10% and 20% CDA contents respectively, while 30% CDA content recorded 26.5% tensile strength loss.

7. A gradual increase of water absorption of concrete cubes was recorded from 0% to 10% CDA replacement for all the curing days. Beyond 20% CDA content, water absorption of concrete slowly decreased for all the four curing ages, namely 7, 14, 21 and 28 days.

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