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INFLUENCE OF AGRICULTURAL WASTE ASH AS POZZOLANA ON THE PHYSICAL PROPERTIES AND COMPRESSIVE STRENGTH OF CEMENT MORTAR

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KEY WORDS: cement, consistency, filler, mortar, pozzolana, workability.

ABSTRACT:

The increasing demand in cement has inspired researchers in both developed and developing countries around the world to explore and consider alternative materials as partial replacement of cement both in concrete and in mortar. In this study, the influence of agricultural waste, particularly corn cob ash, (CCA) as pozzolanic material or supplementary cementitious material (SCM) on the physical properties and compressive strength of cement mortar was investigated. CCA was used as partial replacement of cement ranging from 0% to 20% by weight at water-cementitious ratio of 0.6 and mix proportion of 1 cementitious: 3 fillers. The physical properties evaluated for the mortar paste were setting time and consistency; and compressive strength of hardened mortar cube. The chemical analysis of CCA was conducted, and results indicated that the CCA used in this study is classified as Class C pozzolana with combined $SiO_2 + Al_2O_3 + Fe_2O_3$ of 55.86%. The addition of CCA increases the initial and final setting time. The study also revealed that the addition of CCA in the mortar mix reduces the plasticity or fluidity of the paste. Further, the result indicated that the compressive strength of mortars with CCA decreased as the amount of CCA replacements increased in the mixture. The mortar pastes with varying amount of cement replacements, however, are superior for use as mortar for masonry construction.

1. INTRODUCTION

The continued expansion of global economies leads to intensification in construction activities and rising demand in construction materials. Propelled by the continued increase in cement consumption, the worldwide production of cement is projected to grow to over 5 billion tons globally by 2030 (An, 2016). Portland cement has high-energy consumptions and emissions (greenhouse gas and particulates) associated with its manufacture, which is reduced or conserved when amount used in concrete is reduced (Chindaprasirt et al., 2008). Portland cement is the primary component in concrete as well in mortar for masonry. According to Kamau et al. (2016), the heavy energy-intensive processes involved in cement production contribute to about 7% to 10% of the overall worldwide emissions and are economically expensive with potential adverse environmental implications. Hardin and McCool (2015) stated that the required amount of heat to produce one ton of Portland cement creates one ton of carbon dioxide (CO_2). Olutoge et al. (2010) reported that the production of cement is increasing annually by 3%. Furthermore, 7% of the world's carbon dioxide emission is attributed to Portland cement industry. In fact, in 2016, it was estimated that more than one ton of concrete was produced every year for each person on the planet (Neuwald, 2004). The cost of fuel and energy continues to increase, as does the cost of building materials, particularly in developing countries. Building materials accounted for two-third of the building production costs (Ayangade et al., 2012), so a reduction in its costs would definitely decrease the overall costs of the construction project. The increasing demand in cement has inspired researchers in both developed and developing countries to explore alternative materials as partial replacement of cement. These materials include the potential use of industrial by-products and agricultural waste as supplementary cementitious materials (SCM) or as pozzolanic materials. The increased utilization of pozzolanic materials as cement replacement in concrete resulted to diverse benefits such as reduction in cement use, cut production costs, improvement of the mechanical and durability properties of the concrete and so on. Pozzolans are fine materials that contain silica and/or alumina. However, pozzolanic material does not exhibit any cementation properties of their own except in the presence of calcium oxide (CaO) or calcium hydroxide ($Ca(OH)_2$) (Anwar and Gaweesh, 2000).

In past years, there were considerable efforts worldwide to utilize indigenous agricultural by-products and industrial waste as materials in concrete (Karim et al., 2014). Strict air pollution controls and regulations have produced great quantities of industrial by-products and agricultural wastes that can be used as supplementary cementitious materials (SCM) or pozzolana. In addition, sustainability advocates and construction rating system agencies give credits for the use of such by-products as fly ash content in

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concrete mixtures (Hardin and McCool, 2015).

Supplementary cementitious materials or pozzolana such as fly ash, silica fume, calcined kaolin, blast furnace slag, and rice husk ash are some of the industry by-products and are increasingly finding their use in construction industry as partial replacement of Portland cement worldwide. These by-products are all considered waste, and some are hazardous to the environment. The use of such by-products not only prevents them from being landfilled but also improve the properties of concrete or mortar both in the fresh and hardened state (Malhorta and Mehta, 1996). Results from various studies showed that the use of such by-products have demonstrated potential benefit as an alternative replacement to cement. Malhorta and Mehta (1996) reported that there have been studies undertaken and are receiving more attention now since their uses have shown advantageous properties. These properties include cost reduction, decreased in heat evolution, reduced permeability, and enhanced chemical resistance.

Conversely, there have been limited studies conducted in past years about the use of CCA as potential SCMs or pozzolana. Kamau et al. (2016) stated that CCA has been neither widely studied nor applied in practice. In fact, Bapat (2013) pointed out that CCA is one of the remotely known potentially useful admixtures. It was noted in a previous study by Kamau and Ahmed (2017) that the use of corncob ash in concrete demonstrated compressive strengths that were capable of being used for structural concrete. Price et al. (2014) indicated that up to 10% replacement of CCA could be used in cement production without compromising the structural integrity. Reported studies indicated varying optimum CCA replacement of 10% (Price et al., 2014), 8% (Adesanya and Raheem, 2008), and 6.43% (Bagcal and Baccay, 2019), which could be utilized having compressive strengths capable of use for structural purposes.

Studies reported by Kamau et al (2016); Olafusi and Olutoge (2012); Ettu et al. (2013) obtained compressive strengths of 37.9 MPa, 20 MPa, and 21.1 MPa respectively with 10% CCA replacement at 28 days curing. In addition, at 20% CCA replacement Kamau et al (2016); Adesanya and Raheem (2008); Olafusi and Olutoge (2012) reported compressive strengths of 23.5 MPa, 18.0 MPa, and 13.8 MPa respectively. Further, the chemical characteristics of the corn cob ash used in their studies varies in the silica content. Kamau et al. (2016) reported a silica content of 38.8% whereas Adesanya and Raheem (2008); and Udoeyo and Abubakar (2003) obtained values of 66.38% and 79.29% respectively. These results reported provide inconsistency in values. The varying values and inconsistencies especially in the areas of workability, density, compressive strength, and water absorption, Kamau and Ahmed (2017) recommended further research targeting these areas of anomaly. Thus, this study was conducted to investigate the influence of CCA as pozzolanic material or supplementary cementitious material on the physical properties and compressive strength of mortar paste. Vladimir et al. (2011) stated that the knowledge on both the fresh and hardened properties of mortar is fundamental to assure high quality performance of masonry walls. Cement mortar is a construction material created from combining cementitious material, filler, and water. The use of masonry materials such as in clay masonry and concrete masonry are considered more economical exterior veneer alternatives and are widely used in the US and most developing countries.

2. MATERIALS AND METHODS

The agricultural waste by-product, particularly local Corn Cob Ash (CCA) was utilized in this study as a direct replacement by weight of Portland cement Type IP at various amounts of CCA. The chemical and physical analysis of CCA and the cement used were analysed and evaluated. The mortar pastes with varying amount of CCA ranging from 0% to 20% were subjected to laboratory tests to determine the physical properties and compressive strength of the cement mortar. The 0% CCA is considered as the control specimen. The physical properties of fine aggregates used in this study were also analysed and evaluated.

2.1 Project Structure

Mortar is a construction material composed of water, cement, and filler, and is used to hold or bind building materials together such as brick, CMU, stone or glass masonry. The American Concrete Institute, ACI 211 recommended an aggregate ratio ranging from 2-1/4 to 3-1/2 of the sum of the cementitious materials. In this study, the mortar mixture used was 1 binder: 3 fillers. The binder consisted of cement and CCA at varying percentage replacements of ordinary Portland cement Type IP. The chemical and physical properties of the CCA used were analysed and evaluated following ASTM C114. The filler consisted of well-graded, clean, and standard sand. The physical properties and gradation of the filler were performed. The water-cementitious ratio considered in the mortar mixture was 0.6. There were 30 cubical specimens (50 mm x 50 mm x 50 mm) prepared, casted, cured, and tested at 7, 14, and 28 days curing age. The mortar cubes were tested with compressive strengths.

2.2 Materials

Type IP (Portland cement with natural minerals) was the type of Portland cement used in this study which is readily available at the local market. The specific gravity of the Portland cement Type IP is 3.12. The Corn cobs used in this study were acquired from local farmers and were crushed to a maximum size of 1 inch before subjected to air or sun drying for a period of 6±2 hours to ensure complete incineration of the cobs. In order to achieve optimum amorphous silica, the Corn cobs were subjected to closed pit burning to confine the heat, and then cooled. The burnt cobs were powdered to achieve a particle size of not more than 150 μm as shown in Figure 1 using mortar and pestle. The CCA was sieved using No. 100 mesh to eliminate larger particles before being added to concrete. The specific gravity and moisture content obtained for the CCA were 2.03 and 0.77 respectively. The fine aggregates used in the study were obtained from a local supplier. The physical properties of the fine aggregates such as specific gravity, absorption, and modulus of fineness were 2.60, 2.84, and 2.47 respectively. The water content was 6%. The water used was taken from the water supplied by the city.

Figure 1. Ground Corn Cob Ash

2.3 Testing for Physical Properties of Mortar Paste

2.3.1 Setting Time

The testing method used in determining the initial and final setting of mortar was the ASTM (American Society for Testing and Materials) C191 using Vicat apparatus. In this study, the Vicat apparatus (Figure 2) was used to determine the initial and final setting. The 1 mm diameter needle was allowed to penetrate the paste for 30 seconds and the amount of penetration was measured. The penetration process was conducted in a period 15 minutes interval until a penetration of 25 mm or less was obtained. The time when a penetration of 25 mm occurred was determined and recorded as the initial set time. The final set time was when the needle did not penetrate visibly into the paste (Mamlouk and Zaniewski, 2006).

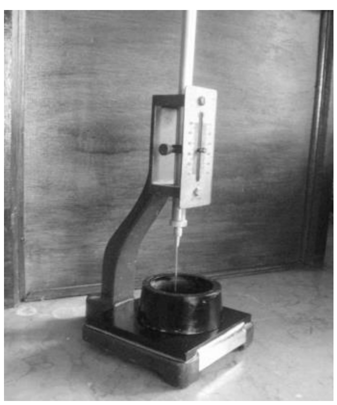

Figure 2. Vicat Apparatus as used in this study for determining setting time

2.3.2 Mortar Flow and Consistency of Mortar Paste

Mortar flow was determined by a laboratory test using a truncated cone and flow table such as the one shown in Figure 3 in accordance with ASTM C1437. A cone of mortar was formed on the table with an original base diameter of 4 in., then the table was raised and dropped 25 times in 15 seconds and the diameter of the mortar mass was measured. If the original 4 in. diameter measures 8 in. after the test, the mortar would have a flow of 100%. Flow values that range from 130% to 150% are required for construction projects.

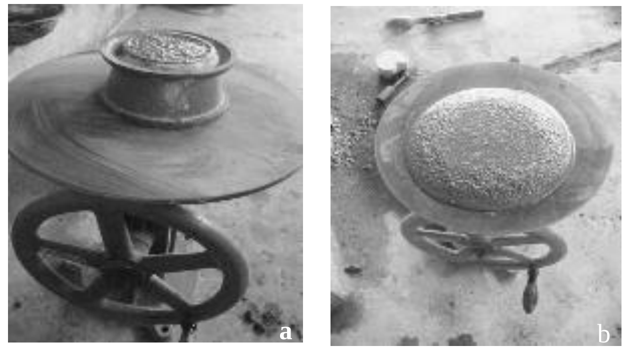

Figure 3. Truncated Cone and Flow Table, a) Cone of mortar before flow testing, b) Mortar mass after flow testing

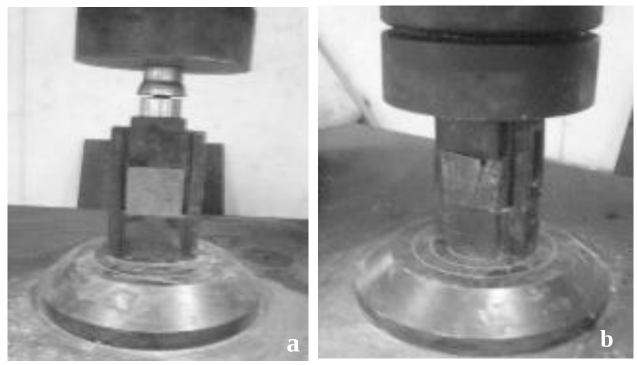

Figure 4. Compressive Strength Testing, a) Mortar cube before testing, b) Mortar cube at failure

2.4 Testing of Hardened Mortar Cubes

The hardened mortar cubes were tested in three different curing ages such as 7, 14, and 28 days. ASTM C109 illustrates the methodology to perform compression strength testing of mortar using cubes of material that are 50 mm on a side. A mechanical testing machine equipped with the appropriate compression accessories is used for the test. Figure 4 illustrates the set up before and after testing the compressive strength of hardened mortar.

3. RESULTS AND DISCUSSION

3.1 Chemical Composition and Physical Properties of CCA and Ordinary Portland cement Type IP

Table 1 shows the chemical compositions of locally found CCA as compared with ordinary Portland cement. The silica content of CCA is determined to be 41.3%. The amount of silica can be characterized as relatively low as compared to other pozzolana such as Rice Husk Ash, Fly Ash, and Slag (Malhorta and Mehta, 1996). The low silica content in CCA could be attributed to the method of burning the Corn cobs in which in this study, the cobs were burnt in an uncontrolled environment. The result shows that the combined total of silicon oxide, alumina oxide, and ferrous oxide of CCA is 55.86% and it is slightly higher than the amount obtained by Kamau et al. (2016) of 54.1%. This signifies that locally found CCA as used in this study could be categorized as Class C pozzolana as per the requirements of ASTM C618 in which the minimum combined total of the three major oxides ($SiO_2 + Al_2O_3 + Fe_2O_3$) of 50% is required. Further, the CCA used had 5.1% loss on ignition, which also complies with the required loss on ignition of 6% maximum.

Table 1. Chemical Composition of CCA and Cement Type IP

Components	Percentage Composition, %	
	CCA	Cement
SiO_2	41.3	23.9
Al_2O_3	12.3	6.4
Fe_2O_3	2.26	3.34
CaO	6.9	55.9
MgO	3.6	2.0
SO_3	1.43	1.56
Na_2O	-	-
K_2O	-	-
LOI	5.1	5
Others	27.1	1.90
Total	100	100

It can be noted also that the chemical analysis of the ordinary Portland cement Type IP revealed that the silicon dioxide (SiO_2) content of 23.9% was high as compared to a typical range of 18.7% to 22.0% for Type I Portland cement (Udoeyo and Abubakar, 2003). The amount of Calcium Oxide content was well below the typical value of 60.6% to 66.3% (ASTM C150). Thus, the study confirmed that the cement used was blended cement with natural minerals added. It has to be recalled that the calcium oxide was responsible for reacting with pozollana to produce compounds possessing cementitious properties.

In Table 2, the percentage of particles retained in No. 325 sieved (45 μm) for CCA was 45.7% which is above the requirement of 34% according to ASTM C618. The high value for the particles size retained in No. 325 was because the Corn cob was burnt in an uncontrolled temperature and the sieve size used in the experiment was No. 100 (149 μm). Malhorta and Mehta (1996) stated that the mechanisms by which mineral admixtures (pozzolana) influence the properties of fresh and hardened concrete are dependent more on the size, shape, and texture of the particles than on the chemical composition. Zareei et. al. (2017) noted that when the rice husk was converted to ash by uncontrolled incineration below 500 °C, a considerable amount of unburnt carbon was found in the resulting ash because of incomplete ignition. Thus, a considerable amount of unburnt carbon could lead to lesser amorphous properties such as lower silica oxide content and this could be the case for the CCA used in this study.

The moisture content of the CCA was 0.77%. This amount is within the prescribed requirement of ASTM C618 of 3% maximum. In addition, the autoclave expansion obtained for the CCA was 0.12%, well below the required value of 0.80%. The specific gravity of CCA is 2.03 as compared with that of cement at 3.12 and it is higher than the value obtained by Ettu et al. (2013) of 1.90. This indicates that CCA is lighter than the cement used in the study.

Table 2. Physical Properties of CCA and Cement Type IP

Physical Properties	***CCA***	***Cement***
Fineness:		
Air Permeability	-	471 m^2/kg
% Retained on No. 325	45.7	-
Specific Gravity	2.03	3.12
Soundness, %	0.12	-
Moisture Content, %	0.77	-

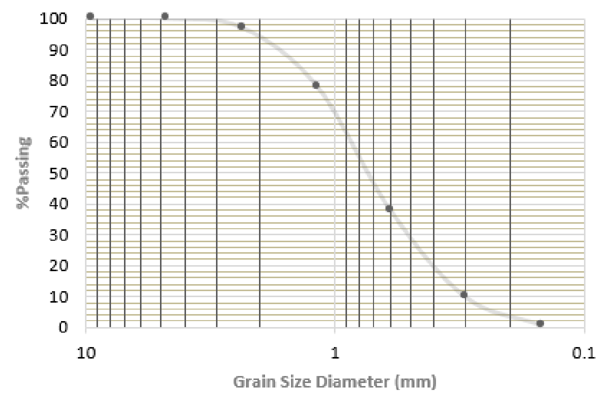

Figure 5. Fine Aggregates Gradation

3.2 Physical Properties of Fine Aggregates

Grain size distribution significantly affects some characteristics of mortar like packing density, voids content, and, consequently, workability, segregation, and durability (Abu Seif, 2013). Shown in Table 3 are the physical properties of fine aggregates used in this study and the gradation is illustrated in Figure 5. In this study, wet fine aggregates were used (having water content of 6%), and thus the water-cementitious ratios were adjusted in order to account the amount of water in the fine aggregates. The high amount of moisture in the fine aggregates was due to the current condition at the time of experiments in which frequent occurrence of heavy rains.

The fineness modulus (FM) of the fine aggregate used in this study was 2.47. Fineness modulus of fine aggregate serves as an index number that represents the mean size of the particles in sand. ASTM C33 specified the range of FM as having no less than 2.3 nor more than 3.1.

Table 3. Physical Properties of Fine Aggregates

Physical Properties	**Values Measured**
Fineness Modulus, %	2.47
Bulk Specific Gravity	2.6
Absorption, %	2.84

The comparison of the fine aggregates used in this study with that of the ASTM gradation specifications for fine aggregates for Portland cement concrete is presented in Table 4. It has to be noted that the fine aggregates used were within the range required by the ASTM specifications. The gradation of fine aggregates is shown in Figure 5. The importance of using the type and quality of aggregates is critical to the physical and compressive strength of mortar. Masonry mortar comprised majority of fine aggregates (sands); therefore, they have significant effect upon the properties of the product in both fresh and hardened states. Abu Seif (2013) stated that the selection of suitable aggregates, which can produce a product with optimum properties, is very important.

Table 4. Comparison of Fine Aggregates Gradation

Sieve Size	*ASTM Specification % Passing*	*Fine Aggregates Used % Passing*
9.5 mm (3/8)	100	100
4.75 mm (No. 4)	95-100	100
2.36 mm (No. 8)	80-100	97
1.18 mm (No. 16)	50-85	78
0.60 mm (No.30)	25-60	38
0.30 mm (No. 50)	10-30	10
0.15 mm (No. 100)	2-10	1

3.3 Physical and Mechanical Properties of Mortar Paste

3.3.1 Setting Time of Mortar Paste

The initial and final setting times of the mortar paste at a given mixture proportion of 1 binder: 3 fillers are shown in Table 5. It can be observed that as the amount of CCA increased, both the initial and final setting time also increased. The influence of CCA on the setting times of cement paste showed that there were considerable effects. The initial and final settings of the control mortar paste (0% CCA) was 150 minutes (2h, 30 min.) and 215 minutes (3h, 35 min) respectively as compared with the mixture of 20% CCA having an initial setting and final setting time of 215 minutes (3h, 35 min) and 365 minutes (6h, 5 min) respectively. The addition of CCA in the mortar paste exerts a somewhat retarding influence on the setting time of the mortar. This indicates that the hydration reaction between the ordinary Portland cement and CCA were slow at an early age. It also implies that CCA acted only as a filler. Further, Dodson (1981) concluded in his study that pozzolana such as fly ash containing low-calcium had extended setting time. This could be the case for CCA since it contains relatively low calcium oxide of 6.9%. Dodson further concluded that the extended setting time is ascribed to the secondary influences of dilution of the Portland cement content.

Table 5. Physical Properties of Mortar Paste

CCA (%)	*Initial Setting h:m*	*Final Setting h:m*	*Mortar Flow %*
0	2:30	3:35	150
5	2:50	4:45	131.25
10	3:17	5:25	112.5
15	3:30	5:50	75
20	3:35	6:05	62.5

The initial and final settings, however, for all mixes were within the prescribed time limits of 45 minutes (minimum initial setting) and 375 minutes (maximum final setting) of the ASTM C150 and ASTM C595.

Since the mixtures with CCA have higher setting times, it indicates that they are most applicable at construction works where a low rate of heat development is required. This is also of specific importance in ready mixed concrete as there is extra time to deliver the fresh concrete to the construction site.

3.3.2 Flow Consistency of Mortar Paste

Table 5 also shows the percentage flow of the mortar paste and Figure 3 illustrates the laboratory test conducted for the mortar flow. The result reveals that as the amount of CCA added in the paste increases, the mortar flow decreases. This indicates that the addition of CCA reduces the plasticity or fluidity of the mortar paste. Thus, increasing the amount of CCA in the mortar mixture reduces workability and water retentivity as well as reduces cohesiveness and creates harder spreadability of mortar paste. According to Mamlouk and Zaniewski (2006), the mortar flow required for construction projects ranges from 130% to 150%. From this standpoint, the control mortar and mortar with 5% CCA were the only acceptable amounts in terms of fluidity of the mortar paste. The lower flow tendency and the higher water demand can be attributed to the permeable or porous nature of pozzolan materials and possible larger surface area. It was reported that a greater amount of water was required to obtain the desired consistency and a lower flow ability is common among pozzolana (Ahmad and Shaikh, 1992).

3.3.3 Mechanical Properties of Mortar Cubes

3.3.3.1 Compressive Strength

The influence of CCA on the compressive strength of the hardened mortar pastes is illustrated in Figure 6 at various curing ages. It is evident from the result that at 7 days of age, the strength of mortar paste decreased as the amount of replacement level of Portland cement with CCA increased. The compressive strength of the control mortar and the 20% CCA were 13.14 MPa and 5.77 MPa respectively. The values obtained at 7 days were well above the prescribed compressive strength for mortar paste Type N (general purpose) of the ASTM C 91 of 3 MPa. This signifies that the mortar mixtures regardless of the amount of CCA added are superior for use as mortar for construction.

The compressive strength of the control mortar and 20% CCA at 14 days curing were 15.76 MPa and 8.63 MPa respectively, while the compressive strength of control and 20% CCA at 28 days curing were 19.62 MPa. and 11.11 MPa., respectively.

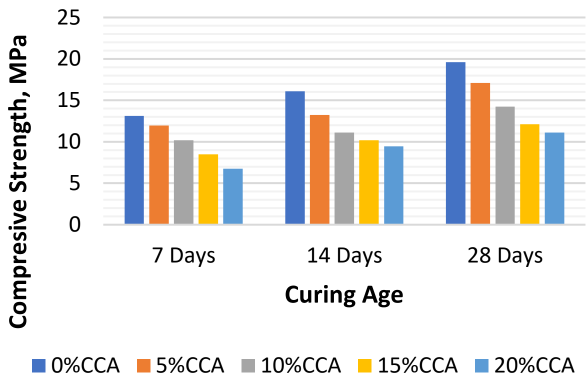

Figure 6. Compressive Strength of Mortar Cubes with Varying CCA

At 28 curing days, as shown in Figure 7, the compressive strengths of mortars with CCA are lower than that of the control mortar. Generally, increasing the amount of CCA with respect to the amount of Portland cement decreases the compressive strength of the hardened mortar. Nevertheless, in all mortar mixtures, the compressive strengths are higher than the minimum compressive strength of Type O (2.4 MPa) mortar as per ASTM C270. Mortars with 5% and 10% CCA can be used as Type M (17.2 MPa) and Type S (17.2 MPA) for foundation walls and load bearing walls respectively as per ASTM C270 requirements. Mortar with 15% CCA and 20% CCA can be used as Type N mortar.

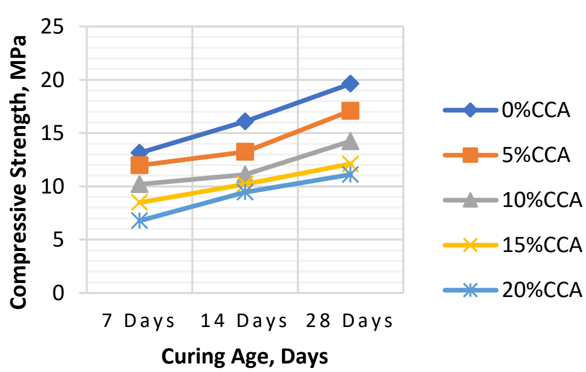

Figure 7. Compressive Strength of Mortar Cubes at Various Curing Ages

3.3.3.2 Strength Development

Figure 8 shows the strength development of the mortars. It is evident in the figure that up to 7 days, the strengths of the mortars with CCA, with exception to 20% CCA, were almost proportional to that of the control mortar. This implies that in the 7 days curing, the pozzolanic reactions had not commenced or progressed enough to enhance the strength. The mortar with CCA showed slow pozzolanic reaction and that at early age, the cement containing CCA, show lower strength than that of the control specimen. This perception is supported by Hanesson et al. (2012) that SCMs are characterized by a delayed gain in strength because they contain lower levels of CaO, which is essential for early strength development. At 14 days curing, the 15% CCA and 20% CCA gained strength at about 15% to 24% of their 28 days compressive strength and higher than the strength gains of control mortar. At 28 days curing age, however, the strength of the 5% CCA and 10% CCA reached strength increases in excess of 22% as compared to 18% on the control mortar. The average percentage of strength for the 5% CCA and 10% CCA mortars as compared to the strength of control mortar are 87% and 73% respectively as shown in Figure 9. In all curing ages (7, 14, and 28 days curing ages), results suggested that for the mix ratio of 1 binder: 3 filler, the cement mortar with various replacement amounts of ordinary Portland cement Type IP with CCA gained strength slowly and steadily. It can be concluded, however, that within the 7 to 28 days hydration period, the beneficial effect on strength resulting from pozzolanic reaction was not substantial.

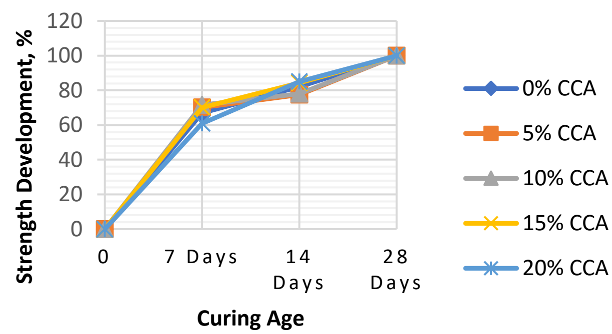

Figure 8. Strength Development of Mortar

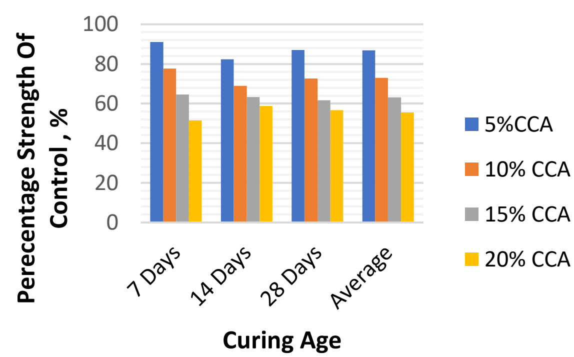

Figure 9. Percentage Strength of Control Mortar

4. CONCLUSIONS

Based on the foregoing findings and within the context and limitation of this study, the following conclusions are drawn:

1. The locally found agricultural waste CCA is classified as Class C pozzolana as evident from the chemical evaluation and analysis, thus, it can be used as pozzolanic material in concrete and masonry mortar. The physical properties of CCA, particularly the moisture content, loss on ignition, and soundness, comply with the ASTM C595 requirements for class C pozzolana. The specific gravity

of the CCA used was 2.03. The Portland cement used in the study was confirmed to have natural minerals added based on the chemical analysis having high silicon oxide and low calcium oxide content as compared with the usual range for ordinary Portland cement Type I.

2. The mortar pastes with 5% to 20% CCA having 1 binder: 3-filler ratio are superior for use as mortar for masonry construction as per ASTM C270 particularly with 5% CCA.

3. The addition of CCA increases the initial and final setting times; however, the values are within the required time as prescribed by ASTM. The retardation in the setting time of the fresh concrete is important for construction that requires low heat of hydration.

4. The addition of CCA in the mortar increased the water requirement to obtain desired plasticity as evident in the decreasing value of the mortar flow.

5. The compressive strength of the hardened mortar cube decreased as the replacement level of ordinary Portland cement with CCA increased.

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