Effects of Corn Cob Ash as Mineral Admixture on Mechanical and Durability Properties of Concrete – A Review

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Abstract. Concrete is the second most consumed product next to water on earth. Cement is the key ingredient for making concrete. India is the second largest cement producer in the world. The production of cement is emitting an equal amount of CO₂ in to the atmosphere and is accounted as about 8% of the world’s total emissions. The addition of mineral additives as supplementary cementitious materials in concrete is one of the solution to avoid such environmental pollution. The natural mineral admixture obtained from the novel agricultural by-product, namely corn cob ash (CCA), is being utilized in cement manufacturing and concrete construction. The similarities in both physical and chemical properties of CCA were established when compared to the decade old agro-based mineral admixtures like rice husk ash (RHA) and sugar cane bagasse ash (BA) through research findings. The results are mentioned that the CCA can be used as chemically active mineral admixture and micro-filler in concrete. With this background, the paper presents a review on the effect of substituting CCA in fresh, mechanical and durability properties of concrete.

1. Introduction
Cement and its products are the highly necessitated man-made products in the world. Indian cement production is positioned in the second place next to China. India has a huge potential of cement demand during the forthcoming decades due to recent major initiatives of Government such as development of 98 smart cities and concrete pavement projects. The cement production in India had been raised at a level of 28.3 million tons per annum as on June 2019 statistics. The production is expected to raise up to further 20 million tons per annum in the year 30-31. The projected cement production strategy is expected as more than 50 million tons per annum during 2050 and expected to reach the top most cement producer in the world [1]. The production of cement is emitting an equal amount of CO₂ in to the atmosphere and is accounted as about 8% of the world’s total emissions. There have been three main ways to reduce CO₂ emissions from cement industry:

- Increasing energy efficiency by optimizing processes and modernizing factories by introducing new cement plants using the best available technology or upgrading old plants.
Substituting fossil fuels with other energy sources by using alternative fuels such as biomass and industrial waste and to replace fossil fuels in cement kilns.

Using additives in cement clinkers to produce a large range of cement according to their application by utilizing the natural products such as pozzolanic materials or industrial by-products such as fly ash, slag and ashes from agricultural waste.

The pozzolanic material mentioned in the third option is defined as a siliceous and aluminous material which possesses little or no cementitious value however it chemically reacts with the calcium hydroxide at ordinary temperature in the presence of water in finely divided form to develop the compound possessing cementitious properties [2]. Due to the depletion of raw materials and focusing towards the reduction of CO$_2$ emission, the usage of Portland Pozzolana Cement (PPC) is emerging all over the world. In the last few decades, several technological and scientific developments were achieved after using pozzolanic material as one of the raw materials for the production of factory-blended composite cement and as partial replacement of cement in cement concrete and mortar [3, 4, 5].

The by-products, obtained from mechanical and agricultural industry having pozzolanic characteristics which can impart the advantages of making blended cement. The research findings were proved that the usage of blended cement is improved durability of concrete in addition to the strength and hence the pozzolanic materials are called as Supplementary Cementitious Materials (SCM). Their properties are varied considerably depending upon their origin because of the variable physical and mineralogical characteristics. It can exist in various forms ranging from amorphous reactive materials to crystalline products. The presence of amorphous silica can react with calcium hydroxide and alkaline more rapidly than the silica in crystalline form [6]. The suitability and benefits of natural SCM such as volcanic tuff [7], pumice [8], diatomite [9] and metakaolin [10] were investigated in all over the world more than a century. Later industrial by-products like fly-ash (FA), ground granulated blast furnace slag (GGBS) and silica fume (SF) [10, 11, 12] and the by-product from agricultural industry such as rice husk ash [12, 13], palm oil clinker powder [14] and sugar cane bagasse ash [12, 13] were considered as artificial SCM. The suitability of these SCMs are examined in mortar and concrete and found suitable for enhancing the performance in mechanical and durable properties.

2. Corn cob ash

Corn cob is the hard core portion of the corn and base of the kernel as shown in figure 1. Maize (corn crop) is the third most important cereal crop in the world. In India, Telangana state is the second largest leading producer of maize which is about 16% next to the leading producer Karnataka about 18% as per the production statistics of the year 2017 as shown in Figures 1,2 [15]. More than 30 Million MT maize being produced in India every year and simultaneously an equal amount of corn cob waste was generated. The corn cob is generally used as fire wood in various industries. The ash generated from this corn cob is then dumped in low-level arrears or land filling which causes the environmental problems particularly the habitat in nearby areas. Corn Cob Ash (CCA) is one among the agricultural by-products. This can be considered for recycling or reusing in to various ways. One of the opportunity is reusing as pozzolanic material in cement or concrete. It is rich in silica similar to BA and RHA and can be used as SCM in cement and concrete. The CCA was considered as pozzolanic material during manufacturing of blended cement by adding with cement clinkers during grinding process [16] and also added as partial replacement of OPC while making concrete or mortar [17]. Researchers are doing investigation from the last few decades for suitability of CCA as pozzolanic materials and finding the behaviour of CCA blended cement concrete [17, 18]. In this background this paper is intended to highlight the results published by various authors across the globe.
3. Production of CCA

The composition of corn cob is expected to differ from place to place depends upon the soil composition where the maize cultivated [1]. Naturally the corn cobs are wet condition and dried in sunlight for a few days to remove the moisture content and avoid the growth of fungus. The dried corn cob is then allowed calcination process which is transform the crystalline stage of ash into amorphous stage. Olafusi et al prepared the CCA from the sun-dried corn cob in open air to reduce moisture and milled into pieces. The scraped corn cob were placed in a porcelain crucible inside the muffle carbonite furnace at a temperature of 650°C for 5 hours to completely remove the carbonaceous material until a white substance was formed from the original corn cob sample. The sequence of this process is shown in Figure 3(i) to 3(iv) [19,20].

![Figure 1. Pieces of corn cob after removing kernel](image1)

![Figure 2. State wise Maize production share in India based on 2010-2016 data [15].](image2)
Kamau et al [17] had conducted incineration process of dried corncobs under uncontrolled conditions in open air at about 650°C to 800°C for over 8 hours until they turned to ashes. In order to facilitate calcination, the samples were grinded for 30 min using a porcelain ball mill and transferred into muffle furnace at selected temperatures ranged from 550°C-800°C with 50°C intervals and burning times ranging from 1-4 h with 1 h intervals [21]. Shazim Ali Memon conducted investigation to find the optimum incineration temperature by varying the temperature from 400°C to 800°C in muffle furnace at the rate of 10°C for 2 hours and also determined optimum incineration time by conducting the investigation with 15, 30, 60 and 120 minutes intervals [22]. A measured quantity of corn cob was chopped to maximum size of 12mm put in an electric muffle furnace and the temperature of the furnace was to 600°C, which was attained in a period of 15 minutes and maintained for a continuous period of 10 hours. After the cob has visibly turned to ash, the residue was recovered and weighed. This was repeated 12 times for getting the correct CCA [16].

4. Physical characteristics of CCA
The physical characteristics of mineral admixture, such as particle size, specific surface area and specific gravity are plays essential role in the properties of blended cement, concrete and mortar. Adesanya and Raheem was found the specific surface area of CCA as 272 m²/kg [23] and noticed that it
is lower than the other agro-based mineral admixtures such as Bagasse Ash (BA) and Rice Husk Ash (RHA) and comparable with Fly-ash (FA). Suwanmaneechot et al.[21] examined the specific surface area using the Brunauer, Emmett and Teller (BET) method and found that the specific surface area of CCA was higher (9050 m²/kg) than that of OPC (3200 m²/kg). After calcining at 600°C for 4 h, specific surface area of CCA reduced insignificantly (7441 m²/kg). The agglomeration of CCA particles initiates due to calcining at 200°C and further extending the calcining temperature increases the particle size due to the melting of smaller particles and amalgamate with larger particles. At 600°C calcining temperature, the complete agglomerate effect was developed and increase the mean particle size of CCA [19]. An average particle size 10-30 μm was developed after 650°C calcining temperature [19-20]. Suwanmaneechot et al.[21] was found the particle size of CCA at 600°C ranging from 23.56 to 28.45 μm. The specific gravity of CCA was noticed from the literature ranging from 1.95 to 2.55 [22, 24,28,37] and the values are almost equivalent to BA and RHA. The bulk density of CCA was found as 800 kg/m³ by Ettu et al.[37]. Interestingly it is slightly lower than the specific gravity of FA. The results of SEM image, as shown in figure 4, had shown that the raw CCA are polygonal shape with various particle size distribution [21].

![SEM Image of CCA and calcined CCA](image)

(a) CCA (b) CCA calcined at 200°C for 4 hours, (c) CCA calcined at 400°C for 4 hours and d) CCA calcined at 600°C for 4 hours [21]

**Figure 4.** SEM Image of CCA and calcined CCA

5. Chemical compositions

The chemical compositions of CCA from various references are shown in Table 1. The EDS spectrum evaluation of calcined CCA at 650°C for 2 hours is shown in Figure 5, which shows the range of major
chemical compounds in CCA. The silica (SiO₂) content were noticed more than 50% and it varies up to a maximum of 79% [21]. However, ASTM C618 specified the requirement of sum of SiO₂ + Al₂O₃ + Fe₂O₃ should be more than or equal to 70% and all the references selected for review are satisfied this requirement [25,26]. Most of the CCA contains more than 10% CaO content which is essential for pozzolanic and cementitious properties [17]. These results had shown that CCA can be used as supplementary cementitious materials in concrete. Even though the chemical compositions are satisfied the ASTM C618 criteria, variations in chemical compositions are reported which could be attributed to the source of CCA and incineration process and later the pulverized methods employed by the various researchers. The research finding on the development of CCA blended factory made cement was reported after grinding along with OPC clinkers in a milling machine. The silica content of the CCA blended cements increased from 21.48% to 23.69% and the CaO content decreased from 63.65% to 61.46% when 25% CCA replacement respectively as shown in Figure 6 [14, 21]. This reduction of CaO content enhance the soundness of cement due to the reduction of free lime in the blended cement [23, 24]. The variations in major oxide compounds of CCA blended cement agrees with the literature evidences for the requirements of Portland pozzolana cement [27].

**Table 1** Chemical compositions of CCA from various sources

| References                  | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO   | MgO | Na₂O | K₂O | LOI |
|-----------------------------|------|-------|-------|-------|-----|------|-----|-----|
| ASTM C618 [26]              |      |       |       |       |     |      |     |     |
|                             | SiO₂ + Al₂O₃ + Fe₂O₃ > 70% | - |     |       | > 4% | ≤ 0.70 | - | ≤ 10% |
| Adesanya and Raheem [16]    | 66.38| 7.48  | 4.44  | 11.57 | 2.06| 0.41 | 4.92| -   |
| Udoeoy and Abubakar [35]    | 79.29| 0.98  | 0.64  | 8.97  | 0.98| 0.0003| 3.83| 10.8|
| Oluborode and Olofintuyi[28]| 56.39| 17.57 | 9.07  | 11.47 | 0.98| 0.19  | 1.98| -   |
| Oyebisi et al. [29]         | 64.50| 6.48  | 4.03  | 16.23 | 1.99| 0.90  | 1.05| 5.95|
| Komalpreet Singh [30]       | 64.56| 9.42  | 5.12  | 12.0  | 3.01| -     | -   | -   |
| Akila et al. [31]           | 67.33| 7.34  | 3.74  | 10.29 | 1.82| 0.39  | 4.20| -   |
| Desai[32]                   | 62.30| 6.25  | 4.40  | 10.57 | 1.86| 0.36  | 3.89| -   |
| P.Suwanmaneechoth [21]      | 63.91| 4.01  | 3.95  | 4.13  | 2.91| -     | 12.12|     |
| Nnochiri[33]                | 64.90| 10.79 | 4.75  | 10.24 | 2.08| 0.43  | 4.23|     |
6. Effect of CCA on fresh concrete properties

Almost majority of the research findings clearly stated that the slump cone test was employed for finding the workability of concrete however few authors were conducted compacting factor tests for finding the effect of CCA in workability of fresh concrete. The results showed that the slump value and compaction factor decreased when CCA content increased which indicated that concrete becomes less workable as the CCA percentage increases [24, 34]. Udoeyo and Abubakar [35] conducted investigation of 1:2:4: mix concrete with water cement ratio of 0.6 using the CCA replacement level of 0% to 30% and found that the average slump value was decreased gradually from 25 mm at 0% to 2 mm at 30% [23]. Adesanya [34] and Olufusi et al. [19] reported their results that the decreasing the slump value was attributed due to the increased size of irregular shape particle after heat treating more than 600°C and higher amount of silica presence in CCA. The trend line effect of OPC replacement by CCA on slump value and compaction factor is shown in Figure 7 and Figure 8 respectively [16, 35]. In contrast, Kamau et al [17] found that the addition of CCA with SiO₂ content of 38.8% resulting an increase of slump value. Further the author explained that the use of inferior chemical composition of the selected CCA with uncontrolled incineration process caused the increase in slump value.
7. Effect of CCA on hardened concrete properties

7.1. Density
Density of 10% CCA blended 28 days cured concrete was observed as 2373 kg/m³ [36] which is slightly lesser than the control concrete. Similar to other agro based SCMs, the density of CCA added concrete was decreasing due to the lower specific gravity and density of CCA particles. Further decrease in density was also observed with increasing curing periods due to the consumption of free lime.
obtained from hydration of cement during early periods and also the SiO2 portion of CCA. The density variation observed in 28 and 90 days by Kamau et al [17] are shown in Figure 9.

![Figure 9 Effect of CCA replacement on Density concrete [17]](image)

7.2 Compressive strength
Adesanya and Raheem (2009) examined the CCA blended cement concrete using 1:1 ½ : 3, 1:2:4 and 1:3:6 mix with w/c ratio of 0.5, 0.6 and 0.7 respectively and found that the compressive strength was more inferior to the control concrete at early curing periods [34]. After the prolonged curing, the compressive strength was improved significantly and had shown higher than the control concrete. The authors found that the substitution of 8% CCA found to be the optimum replacement level in all the mixes considered for investigation. The same trend was found in Ettu et al. investigation [37]. Based on the 90 days strength of OPC with CCA blended concrete, 10% CCA+90%OPC blended concrete had shown higher compressive strength than other proportions including the control concrete. The rate strength gain up to 21 days was found as very slow due to the slower rate of pozzolanic reaction. The strength development of concrete during the early period was exclusively due to the hydration of cement and supplementary cementitious materials like CCA are acting only filler materials and not contributing the development of strength. Further the creation of Ca(OH)2 in concrete during hydration react with the SiO2 presence in CCA and create secondary hydration products to contribute the strength development of later period [38, 39]. Price et al [24] found that CCA blended concrete was suitable based on the compressive strength up to 10% replacement level of CCA. However, all most all the literature evidences had clearly mentioned that the optimum replacement of CCA was restricted to 8 – 10% of OPC replacement with prolonged curing [23, 24, 34, 35]. The comparison of few the findings at 28 days curing are shown in Figure 10.
7.3 Tensile strength

The tensile strength of CCA blended concrete decreased with increasing OPC replacement [17, 20, 35]. Desai [32] was examined the splitting tensile strength of CCA blended concrete and concluded that the tensile strength was gradually reduced similar to the compressive strength at the age of 28 days when compared to the control concrete however an increasing trend was observed while increasing the curing period. The tensile strength variations observed from various literature are shown in Figure 11.

![Figure 11](image1.png)

**Figure 11** Effect of CCA replacement on tensile strength of concrete
7.4 Durability properties
Adesanya and Raheem [40] conducted water absorption and permeability investigation of CCA blended concrete in three different mix proportions as shown in Figure 12 and found decrease in water absorption up to 10% CCA substitution. The reduction of water absorption may be attributed to the pore filling effect of CCA before pozzolanic reaction starts. The CCA blended cement is contributed to improve the permeability properties of concrete [17]. The incorporation of CCA improves the resistance against chemical attack significantly in blended cement mortar. The loss of weight due to acid attack of CCA blended concrete was investigated by Adesanya and Raheem [38] and concluded that the presence of CCA reduces the loss of weight due to acid attack which indicates the improvement of impermeability of concrete and reduction in strength deterioration factor (SDF) when immersed in sodium sulphate solution. Kamau et al (2016) reported that the reduction of elongation of CCA specimen when immersed in Na₂SO₄ solution [17]. The filler effect of CCA during initial stage and the pozzolanic reaction in the later stage could be attributed the improvement in chemical attack.

8. Conclusions
After assessing the various research findings relating to substituting CCA as part of cement by various authors, the following conclusions are developed:

- In order to develop CCA as mineral admixture, the scraped corn cob should be calcinated at a temperature of 600° - 650°C for 5 hours to completely remove the carbonaceous material until a white substance was formed.
- An average particle size of 10 - 30 μm was able to develop after 650°C calcinating temperature with the specific gravity of 1.95 to 2.55.
- The chemical compositions of fully incinerated CCA was satisfied the limitations specified in ASTM C618 and possible to utilize as pozzolanic material similar to other agro based mineral admixtures.
- The results of all the literature evidenced that the workability was decreased due to the addition of CCA as cementitious material in concrete.
- There was reduction of mechanical properties such as density, compressive strength and tensile strength of concrete due to the substitution of more than 10% CSA.
- The improvement in durability properties of concrete with 10% CCA was observed from the literature and it can be concluded that the CCA can be used as supplementary cementitious material for making factory made cement or added as partial replacement material at work site.
- The proper awareness has to be encouraged for better utilization of CCA and also possible to convert as wealthy material in order to avoid the environmental threats.
**Figure 12** Effect of CCA replacement on water absorption of concrete [40]

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