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Assessment of Embodied Energy and Carbon IV Oxide Emission of Concrete Containing Corncob Ash

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Abstract: The purpose of this study is to assess the Embodied Energy (EE) and Carbon IV Oxide (CO_2) emissions saving potentials of Corn Cob Ash (CCA) as partial replacement of Ordinary Portland Cement (OPC) in concrete. Cement manufacture is energy intensive and contributes considerable amount of CO_2 emissions into the atmosphere. Globally, Concrete is the most consumed man-made material and about 95% of CO_2 emissions from a cubic meter of concrete are from cement manufacturing. In this study, the experimental plan was designed to carry out compressive strength, flexural strength, density and water absorption tests on the concrete using 0, 5, 10, 15 and 20% CCA contents to replace OPC. Inventory method of analysis was used to determine the EE and CO_2 emission for all the concrete mixes. The results indicated that the water absorption, density, compressive and flexural strength decreased with increase in CCA content and increased with curing period. The optimum blend was obtained at 10% CCA and 90% OPC contents. The EE and CO_2 emission decreased with increase in CCA contents. At 20% CCA content the EE was 2382 MJ/m^3 which is 12.04% less than that of control samples. Also, 16.37% embodied CO_2 emission saving was obtained for samples containing 20% CCA. The regression equations generated gave standard deviation, S, < 1.0, P-value < 0.05, T-statistics > T24, 0.05 and F-statistics > F1, 23, 0.05. All these indicated that there is good relationship between the predictors and the responses.

Keywords: Carbon IV Oxide Emission, Compressive Strength, Concrete, Corn Cob Ash, Embodied Energy

1. Introduction

The worldwide increasing demand for energy is one of the major causes for the unsustainable development of our Planet. Organization for Economic Co-operation and Development (OECD) reported that from 2007 to 2030 energy demand is projected to increase by about 40% which is about 15.24 billion tonnes of petroleum equivalent [1]. Concrete is considered as the world's most consumed man-made material. Every one tonne of concrete leads to CO_2 emission which varies between 0.05 to 0.13 tonnes. About 95% of all CO_2 emissions from a cubic meter of concrete are from cement manufacturing. The annual global production of concrete is about 4.54 billion tonnes. If the production of this building material remains at this frightening level, it is expected that about 3.5 billion tonnes of cement would be produced by the end of 2050 which amounts to doubling the CO_2 emissions [2].

Energy used in concrete production includes EE in cement, energy used to extract and process aggregates, transportation energy, and energy used in the concrete plant. The EE of cement production contributes a large proportion of the total EE of concrete. The EE of structural components makes up about a quarter of the EE of all elements installed at the time of construction [3]. Also, process of cement production emits large amount of CO_2 into the atmosphere, every tonne of cement produced releases approximately one tonne of CO_2 into the atmosphere which is a major contributor for greenhouse effect and the global warming [4]. The calcination process is responsible for 50% of CO_2 emissions, 45% due to burning fuel and 5% due to mining and transportation [5].

Olivier, Janssens-Maenhout, and Peters [6] reported that in 2015, CO_2 emissions generated by carbonate oxidation in the cement clinker production process, the main constituent of cement and the largest of non-combustion sources of CO_2 from industrial manufacturing, contributed about 4.0% of the total global CO_2 emissions while fuel combustion emissions of CO_2 related to cement production are of approximately the same level, so, in total, cement production accounts for roughly 8% of the total global CO_2 emissions. González and Navarro [7] estimated that the selection of building materials with low impacts can reduce CO_2 emissions by up to 30%. Therefore, partial replacement of OPC with supplementary cementitious materials such as CCA is expected to yield a significant reduction in EE and CO2 emissions.

According to the United Nation Centre for Human Settlement (UNCHS) [8], the main step that can be adopted to mitigate the consumption of energy and CO_2 emission associated with construction materials is to reduce their total primary energy consumption. Increasing the efficiency of energy use in construction materials production is important for three reasons, apart from the obvious advantage of energy saving: it can help to make durable construction materials available at bearable costs; it will help to reduce the environmental degradation caused by the excessive use of biomass fuels; and it will also help to reduce the need for imported construction materials or production processes. The aim of energy analysis is to determine the total quantity of energy that should be taken from primary energy resources in order to produce a given material. The analysis also has to include the amount of energy expended in obtaining the raw materials and the energy used in transporting them to the factory. It should also include the energy used to produce and maintain the machinery used in the production process. The total energy calculated in this way is the energy embodied in that material [8].

1.1. Corncob Ash

Corncob is an agricultural by-product obtained from maize. It is the hard thick approximately cylindrical central core of maize (on which are borne the grains). The ash resulting from burning the corncob at elevated temperature (450°C-650°C) is known as corn cob ash (CCA) and it has been classified as pozzolana [9].

CCA has pozzolanic properties and has been shown to chemically react with the calcium hydroxide released during the hydration process of cement to form cement compounds. Active pozzolanas gain their binding properties when they react with calcium hydroxide in cement in the presence of water. Studies showed that CCA improves the properties of cement materials, based on its pozzolanic properties [10, 11].

1.2. Embodied Energy

EE is the amount of energy consumed in all processes associated with the production of a material, from mining and processing of natural resources to manufacturing, transporting and then the delivery of the product [12]. It includes the direct and indirect energies consumed in processing the product. Direct energy is consumed in various on-site and off-site operations like construction, prefabrication, transportation and administration. Indirect energy is the energy used during the manufacturing of building materials, in the main process, upstream processes and downstream processes and during renovation, refurbishment, and demolition. This includes initial embodied energy, recurrent embodied energy and demolition energy [13].

Various approaches to measure EE employ different system boundaries and collect data from different sources, which could result in significantly different values of EE for the same product. System boundaries may range from a restrictive analysis of direct energy required for a particular process, to an expansive analysis including energy used by entire industrial input chains and society as a whole. Analyses may consider only purchased fossil fuel energy inputs, or may include renewable sources or combustible process by-products. Data may be direct measurements of energy used by a particular machine or factory, or may be aggregated for an entire industrial sector [14].

Basically there are four methods of measuring EE: process analysis, input-output analysis, hybrid analysis and inventory analysis. This research work uses the inventory method of analysis developed by Hammond and Jones at University of Bath [15, 16]. They published an Inventory of Carbon and Energy (ICE), which is a database containing EE and CO_2 values per functional unit of material (which could be in form of area (m^2), mass (kg) or volume (m^3) for different common building materials. The data for this inventory was extracted from peer reviewed literature on the basis of a defined methodology and criteria. It is considered that the strict criteria used in the selection of source material for the creation of the ICE serve to significantly increase its accuracy and relevancy.

According to Berndt [17], there are several essentials which can reduce the environmental impact factor and CO_2 intensity of concrete used for construction, which include maximizing the concrete durability, conservation of materials, use of waste and supplementing cementing materials and recycling of concrete. Partial replacement of cement with waste supplementary cementitious materials such as fly ash, ground granulated blast furnace slag, silica fume, rice husk ash and metakaolin not only improves the concrete durability and reduce the risk of thermal cracking in mass concrete but also emits less CO_2 than cement.

In view of the above, this study is aimed at investigating the EE and CO_2 emission saving potentials of CCA when used as partial replacement of cement in concrete.

2. Materials and Methods

2.1. Materials

Ordinary Portland cement (OPC) was used throughout the research. It has a consistency of 36%, initial setting time of 43 minutes, final setting time of 492 minutes and specific gravity of 3.09. The tests were conducted in accordance with BS EN 196: 3 [18] and BS EN 197: 1 [19] specifications.

The oxides composition of the OPC is presented in Table 1 The fine aggregate (sand) used was obtained from a stream at Bayara village along Bauchi–Dass road with maximum size of 4.75 mm and specific gravity of 2.63. The coarse aggregate used was crushed normal weight igneous rock aggregate with maximum size of 20 mm obtained from a quarry site in Bauchi. It has specific gravity of 2.65, aggregate crushing value of 14.5% and aggregate impact value of 7.64%. The materials were tested in accordance with BS EN 1097: 6 [20], BS 812: 2 [21], BS 812: 110 [22] and BS EN 933: 1 [23] specifications. The corncobs used were collected from white floury maize variety and stored in polythene bags for about three months before burning. The CCA was produced using controlled burning process in a kerosene powered kiln at elevated temperature of about 500°C. The resulting CCA was ground using mortar and pestle before sieving with 212 μ m sieve size. Figure 1 shows the flow diagram for the production of CCA while oxides composition of the CCA is presented in Table 1. The physical properties of the CCA determined were the specific gravity (2.27) and loose bulk density (304 kg/m^3). The water used was portable drinking water obtained from tap source, within the laboratory.

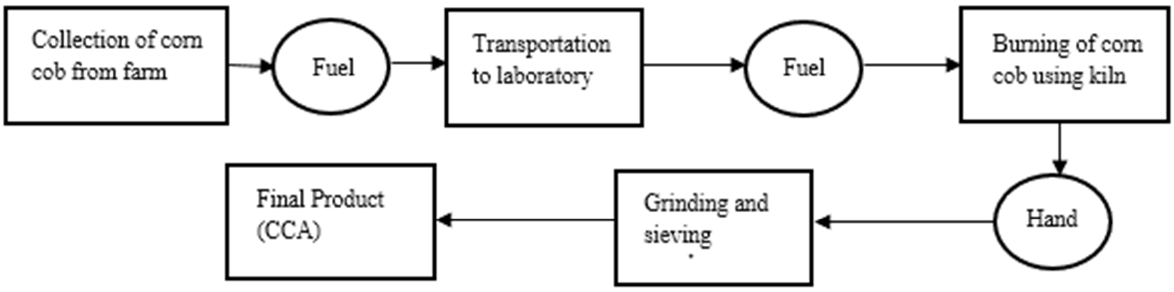

Figure 1. *Flow diagram showing the process of CCA production.*

Table 1. *Percentage oxides composition of OPC and CCA.*

Oxides	OPC	CCA
SiO_2	20.7	66.4
Al_2O_3	6.1	7.5
Fe_2O_3	2.3	4.4
CaO	62.1	11.6
MgO	1.2	2.1
K_2O	1.0	4.9
Na_2O	0.9	0.4
SO_3	1.6	1.1
LOI	1.0	-

Grade 30 concrete was designed and mix ratio of 1: 1.41: 2.88 was obtained at water-to-cement ratio of 0.46. The water content per cubic meter of concrete was 191.58 kg, cement content was 416.47 kg/m^3, fine aggregate content was 589.15 and coarse aggregate content was 1200.04 kg/m^3. Five different mixes were designed using CCA of 0, 5, 10, 15 and 20 percent to replace OPC by weight. The samples were produced and cured by immersion in water according to BS EN 12390 part1 & 2 specifications [24, 25]. Concrete cubes of size 100mm x100mm x 100mm and beams of size 100mm x 100mm x 500mm were cast using the designed mix and cured for 90 days respectively. The cubes and beams were tested for density, water absorption, compressive and flexural strengths in accordance with BS 1881 [26], BS EN 12390: 7 [27], BS EN 12390: 3 [28] and BS EN 12390: 5 [29] specifications respectively.

2.2. Methods

2.2.1. Determination of EE and CO_2 Emission

The EE and CO_2 emission of the concrete samples containing CCA were determined using inventory method of analysis. The main advantage of this method is that it has greater accuracy and flexibility than the other methods and tedious procedures that involve chemical equations are avoided by using emission factors. The EE and CO_2 emission values for various mixes were calculated using the model equations presented in equations (1, 2, 3, 4, 5) and (6). The boundary for the EE and CO2 analysis was 'Cradle to Site'.

$$\text{Cradle to Site EE} = \text{Cradle to Gate EE} + \text{Transportation EE} \tag{1}$$

$$\text{Cradle to Gate EE} = \text{Quantity of material } \times \text{EE coefficien} \tag{2}$$

Therefore,

$$\text{Cradle to Site EE} = (1+m)(Cx_c + S\,x_s + Ax_A + Wx_W + Rx_R) + T \tag{3}$$

The CO_2 Emission was calculated using:

$$\text{Cradle to Site } CO_2 \text{ emission} = \text{Cradle to Gate } CO_2 \text{ emission} + \text{Transport } CO_2 \text{ emission} \tag{4}$$

$$\text{Cradle to Gate EE} = \text{Quantity of material } \times CO_2 \text{emission factor} \tag{5}$$

$$\text{Cradle to Site } CO_2 \text{ emission} = (1+m)(Cx_c + S\,x_s + Ax_A + Wx_W + Rx_R) + T \tag{6}$$

Where m is the wastage factor (%), C, S, A, W and R (in Kg) of cement, sand, aggregate, water, and cement replacement respectively. T is the transportation energy calculated using equation (11). The parameters x_C, x_S, x_A, x_W, and x_R are the EE coefficients/CO_2 emission per kilogram for the materials mentioned above (Hammond and Jones, 2008).

Generally, waste materials are assumed to have zero EE. Therefore, corn cob has zero EE and CO_2 emission at the point of collection in the farm. The CCA is produced using controlled burning in a kiln at temperature of about 450^0C. The process of burning the corncob to produce CCA consumed energy and emitted CO_2. Therefore, the EE and CO_2 emission of the CCA was calculated from the EE of fuel (Kerosene) used to power the kiln as follows:

10 liters of kerosene was used to power the kiln. Density of kerosene is 780 kg/m^3.

$$\text{mass of 10 liters of kerosene} = 780 \times (10 \times 10^{-3}) = 7.8 \text{ kg}$$

$$\text{EE of kerosene} = 3.45 \text{ MJ/kg}$$

$$\text{Total EE of burning 10 liters of kerosene} = 7.8 \times 3.45 = 26.91 \text{ MJ}$$

Approximately 20 kg of CCA was obtained from burning of 10 liters of kerosene.

Therefore,

$$\text{EE of CCA} = \frac{26.91}{20} = 1.35 \text{ MJ/kg}$$

Equation (7) shows the relationship between the EE and embodied carbon (EC) equivalent developed by Hammond and Jones [30].

$$\text{EC equivalent (kg)} = 0.021 \times \text{EE} \quad (7)$$

The EC equivalent was converted to embodied CO_2 using equation (8) (Jones, 2010).

$$\text{EC equivalent} = 3.67 \times CO_2 \text{ (kg)} \quad (8)$$

Equation (9) was obtained by substituting equation (8) into equation (7) and CO_2 was made the subject of the relation.

$$\text{Embodied } CO_2 \text{(kg)} = 0.0057 \times \text{EE} \quad (9)$$

But total EE of CCA was 26.91 MJ,

$$\text{Therefore, Embodied } CO_2 = 0.0057 \times 26.91 = 0.1534 \text{ kg of } CO_2$$

The unit CO_2 emission per kilogram of CCA was obtained as follows:

$$\text{Embodied } CO_2 = \frac{0.1534}{20} = 0.008 \text{ kg of } CO_2\text{/kg} \quad (10)$$

Table 2 showed the EE coefficients and CO_2 emission factors for the materials. These factors were obtained from the database of Inventory of Carbon and Energy (ICE) developed at the University of Bath.

Table 2. *EE coefficient and CO_2 emission factors for concrete materials.*

Material	EE coefficient (MJ/kg)	CO_2 emission factor (kg CO_2/kg)
Fine aggregate	0.10	0.005
Coarse aggregate	0.30	0.100
Cement	4.60	0.830
CCA	1.35*	0.008*
water	0.00	0.000

Sources: Hammond and Jones [15],

* calculated using equations [1] to [10].

2.2.2. Transportation EE and CO_2 Emission

Transportation of construction materials consume a lot of fuel energies and emit CO_2 into the atmosphere. These energies and CO_2 are also embodied into the materials. According to Bribian, Capilla & Uson (2011) EE and CO_2 emissions due to transportation of all the materials were calculated using the linear correlation shown in equation (11).

Table 3 shows the values to be applied in order to evaluate the impact of transporting one tonne by various means of transportation, where d_i is the distance travelled by the i-th mode of the transport (in km) and m_i represents the coefficients applied to the i-th form of transport.

$$Transport\ impact = m_1 \times d_1 + m_2 \times d_2 + m_3 \times d_3 \quad (11)$$

Table 3. *EE and CO_2 emission coefficients for transportation of one tonne of material.*

Impact category	Mode of transportation		
	Road (m_1)	Rail (m_2)	Ship (m_3)
Primary energy demand (MJ/km)	3.266	0.751	0.170
CO_2 emission (kg/km)	0.193	0.039	0.011

Source: Bribian *et al.* [31]

Table 4 showed the locations and average haulage distances from point of manufacture or collection of each material to the laboratory.

Table 4. *Average haulage distances of materials.*

Material	Place of manufacture/collection	Average haulage distance (km)	Location coordinates
Fine aggregate	Bayara village, Bauchi	10.78	10° 13' 01"N, 9° 43' 45" E
Coarse aggregate	Triacta quarry, Bauchi	6.76	10° 14' 22"N, 9° 45' 26" E
Cement	Ashaka, Gombe	239	10° 55' 44"N, 11° 28' 29" E
CCA	Bishi village, Bauchi	34	10° 15' 09"N, 10° 06' 12" E
water	Borehole	0.0	10° 16' 47"N, 9° 47' 24" E

Tables 5 and 6 showed the computations of EE and CO_2 emissions respectively from excel spreadsheets using equations (3, 6) and (11) for concrete containing 5% CCA as OPC replacement.

Table 5. *EE of concrete containing 5% CCA.*

Material	Mass (kg)	EE coefficient (MJ/kg)	Transportation distance (km)	Transportation EE (MJ)	Embodied energy (MJ)
OPC	5.938	4.6	239	4.635048412	31.94984841
CCA	0.312	1.35	34.00	0.034645728	0.455845728
FA	8.837	0.10	10.78	0.311128501	1.194828501
CA	18.001	0.30	6.76	0.397428958	5.797728958
Water	2.874	0.00	0.00	0	0
Total Embodied Energy (MJ)=					39.3982516

Table 6. *CO_2 emission of concrete containing 5% CCA.*

Material	Mass (kg)	CO_2 emission factor (kg CO_2/kg)	Transportation distance (km)	Transportation CO_2 emission (kg)	CO_2 emission (kg)
OPC	5.938	0.83	239	0.273902126	5.202442126
CCA	0.312	0.008	34.00	0.002047344	0.004543344
FA	8.837	0.005	10.78	0.018385732	0.062570732
CA	18.001	0.017	6.76	0.023485545	0.329502545
Water	2.874	0.00	0.00	0	0
Total CO_2 Emission (Kg)=					5.599058747

3. Results and Discussion

3.1. Mechanical Properties

The results of mechanical properties of concrete cured at 90 days is presented in Table 7. Generally the densities decreased with increase in CCA content. The density decreased from 2473 kg/m^3 at 0% CCA content to 2397 kg/m^3 at 20% CCA content. These lie within the range of 2200 to 2600 kg/m^3 specified as the density of normal weight concrete [32]. Also, the water absorptions decreased with increase in CCA contents. The low range of water absorption obtained is as a result of a less permeable calcium silicate hydrate (C-S-H) produced when SiO_2 from CCA reacted with $Ca(OH)_2$ from cement [33]. The lower the water absorption of concrete the more durable is the concrete. Durability of concrete is improved by decreasing its porosity and transport properties [34]. The results also show decrease in compressive and flexural strengths with increase in CCA contents. The optimum blend was obtained at 10% CCA and 90% OPC contents with compressive strength value of 30.17 N/mm^2. This agrees with the findings of other researchers [35, 10] and [36]. This strength gain can be attributed to the cementitious products formed as a result of hydration of cement and those formed when lime reacts with the pozzolana incorporated [37]

Table 7. *Mechanical properties of concrete at 90 days curing.*

Mix no.	Density (kg/m^3)	Water Absorption (%)	Flexural Strength (N/mm^2)	Compressive Strength (N/mm^2)
CCA-00	2473	3.21	5.85	32.85
CCA-05	2437	2.57	5.49	29.05
CCA-10	2416	2.10	5.64	30.17
CCA-15	2408	1.93	4.77	24.56
CCA-20	2397	1.80	4.32	20.68

Table 8. *Embodied energy.*

Mix no.	OPC (kg)	CCA (kg)	FA (kg)	CA (kg)	Water (kg)	Embodied energy (MJ)	Embodied energy (MJ/m^3)	Embodied energy saved (%)
CCA-00	6.250	0.000	8.837	18.001	2.874	40.6211	2708	0.0000
CCA-05	5.938	0.312	8.837	18.001	2.874	39.3983	2627	3.0105
CCA-10	5.626	0.624	8.837	18.001	2.874	38.1754	2545	6.0210
CCA-15	5.314	0.936	8.837	18.001	2.874	36.9525	2464	9.0315
CCA-20	5.002	1.248	8.837	18.001	2.874	35.7296	2382	12.0419

3.2. Embodied Energy

The results of EE of concrete containing CCA were presented in Table 8. The table showed the quantities of materials in kilogram required to produce the batch of fifteen sample cubes, their EE in Mega Joule, the EE per cubic meter of concrete and the percentage of EE saving of the CCA. The results indicated that the EE decreases with increase in CCA contents.

Figure 2 shows the plot of the variation of EE with CCA contents. The EE decreased from 40.6211 MJ (2708 MJ/m^3) at 0% CCA content to 35.7296 MJ (2382 MJ/m^3) at 20% CCA content. At 10% CCA content the percentage decease in EE of the concrete is 6.02% while at 20% CCA content is 12.04%. The high percentage of EE saving obtained indicates that OPC is the major contributor of the concrete EE. The regression model for the relationship between EE and CCA contents is presented in equation (12).

$$EE_c = 40.62 - 0.2446CCA \quad (12)$$

Table 9 shows the results of regression analysis of EE. The standard deviation, S=7.4388 x10^{-15}. The T-statistics are 1.5764x10^{16} and 1.1625x10^{15} for constant and CCA terms respectively. These values are greater than the T-critical (T_{24}, 0.05=1.711) at 5% level of significance. The probability of the t-statistic, P=0.0000 for the constant and CCA terms which is less than the P-value (0.05). All these show that there is good relationship between the CCA content and the EE and the model equation is a good predictor of the response (EE_C).

Table 10 shows the results of ANOVA for the EE of the concrete. The results show the effect of CCA on EE of the concrete at 5% level of significance The F-statistic is 1.4916 x10^{06} for both the constant and CCA terms. The value is greater than the F-critical (F1, 23, 0.05=4.28). The probability of the F-statistic, P=0.0000 for the constant and CCA terms which is less than the P-value (0.05). These show that the variation in EE of the concrete is associated with the variation in CCA contents.

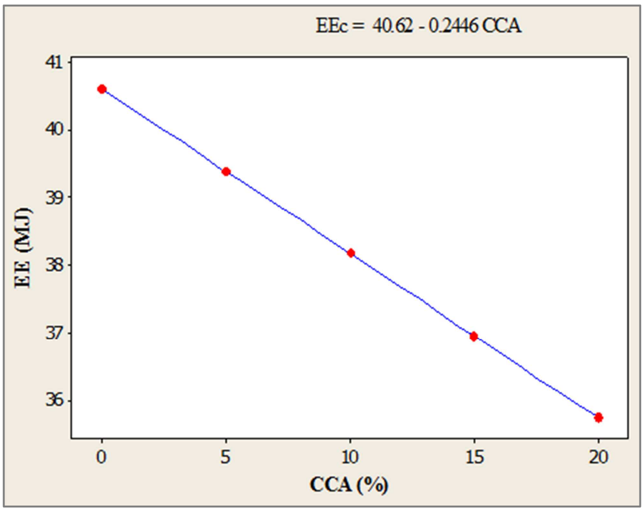

Figure 2. *Variation of EE (MJ) with CCA (%).*

Table 9. *Regression analysis for EE of concrete.*

Term	Coefficient	SE Coefficient	T	P	Relationship
Constant	40.6211	0.0000	1.5764 E16	0.0000	Significant
CCA	-0.2446	0.0000	-1.1625 E15	0.0000	Significant
S=7.4388 E-15					

Table 10. *ANOVA for the EE of concrete at 5% level of significance.*

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Effect
Regression	1	74.7734	74.7734	74.7734	1.4916 E06	0.0000	Significant
CCA	1	74.7734	74.7734	74.7734	1.4916 E06	0.0000	Significant
Error	23	0.0000	0.0000	0.0000			
Total	24	74.773					

3.3. Embodied Carbon IV Oxide Emission

The results of CO_2 emission of concrete containing CCA were presented in Table 11. The table presented the quantities of the materials in kilogram required to produce the batch of fifteen sample cubes, their CO_2 emission in kilogram, the CO_2 emission per cubic meter of concrete and the percentage of CO_2 emission saving of the CCA.

Table 11. *Embodied carbon IV oxide emission.*

MIX NO.	OPC (Kg)	CCA (Kg)	FA (Kg)	CA (Kg)	Water (Kg)	CO_2 Emission (Kg)	CO_2 Emission (Kg/m^3)	CO_2 Emission Saved (%)
CCA-00	6.250	0.000	8.837	18.001	2.874	5.8679	391.2	0.0000
CCA-05	5.938	0.312	8.837	18.001	2.874	5.6278	375.2	4.0918
CCA-10	5.626	0.624	8.837	18.001	2.874	5.3877	359.2	8.1837
CCA-15	5.314	0.936	8.837	18.001	2.874	5.1476	343.2	12.2755
CCA-20	5.002	1.248	8.837	18.001	2.874	4.9075	327.2	16.3674

The results indicated that the CO_2 emission decreases with increase in CCA contents. Figure 3 shows the graph of variation of CO_2 emission with CCA contents. The values of CO_2 emissions obtained per 15 cubes are 5.8679 kg, 5.6278 kg, 5.3877 kg, 5.1476 kg and 4.90756 kg for 0, 5, 10, 15 and 20% CCA contents, which were equivalent to 391.2 kg/m^3, 375.2 kg/m^3, 359.2 kg/m^3, 343.2 kg/m^3 and 327.2 kg/m^3 respectively. At 20% CCA contents the CO_2 emission was lower than that of the control concrete by 16.37%. This indicates that OPC is the major contributor of concrete's CO_2 emission. The regression model for the relationship between CO_2 emission and CCA content is presented in equation (13).

$$CO_{2\,c} = 5.868 - 0.05376CCA \quad (13)$$

The regression results for the relationship between CO_2 emission and CCA content are presented in Table 12. The standard deviation of error in the model, S=7.861 x 10^{-09}. The T-statistics are 2.155x10^{09} and 2.418x10^{08} for constant and CCA terms respectively. These values are greater than the T-critical (T24, 0.05=1.711) at 5% level of significance. The probability of the T-statistic, P=0.000 for the constant and CCA terms which is less than the P-value (0.05). All these show that there is an excellent linear relationship between the CO_2 emission and CCA content, and therefore CCA is a useful predictor of the regression model.

Table 13 shows the results of ANOVA for the CO_2 emission of the concrete. The results show the effect of CCA on the CO_2 emission of the concrete at 5% level of significance. The F-statistic is 5.846 x10^{16} which is greater than the F-critical (F1, 23, 0.05=4.28). The probability of the F-statistic, P=0.00 which is less than the P-value (0.05). These show that the CCA content has significant effect in variation of CO_2 emission of the concrete.

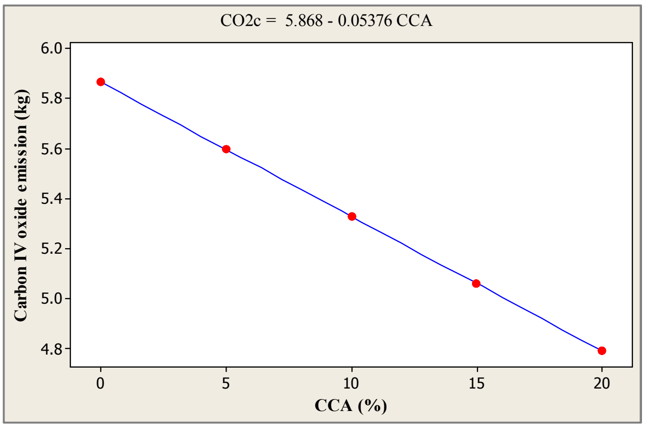

Figure 3. *Variation of CO_2 Emission (kg) with CCA (%).*

Table 12. *Regression analysis for CO_2 emission of concrete.*

Predictor	Coefficient	SE coefficient	T	P	Relationship
Constant	5.8679	0.0000	2.1547 E9	0.0000	Significant
CCA	-0.05376	0.0000	-2.4178 E8	0.0000	Significant
S=7.8616 E-09					

Table 13. *ANOVA for the CO_2 emission of concrete at 5% level of significance.*

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Effect
Regression	1	3.6126	3.6126	3.6126	5.8456 E16	0.0000	Significant
CCA	1	3.6126	3.6126	3.6126	5.8456 E16	0.0000	Significant
Error	23	0.0000	0.0000	0.0000			
Total	24	3.6126					

4. Summary, Conclusion and Recommendation

4.1. Summary

The EE and CO_2 emission analysis of concrete containing CCA was explored. The CCA was proven to reduce the EE and CO_2 emission of the concrete. Empirical relations that relate EE, CO_2 emission and CCA contents were developed using Minitab Statistical Software. The performance of the models was tested using ANOVA.

4.2. Conclusion

Based on the results of this research work the following conclusions can be drawn:

1. The use of CCA to replace OPC in concrete has the potential to reduce its EE. The energy savings increased with increase in CCA contents. Concrete containing 20% CCA have 12.04% EE saving.
2. The CCA also has the potential to reduce the CO_2 emission of the concrete. At 20% CCA content the CO_2 emission savings was 16.37%.
3. The compressive and flexural strength decreased with increase in CCA contents. The optimum blend was obtained at 10% CCA and 90% OPC contents.
4. The CCA increased the durability of concrete by decreasing its water absorption.
5. The empirical relations developed provided very good prediction of the response. The developed equations were as follows:

$$EE_c = 40.62 - 0.2446CCA$$

$$CO_{2\,c} = 5.868 - 0.05376CCA$$

6. The P-values for the regression models were less than 0.05 which indicate that there is good relationship between the predictors and the responses. The calculated T-statistics exceeded the T-critical (T24,

0.05=1.711) at 5% level of significance.

7. The calculated F-statistics exceeded the F-critical ($F_{1, 23, 0.05}$=4.28) at 5% level of significance. These indicate that the CCA content has significant effect in the reduction of the EE and CO_2 emission of the concrete.

4.3. Recommendation

Based on the results obtained from this study, CCA is recommended for use as cement replacement in mitigating EE and CO_2 emission of concrete. With regards to mechanical properties, not more than 10% CCA content is recommended as cement replacement in concrete.

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