Chapter 8
Investigating the Effect of Corn Cob Ash on the Characteristics of Cement Paste and Concrete: A Review

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Abstract The increase in the demand for construction materials has led to influence the researchers from the various fields to find an alternative way to utilize the waste. Agricultural fields produce a considerable number of wastes in terms of husk, straw and ash. Various studies have concluded that agricultural by-products possess high silicious content indicating their pozzolanic behavior and successful application in cement and cement-based composites. Apart from the safe stabilization of such wastes in construction works, the overall cost of production has also been reduced, considerably. Corn cob is one of those waste products that remained in the agricultural fields for a longer period after the harvesting, which adversely affects the environment. This chapter reviews the various studies conducted on the incorporation of corn cob in various forms in civil engineering practices to reduce the environmental problems associated with it.

Keywords Agricultural waste · Waste management · Safe disposal · Sustainable manufacturing

8.1 Introduction

With the rapid increase in urbanization in the past few decades, the shortage in the number of construction materials is caused. In order to fulfil the demand of the entire population, it is the need of time to produce enough quantity of the building materials such as natural sand, cement, aggregates and wood [1]. The processes involved in the generation of such building materials lead to produce a large number of problems to human health and the environment. In addition to that, the mitigation ideas of these problems haven't gained much attention. Apart from this, during the

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processing of cement from the clinkers, greenhouse gasses are emitted into the environment [2]. China is responsible for more than half of the world's total cement production. In the year 2018, China produced 2.17 million tonnes followed by India 300 million tonnes [3]. It is anticipated that the total amount of cement production will be increased from 3.27 billion tonnes to 4.83 billion tonnes in the year 2030 [3]. The overall global production of cement in the year 2016 has been reported to be 4174 metric tonnes, which was 24.96% more than the total production in the year 2010 [4]. It has also been reported that approximately 0.5 tonnes of CO_2 are released into the atmosphere during the production of 1 ton of cement which makes 5–6% of total CO_2 emitted in the environment through anthropogenic activities [5]. Globally, many types of wastes are generated annually in the form of liquid, gas and solid. Around 23.7 million tonnes per day of food is produced from agricultural fields across the globe [6]. The growth in the overall production rate has caused a significant impact on the environment in terms of affecting the soil, air and natural water resources [7].

Therefore, to reduce the number of problems and to fulfil the demand for construction materials, the wastes generated from the industrial and agricultural areas have been taken into account by various researchers [8, 9]. It has been found that the addition of some particular types of waste from the respected fields as a replacement material for the conventional materials has caused a positive impact on the environment and the overall cost of the construction activity [8, 9]. In India, a large number of by-products are produced from the agricultural fields after the cultivation of a particular type of crop. Agricultural wastes such as leaves, paddy straw, bagasse, stalks and cobs are usually left in the fields or disposed of in the landfills [10, 11].

Corn is one of the most important crops which is produced in India after wheat and rice. The overall production of the corn crop was around 29.8 million tonnes, in the year 2018–2019 [12]. Because of the higher production amount, by-products such as outer shells with silky hairlike structures and corn cob are also produced in excessive amounts. The outer layer with silky parts consists of the fibres that are used as a medicine to prevent the inflammation of kidney stones and to treat problems related to high blood pressure [13]. But the corn cob remains unused until its natural degradation. Therefore, in order to utilize and eliminate the excessive amount of corn cob waste generated from the agricultural and industrial fields, researchers have already conducted numerous studies to use it by converting it into ash for its utilization in construction activities [14]. It has been observed that this material has proven to give positive results when added up to a certain level of replacement of cement [14, 15].

The effect of several agricultural wastes on the concrete characteristics has been reviewed in recent times [9, 16, 17], but a review study on the effect of corn cob ash (CCA) on the mechanical and durability properties of concrete has not been carried out in the literature. Thus, this chapter reviews the available information regarding the physical and chemical properties of CCA and its effect as a mineral admixture in the concrete as a partial replacement of cement. The mechanical and durability properties of concrete as influenced by the corn cob as a sustainable constructional

Fig. 8.1 (**a**) Fully grown corn crop, (**b**) corn cobs after the removal of grains, (**c**) corn cob residue

material are explained in the further sections. The life cycle of the corn crop from a fully grown cob to the extraction of grains to the final product is illustrated in Fig. 8.1.

8.2 Properties of Corn Cob Ash

In this section, the chemical composition and the physical properties of CCA are given. The effect of these properties on concrete, when mixed with cement, is also discussed in detail.

8.2.1 Chemical Composition

The chemical composition of the CCA analysed by x-ray fluorescence by various authors is given in Table 8.1.

As shown in Table 8.1, the CCA has satisfied the requirement to be a good pozzolanic material by satisfying the combination of SiO_2 and Al_2O_3 more than 70% [2, 27, 31]. In the previous studies, the pozzolan with a higher amount of siliceous compound has been reported to cause positive impacts when blended with cement for concrete production.

8.2.2 Physical Properties

The range of physical properties of the CCA as reported in the literature is given in Table 8.2.

Table 8.1 The range of chemical composition of CCA used in the previous literature [18–30]

Chemical compounds	Value (% by mass)
SiO_2	37.00–79.24
Al_2O_3	0.98–17.57
Fe_2O_3	0.64–9.07
CaO	1.8–13.0
K_2O	0.14–23.5
Na_2O	0.07–4.60
MgO	0.98–7.35
SO_3	0.08–13.76
Cl	–
P_2O_5	0–6.49
MnO	0–0.14
BaO	0.03

Table 8.2 The physical properties of the CCA by various authors [19, 20, 22–24, 26, 27, 31–38]

Properties	Value
Moisture content (%)	0.65–0.77
Specific gravity	1.05–3.49
pH	9.73
L.O.I	1.47–22.50
Colour	Greyish purple
Soundness	0.77–2
Median particle size (μm)	29–45
Blaine fineness (m^2/kg)	272–385

8.3 Effect of Corn Cob Ash on the Mechanical and Durability Attributes of Concrete

In this section, the properties of concrete in the fresh and hardened state are discussed. The effect of the addition of CCA on the mechanical properties of concrete when varying dosages of the mineral admixture and curing period is explained further in the following subsections. The process involved in the concrete manufacturing based on the integration of the waste material, that is, CCA, as a partial replacement of cement, is shown below in Fig. 8.2.

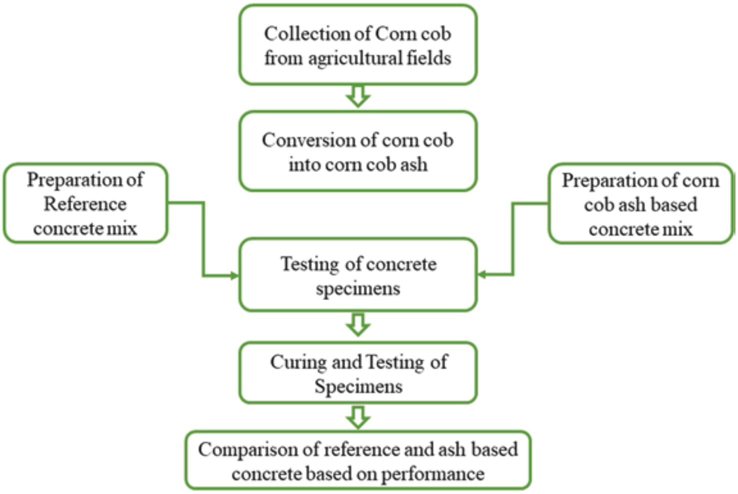

Fig. 8.2 The process to manufacture the CCA-based concrete for the construction activities

8.3.1 Initial and Final Setting Time

The effect of the CCA on the setting times of the cement paste was checked, and it was observed that the CCA had a noticeable effect on the initial setting time than the final setting time [37]. The cement paste having 30% of replacement had the initial setting time of 27 min, whereas the control specimen shows the initial setting time of 56 min. The same paste with 30% replacement had the final setting time of 4 h and 30 min, whereas the control specimens show a final setting time of 4 h and 5 min. However, the study has suggested that replacement up to 20% is more preferable to the other higher replacement percentages [37]. The cement pastes blended with the CCA show higher setting times when compared to the control specimens [19, 31]. Studies have recommended the use of blended CCA-type paste where less development of heat rate is needed, that is, mass concreting [19, 31].

8.3.2 Soundness

The soundness of the cement pastes consisting of CCA was measured with the Le Chatelier apparatus. The soundness of the pastes was between 1.0 and 2.0 mm, that is, below 10 mm, confirming the specifications suggested by the British standards [37].

8.3.3 Hydration of Cement Paste with CCA

The normal cement pastes made with the OPC have two main peaks, that is, silicate and sulfate deletion peak, which is responsible for the fast dissolution of the C_3S compound in order to form the C-S-H gel and conversion of the ettringite from C_3A. The partial replacement of cement with the CCA lowers these peaks. The hydration peaks of cement system containing 20% of CCA replacement generally showed up in 2–3 h; however, these peaks for the OPC and the other mineral admixtures occur between 8 and10 h [39, 40]. Thus, it can be inferred that the hydration of the alite and aluminite in the cement gets faster with the addition of the CCA [41].

8.3.4 Workability

The workability of the concrete has also been reported to be reduced as the percentages of CCA are increased [27]. The mix becomes harsher, that is, more water is required to make the paste workable. As explained earlier, the increase in the amount of water is directly dependent upon the amount of silica present in the mixture. Because the reaction between silica and lime needs extra water except the water required for the hydration of cement [42, 43].

Similar results were obtained in another study where the slump values of the concrete made by the addition of the CCA decreased as the substitution of ash is increased in the mix [44]. A significant reduction in the slump of the mix has been reported, from 35 mm to 12 mm, as the percentage of ash increased. Similarly, the compaction factor was also decreased from 0.89 to 0.67, when the amount of CCA is increased from 0% to 25%. The same trend was seen for all the mixes (1:1½:3, 1:2:4 and 1:3:6 mixes). It has been observed from the results that the mix has become stiffer as the content of CCA is increased, that is, more amount of water is needed to make the concrete workable [44]. The results found by the other authors also showed the trend of a decrease in the workability of the concrete [45, 46]. Authors have also suggested that this could be due to the increase in the amount of silica in the concrete mix by the addition of CCA [34, 37]. However, a few studies claim that the addition of CCA has resulted in the improvement of the workability of all of the mixes [24, 26, 29, 47]. Researchers have suggested that the maximum workability was achieved when 20% and 30% replacement of cement is done with CCA [24, 47].

8.3.5 Compressive Strength

When the CCA is utilized as a pozzolan in addition to the cement for the concrete production, reduction in the strength in early days is observed, but when curing days are increased, that is, 56 days, strength is reported to be increased [44]. A study was conducted to check the effect of the addition of the amount of CCA which was used as a replacement material in the concrete. After a particular curing age of the specimens, that is, 3, 7, 28, 60, 120 and 180 days, results were noted down. The obtained results showed that at 28 days of curing, the strength of the specimens is very low than that of control specimens. Whereas, in the later days (60 days of curing), due to the pozzolanic action of the ash, the compressive strength of the specimens made with CCA starts increasing [44]. The authors have also suggested that to get the maximum gain in the strength, the specimens should be cured for at least 180 days and the maximum possible replacement of CCA in concrete from the load-bearing point is 8% [44].

Another study follows the same trend as above; the compressive strength of the concrete made by the replacement of cement with CCA showed a decrease in the compressive strength when tested at different curing ages [37]. Generally, the specimens that are prepared using only OPC, that is, without any mineral admixture, show an increase in the compressive strength with the curing age, which indicates that the hydration of the cement has commenced. The results of the study represented that the used corn cob ash has failed to provide a sufficient amount of pozzolanic activity to the cement paste which ultimately results in the reduction of the compressive strength at each percentage of replacement and curing age [37]. The obtained results were below the reference specimens. It has also been observed that the rate of development of strength in the CCA concrete is lower in the early days but gets significantly higher in later days of curing [37]. The authors have also suggested that the replacement of CCA in the concrete can be done up to 10% without any major noticeable reduction in the strength [37].

Similar work has been conducted to check the feasibility of using CCA as a pozzolan in the concrete. Various mixes having different replacement percentages and curing periods were cast. It was found that the addition of this pozzolan as a replacement material of cement causes a significant reduction in the compressive strength of the specimens when compared to the control ones [24, 29]. The reason might be that during the initial days, the corn cob acts as a filler or inert material that fills the gaps, while at a later stage, the gain in the strength was due to the formation of calcium-silicate-hydrate (C-S-H) compound through the reaction between the siliceous elements of pozzolan and the excessive lime from the secondary hydration of the cement [24, 29].

An experimental study reported that the strength of concrete decreases as the replacement percentage of CCA is increased in the mix [27]. In the early days, the rate of development of strength in the specimens made with replacement was reported to be very slow in comparison to the normal concrete. The observed behavior is in line with the available literature in which concrete contains the pozzolanic materials and shows a slower gain in strength in the early days [18, 48]. After 56 days, the commencement of the pozzolanic action is observed as the compressive strength of concrete started to increase [27]. The reason for the increment in strength can be credited to the reaction of corn cob ash and sawdust ash with the extra lime released during the secondary hydration of cement. The authors have also suggested the use of such types of pozzolans in the applications of concrete where the strength is not the primary concern such as an application for the floor screed. It has been reported that when 10% of replacement of cement is partially replaced with CCA, the observed compressive strength was slightly higher than that of control specimens. Beyond 10% replacement, a significant reduction in the strength of the specimens has been noticed [47]. Similar results were obtained when the assessment of the integration of CCA in the cement for concrete production was checked, and results suggested that when the amount of replacement is increased, the compressive strength of concrete has been reported to be decreased. The study also revealed that at 10% replacement, the gain in the compressive strength was maximum (27.01 N/mm^2) than the other percentages (23.65 N/mm^2 and 14.06 N/mm^2) after 28 days of curing [34].

In a study, a significant reduction in the compressive strength is observed when the amount of CCA is increased in the cement mixture for concrete production [41]. The results of compressive strength of a study conducted on the CCA in the concrete with replacement percentages of 3% and 20% and tested after 7, 28 and 112 days of curing [41] show that the replacement of the CCA in the concrete with the cement has caused a reduction in the compressive strength even after 112 days of curing when compared to the control specimens [41]. The reason for the reduction may be caused by the inert nature of ash or the higher alkali content in it [41]. As reported in the American Society for Testing and Materials (ASTM), C90 [49] needs at least the compressive strength of 13.8 MPa for the masonry items; therefore, the load-bearing masonry items can be easily made with the use of CCA to fulfil the requirement. Authors have also suggested that the incineration of corn cob at higher temperatures could result to produce more reactive ash which may be useful to provide sufficient pozzolanic behavior to the ash during the hydration reaction [37].

8.3.6 Tensile Strength

As the amount of CCA is increased, a significant reduction in the tensile strength has been observed [26]. The specimens cast with 10% replacement of cement showed 80% strength of control specimens, whereas at 20% of replacement, the tensile strength gets reduced up to 50–60% of control specimens. The increase in the curing days and replacement percentage has caused more reduction in the tensile strength as a similar trend has been observed when the specimens were tested even after 91 days [26]. The other previous studies conducted showed that the tensile strength of the concrete specimens cast with the addition of CCA has also been reported to be low [24, 29, 37].

8.3.7 Density

The densities of the specimens cast with the different dosages of CCA were less than the control specimens which confirm the hypotheses in the previous literature that the supplementary cementitious materials possess the low specific gravity which ultimately increases the overall volume of the concrete mixes per unit mass [50]. The densities of the concrete specimens were noticed to decrease even after the curing period is increased up to 91 days [24]. The previously available literature has also reported that the addition of CCA as a pozzolan in the concrete has caused a negative impact on the tensile strength of the specimens [24, 29, 45, 46].

8.3.8 Water Absorption

CCA successfully reduced the water absorption capacity of the concrete [18, 46]. Better results have been reported when the optimal replacement of 10% of cement is done with corn cob ash for the mixes, that is, 1:1 1/2:3 and 1:2:4 [18]. Whereas another study suggested that the optimal value of replacement of cement with CCA is 7.5% which is sufficient to reduce the absorption of water in the concrete [51].

However, opposite results have been observed in the case of the concrete containing 15% of CCA as it shows a higher percentage of water absorption (9.5%) than the control concrete (5%) [37]. The control concrete has been reported to be more superior to the CCA-based concrete by resisting the penetration of water through the voids. As the water absorption is less than 10%, the CCA concrete is suggested to be used for the construction works [37]. The water absorption gets much higher when the content of CCA is further increased. The reason could be related to the development of the less permeable layer of calcium-silicate-hydrate [18].

8.3.9 Permeability

As the content of CCA is increased in the concrete mix, the amount of pure binder is reduced which resists the proper bonding of all other ingredients such as fine and coarse aggregates. This phenomenon led to the formation of gaps between the particles. The increase in the number of voids in the concrete, thus, increases the permeability [18].

8.3.10 Chemical Attack

The CCA-based concrete has resulted in improving the resistance to the chloride attack and that absorbed less HCl acid water has lower loss in weight after brushing. This confirms the report in the literature that the lower the permeability, the higher the resistance to chemical attack [52, 53]. Authors have also described acid resistance to the attack of HCL and H_2SO_4 that it depends upon the percentage of incorporation of the CCA and the mix proportion in the paste. The obtained results showed that the concrete made by the integration of CCA shows more resistance to the HCL attack when compared to the H_2SO_4 attack [52, 53].

The usage of the pozzolanic materials in the cement has been useful in order to reduce the penetration of the aggressive materials. The admixture holds the $Ca(OH)_2$ compound, which is a very important material in the hydration of cement where the acid attack is a major problem [54, 55]. Better performance of concrete manufactured by the addition of CCA by replacing the cement is observed over the control specimens, when dipped in the Na_2SO_4 and $MgSO_4$ solutions [24]. Similar results were observed when CCA-based concrete was subjected to the HCL solution up to 20% of replacement of cement. Beyond that replacement, a significant deterioration in the performance of concrete is observed [18].

8.3.11 Sulfate Resistance

The specimens cast with the addition of CCA have shown lesser expansions when compared to the control ones. The reason may be associated with the reduction in the amount of ettringite formation as the siliceous content present in the CCA gets used up during the formation of C-S-H gel. The pozzolanic reaction, consumption and reduction in the amount of calcium hydroxide and aluminate hydrate and the filler effect of the CCA itself explain the ability of admixture-based concrete to resist the damaging action of Na_2SO_4 attack. This type of concrete is suggested to be used in acidic environments in order to protect the structures [24, 29].

8.4 Conclusion and Recommendations

This review chapter has reported the available literature on the cement paste and concrete made with the integration of CCA as a replacement material. Authors have discussed the results in detail to find various hidden possibilities to use this admixture in the future for many more constructional activities. Based on the reviewed studies, the following conclusions can be made:

- The addition of CCA in cement has significantly affected the setting times, soundness and hydration of cement pastes.

- The concrete containing the CCA should be allowed to cure for more than 120 days in order to provide sufficient time for its pozzolanic action.
- The fresh, mechanical and durability properties of CCA-based concrete have been reported to be enhanced when the replacement is done up to 8–10% of cement.
- The concrete made by the CCA is suggested to be used for construction activities.

By examining the available literature thoroughly, the author suggests the readers to use this waste in addition to the microbes to get more improvement in the performance of the manufactured concrete, as microbes have already been reported to cause a positive impact on the properties of concrete. The effect of the combination of CCA with other pozzolans such as rice husk, fly ash and silica fume in different concrete dosages and curing conditions can also be explored by the readers.

References

1. B. Alabi, J. Fapohunda, Effects of increase in the cost of building materials on the delivery of affordable housing in South Africa. Sustainability **13**, 1–12 (2021). https://doi.org/10.3390/su13041772
2. K. Singh, J. Singh, S. Kumar, A sustainable environmental study on corn cob ash subjected to elevated temperature. Curr. World Environ. **13**, 144–150 (2018). https://doi.org/10.12944/cwe.13.1.13
3. G. Datis, Worldwide Cement Production From 2015 to 2019 (2020)
4. WBCSD, World Business Council for Sustainable Development (WBCSD), The Getting the Numbers Right (GNR) 2016 data, (2019). https://www.wbcsdcement.org/GNR-2016. Accessed 31 Dec 2020
5. M.A. Etim, K. Babaremu, J. Lazarus, D. Omole, Health risk and environmental assessment of cement production in Nigeria. Atmosphere (Basel) **12**, 1–16 (2021). https://doi.org/10.3390/atmos12091111
6. FAOSTAT, Food and Agriculture Organization of the United Nations (FAO), Strategic Work of FAO for Sustainable Food and Agriculture (2017). http://www.fao.org/3/ai6488e.pdf. Accessed 31 Dec 2020
7. FAOSTAT, Food and Agriculture Organization of the United Nations (FAO), The State of Food and Agriculture 2017. Leveraging Food Systems for Inclusive Rural Transformation., (2017). http://www.fao.org/3/a-i7658e.pdf
8. A.K. Sodhi, N. Bhanot, R. Singh, M. Alkahtani, Effect of integrating industrial and agricultural wastes on concrete performance with and without microbial activity. Environ. Sci. Pollut. Res. **1–17** (2021)
9. J. He, S. Kawasaki, V. Achal, The utilization of agricultural waste as agro-cement in concrete: A review. Sustainability **12** (2020). https://doi.org/10.1088/1757-899X/980/1/012065
10. E. Hsu, Cost-benefit analysis for recycling of agricultural wastes in Taiwan. Waste Manag. **120**, 424–432 (2021). https://doi.org/10.1016/j.wasman.2020.09.051
11. M. Gharieb, A.M. Rashad, An initial study of using sugar-beet waste as a cementitious material. Constr. Build. Mater. **250**, 118843 (2020). https://doi.org/10.1016/j.conbuildmat.2020.118843
12. Pjtsau, Maize Outlook, (2020)
13. F. and D. Administration, CFR – Code of Federal Regulations Title 21, Electronic Code of Federal Regulations (eCFR) 2019

14. N. Bheel, A. Adesina, Influence of binary blend of corn cob ash and glass powder as partial replacement of cement in concrete. Silicon **13**, 1647–1654 (2020). https://doi.org/10.1007/s12633-020-00557-4
15. N.O. Abdullah, R.D.W. Fakhruddin, N.K.R. Bachtiar, A sustainable environmental study on clamshell powder, slag, bagasse ash, fly ash, and corn cob ash as alternative cementitious binder. IOP Conf. Ser. Earth Environ. Sci. **841** (2021). https://doi.org/10.1088/1755-1315/841/1/012003
16. D. Sundaravadivel, Recent studies of sugarcane bagasse ash in concrete and mortar – A review. J. Mater. Cycles Waste Manag **7**, 306–312 (2018)
17. K.S. Sohal, R. Singh, Sustainable use of sugarcane bagasse ash in concrete production, in *Sustainable Development Through Engineering Innovations*, ed. by H. Singh, P. P. S. Cheema, P. Garg, (2020), pp. 397–409
18. D.A. Adesanya, A.A. Raheem, A study of the permeability and acid attack of corn cob ash blended cements. Constr. Build. Mater. **24**, 403–409 (2010). https://doi.org/10.1016/j.conbuildmat.2009.02.001
19. O. Bagcal, M. Baccay, Influence of agricultural waste ash as pozzolana on the physical properties and compressive strength of cement mortar. J. Appl. Eng. Sci. **9**, 29–36 (2019). https://doi.org/10.2478/jaes-2019-0004
20. O.S. Olafusi, W.K. Kupolati, E.R. Sadiku, J. Snyman, J.M. Ndambuki, Characterization of corncob ash (CCA) as a pozzolanic material. Int. J. Civ. Eng. Technol. **9**, 1016–1024 (2018)
21. K. Anjaneyulu, Partial replacement of cement concrete by waste materials. Int. J. Eng. Dev. Res., 1374–1383 (2017)
22. P. Suwanmaneechot, T. Nochaiya, P. Julphunthong, Improvement, characterization and use of waste corn cob ash in cement-based materials. IOP Conf. Ser. Mater. Sci. Eng. **103** (2015). https://doi.org/10.1088/1757-899X/103/1/012023
23. S.A. Memon, M.K. Khan, Ash blended cement composites: Eco-friendly and sustainable option for utilization of corncob ash. J. Clean. Prod. **175**, 442–455 (2018). https://doi.org/10.1016/j.jclepro.2017.12.050
24. J. Kamau, A. Ahmed, P. Hirst, J. Kangwa, Suitability of corncob ash as a supplementary cementitious material. Int. J. Mater. Sci. Eng. **4**, 215–228 (2016). https://doi.org/10.17706/ijmse.2016.4.4.215-228
25. M. Shakouri, D. Trejo, A time-variant model of surface chloride build-up for improved service life predictions. Cem. Concr. Compos. **84**, 99–110 (2017). https://doi.org/10.1016/j.cemconcomp.2017.08.008
26. J. Kamau, A. Ahmed, A review of the use of corncob ash as a supplementary cementitious material. Eur. J. Eng. Res. Sci. **2**, 1–6 (2017)
27. K.A. Mujedu, S.A. Adebara, I.O. Lamidi, The use of corn cob ash and saw dust ash as cement replacement in concrete works. Int. J. Eng. Sci. **4**, 22–28 (2015)
28. M. Shakouri, D. Trejo, P. Gardoni, A probabilistic framework to justify allowable admixed chloride limits in concrete. Constr. Build. Mater. **139**, 490–500 (2017). https://doi.org/10.1016/j.conbuildmat.2017.02.053
29. J. Kamau, A. Ahmed, P. Hirst, J. Kangwa, Viability of using corncob ash as a pozzolan in concrete. Int. J. Sci. Environ. Technol. **5**, 4532–4544 (2016)
30. B.O. Adigun, F.I. Jegede, O. Tunmilayo Sanya, Advanced materials development from corncob ash for economic sustainability. Int. J. Ceram. Eng. Sci. **2**, 17–21 (2020). https://doi.org/10.1002/ces2.10032
31. D.A. Adesanya, A.A. Raheem, Development of corn cob ash blended cement. Constr. Build. Mater. **23**, 347–352 (2009). https://doi.org/10.1016/j.conbuildmat.2007.11.013
32. H. Binici, F. Yucegok, O. Aksogan, H. Kaplan, Effect of corncob, wheat straw, and plane leaf ashes as mineral admixtures on concrete durability. J. Mater. Civ. Eng. **20**, 478–483 (2008). https://doi.org/10.1061/(asce)0899-1561(2008)20:7(478)
33. F.I.J. Bidemi Omowunmi Adigun, O.T. Sanya, Advanced materials development from corn cob ash for economic sustainability, (n.d.) 1–15. https://doi.org/10.1002/ces2.10032.

34. T.Y. Tsado, M. Yewa, S. Yaman, F. Yewa, Comparative analysis of properties of some artificial pozzolana in concrete production. Int. J. Eng. Technol. **4**, 1–5 (2014)
35. K. Oluborode, I. Olofintuyi, Self-compacting concrete: strength evaluation of corn cob ash in a blended portland cement. Am. Sci. Res. J. Eng. Technol. Sci., 123–131 (n.d.)
36. T.A. Owolabi, I.O. Oladipo, O.O. Popoola, Effect of corncob ash as partial substitute for cement in concrete. New York Sci. J **8**, 1–4 (2015)
37. F.F. Udoeyo, S.A. Abubakar, Maize-cob ash as filler in concrete. J. Mater. Civ. Eng. **15**, 205–208 (2003)
38. E.S. Aprianti, A huge number of artificial waste material can be supplementary cementitious material (SCM) for concrete production e a review part II. J. Clean. Prod. **142**, 4178–4194 (2017). https://doi.org/10.1016/j.jclepro.2015.12.115
39. Z. Ge, K. Wang, P.J. Sandberg, J.M. Ruiz, Characterization and performance prediction of cement-based materials using a simple isothermal calorimeter. J. Adv. Concr. Technol. **7**, 355–366 (2009). https://doi.org/10.3151/jact.7.355
40. J. Yu, G. Li, C.K.Y. Leung, Hydration and physical characteristics of ultrahigh-volume fly ash-cement systems with low water/binder ratio. Constr. Build. Mater. **161**, 509–518 (2018). https://doi.org/10.1016/j.conbuildmat.2017.11.104
41. M. Shakouri, C.L. Exstrom, S. Ramanathan, P. Suraneni, Hydration, strength, and durability of cementitious materials incorporating untreated corn cob ash. Constr. Build. Mater. **243**, 118171 (2020). https://doi.org/10.1016/j.conbuildmat.2020.118171
42. M.N. Haque, O. Kayali, Properties of high-strength concrete using a fine fly ash. Cem. Concr. Res. **28**, 1445–1452 (1998)
43. B. Waswa-Sabuni, P.M. Syagga, S.O. Dulo, G.N. Kamau, Rice husk ash cement – An alternative pozzolana cement for kenyan building industry. J. Civ. Eng. **8**, 13–26 (2002)
44. D.A. Adesanya, A.A. Raheem, A study of the workability and compressive strength characteristics of corn cob ash blended cement concrete. Constr. Build. Mater. **23**, 311–317 (2009). https://doi.org/10.1016/j.conbuildmat.2007.12.004
45. O.S. Olafusi, F.A. Olutoge, Strength properties of corn cob ash concrete. J. Emerg. Trends Eng. Appl. Sci. **3**, 297–301 (2012)
46. D.A. Adesanya, Evaluation of blended cement mortar , concrete and stabilized earth made from ordinary Portland cement and corn cob ash. Constr. Build. Mater. **10**, 451–456 (1996)
47. Price, Investigating effects of introduction of corncob ash into portland cements concrete: mechanical and thermal properties, Am. J. Eng. Appl. Sci. 7 (2014) 137–148. https://doi.org/10.3844/ajeassp.2014.137.148.
48. A.A. Raheem, Saw dust ash as partial replacement for cement in concrete. Organ. Technol. Manag. Constr. Int. J. **4**, 474–480 (2012). https://doi.org/10.5592/otmcj.2012.2.3
49. ASTM C90–16a, Standard Specification for Loadbearing Concrete Masonry Units, ASTM International, West Conshohocken, PA, 2016
50. J.D. Bapat, *Mineral Admixtures in Cement and Concrete* (CRC Press, 2012)
51. J. Kamau, A. Ahmed, P. Hirst, J. Kangwa, Permeability of corncob ash, anthill soil and rice. Int. J. Sci. Environ. Technol. **6**, 1299–1308 (2017)
52. A.M. Neville, *Properties of concrete* (Longman, London, 2000)
53. A.E. Long, G.D. Henderson, F.R. Montgomery, Why assess the properties of near-surface concrete? Constr. Build. Mater. **15**, 65–79 (2001). https://doi.org/10.1016/S0950-0618(00)00056-8
54. M.S. Shetty, *Concrete Technology Theory and Practice* (S. Chand and Company Ltd., New Delhi, 2001)
55. S.T. Lee, H.Y. Moon, R.N. Swamy, Sulfate attack and role of silica fume in resisting strength loss. Cem. Concr. Compos. **27**, 65–76 (2005). https://doi.org/10.1016/j.cemconcomp.2003.11.003