Utilization of Corncob Ash as a Partial Replacement of Cement in Concrete: A Review

Margaret Damilola Oyewole[1], Modupe Cecilia Mewomo[1], and James Olaonipekun Toyin[1]

[1]Department of Construction Management and Quantity Surveying,
Durban University of Technology.

modupem@dut.ac.za

Abstract

In construction generally, cement is usually used in concrete as a binding material for construction purposes. The use of cement for concrete increases the emissions of carbon dioxide (CO_2). This emission poses a hazardous effect on humans, the environment, and the climate. Recently, there has been a move to produce lower CO_2 emissions in building projects. Using agricultural wastes such as corn cob ash (CCA) as supplementary cementitious materials (SCMs) can reduce CO_2 emission in concrete and decrease corn cob ending up in landfills. Therefore, this study systematically reviews studies in scientific databases to acquire data on these contexts. This study focused on CCA as a partial replacement for cement. The chemical and physical properties and their effect on concrete strength were investigated. Based on the contribution of scholars, it can be concluded that CCA could be used as a supplementary cementing material in concrete, from 5% to 10% of replacement without sacrificing the strength of the concrete. Also, using CCA helps solve environmental pollution caused by the inappropriate disposal of corn cob and improves concrete properties. Therefore, the findings from this study will help promote sustainability and environmental conservation.

Keywords

Pozzolan, Chemical Property, Physical Property, Sustainability, Compressive strength.

1. Introduction

Concrete is a commonly used binding material because of its strength, durability, and versatility. More than 90% of the buildings, roads, dams, retaining walls, and other structures are constructed of concrete (Patel et al., 2020), but cement; one of the constituents of concrete, consumes a large number of natural resources and energy and as well emits CO_2 during its production thereby contributing to greenhouse gas effect. Each ton of Portland cement produced emits nearly a ton of CO_2 into the atmosphere (Aprianti S, 2017). As a result, the need to protect the environment and conserve our resources has led researchers to discover agricultural and industrial wastes as cement replacement materials in concrete.

Industrial and agricultural wastes are waste generated from farming and industrial activities. According to the Food and Agriculture Organisation of the United Nations (FAO), the world maize production was 1.15 billion tonnes in 2019 (FAO, 2020). In 2018-2019, the United States was reported to be the largest maize producer, while South Africa ranks 10th as the African continent's sole producer of corn.

A million tonnes of agricultural and industrial waste are generated yearly, indicating that they are abundantly available. Therefore, the improper disposal of these wastes contributes to environmental degradation and health hazards. To solve this problem, researchers have begun to look for ways to reuse them and reduce cement's impacts simultaneously.

Some of the agricultural and industrial wastes which have been discovered by researchers as sustainable cementitious materials or partial replacements for cement in concrete production include rice husk ash (Khan et al., 2012), water lily ash (Anchondo-Perez et al., 2021), corncob ash (Olafusi & Olutoge, 2012) and (Adesanya & Raheem, 2010), Ground Granulated Blast Furnace Slag (GGBFS) (Oyebisi et al., 2021), fly ash (FA) (Nath & Sarker, 2011), coconut shell ash (Bheel et al., 2021) and many more. Abubakar et al. (2021) carried out an experimental investigation on the amount of Embodied Energy (EE) consumed and CO_2 emitted by concrete samples with cement partially replaced by CCA and those without CCA. The result revealed that the EE decreases as the CCA percentage increases. And at 20% CCA replacement with CCA, the CO_2 emission was reduced by 16.37% compared to the control concrete. This implies that the partial replacement of cement with CCA can help reduce energy consumption and CO_2 emission.

Therefore, this study seeks to review the suitability of CCA as a partial replacement for cement in concrete production as carried out by various researchers, its property, and the effect of CCA on concrete's fresh and hardened properties to promote sustainable concrete production.

2. Research Methodology

It is essential to build up a review based on past contributions of scholars in the scientific literature (Mewomo et al., 2021) as this will expose what has been covered and is yet to be covered and the future expectations in a particular study domain. Therefore, a systematic review of the past and current literature was adopted in this study to acquire data on the utilization of CCA as a partial replacement of cement in concrete. The collection of relevant academic publications related to this study's aim was obtained through Scopus and Google scholar. Inclusion and exclusion criteria were defined in searching and selecting literature pertinent to the study.

The following keywords were used: "Corn cob ash", "Corn cob Pozzolana", OR "Corn cob waste." Concise keywords are used to locate relevant articles distinctively, and 1,700 records were found. In selecting the relevant literature, inclusion and exclusion criteria were defined. The inclusion criteria were based on the practical applications of CCA as cement replacement in concrete production and its properties. At the same time, papers whose title and abstract do not correlate with the area of study and articles without the author(s) 's details and year of publication and those not written in English were excluded. After thoroughly screening the articles, 24 articles were included in the study. i.e n=24. The review process is summarized in Figure 1.

The paper is structured as follows; firstly, an introduction to the research background, followed by the methodology, the obtained findings and discussion and finally, the study's conclusions and recommendation.

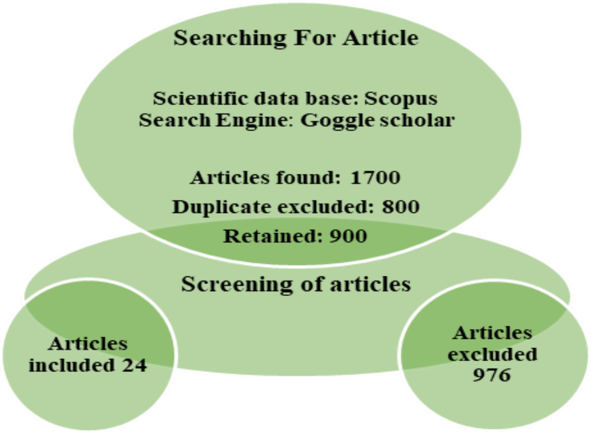

Fig. 1. A chart showing the review process.

3. Findings and Discussion

Corn, also known as maize, is a cereal crop grown worldwide as food and used to produce other products. The central cylindrical core of the corn on which the grains are attached is referred to as a corncob. Corn cob has been utilized so many ways in the construction industry; as an aggregate in the production of lightweight concrete masonry units (Cunha et al., 2015): as an alternative aggregate to produce lightweight concrete for non-structural purposes application purposes (Pinto et al., 2012) and (Helepciuc et al., 2017); as plant wastes in treatment of industrial wastewater (Ali et al., 2014), as a thermal insulation material (Paiva et al., 2012), etc. Chanadee and Chaiyarat (2016) revealed that corn cob is a good source of low-cost silicon powder when burnt in the air, an essential reactant for producing other advanced materials and many more.

Corn cob ash (CCA) material can be obtained by burning corn cob in an open field or using a kiln or furnace at a controlled temperature. Before the cobs are burnt, they are washed or dried to remove dirt and fungi. However, sometimes, they are broken into small pieces or ground before being burnt. According to Rithuparna et al. (2021), grinding the waste ash after burning increases the pozzolanic activity. Therefore, the pozzolanic characteristics of the ash obtained are influenced by the method employed in processing the ash.

In the research of Oyebisi et al. (2017), the researcher subjected the corncob to an uncontrolled (open) process of burning at a temperature of 200°C to 350°C. The ash from the uncontrolled burning process was black, indicating that the ash is of high carbon content. The resulting ash was burnt further in an industrial furnace under controlled conditions for 3hrs 15minutes until the temperature reached 650°C and kept constant for one hour to reduce the carbon content. The ash was further ground to a grain size of 90 microns. The chemical property of the ash was examined (see Table 1 for the result), and the ash was found to meet the specified requirement for class N pozzolans. Also, Chanadee and Chaiyarat (2016), in their study, burnt corn cob in the air at 600°C and 800°C temperatures. The CCA obtained at 600°C temperature looked dark grey because of the existing carbon, while the CCA at 800^0C temperature turned to milky white ash. The variation in the colour of the CCA results from the incineration time and temperature. Therefore, it can be concluded that the method employed in producing corn cob ash is essential and thus significantly influence CCA properties.

3. 1 Physical and chemical composition of corn cob ash

The physical properties of CCA include colour, size, moisture content, specific gravity, etc. In contrast, the chemical properties are the chemical constituents in the ashes, which determine the pozzolanic characteristics of the ash. CCA's physical and chemical properties depend on the burning method, time, and temperature. As carried out by researchers, CCA colour ranges from black to amorphous white. The black colour indicates the presence of excess carbon in the ash. Suwanmaneechot et al. (2015) investigated the heating temperature effect on CCA's physical, chemical, and engineering characteristics. They reported that the CCA heat treated from 200^0C to 600^0C for 4 hrs met the ASTM C618 requirement for natural pozzolans by having the sum of silicon oxide, aluminium oxide, and ferric oxide content ($SiO_2 + Al_2O_3 + Fe_2O_3$) as 72%. Also, the CCA contributes effectively to the performance of the concrete. Olafusi et al. (2018), in their research, burnt the corn cob at a temperature of 625^0C – 650^0C in a furnace for 4 to 5 hours. The ash obtained was greyish purple having a particle size of 75 microns. They reported that the oxide composition test revealed that the ash is pozzolanic as the sum of SiO_2+ Al_2O_3+ Fe_2O_3 is 64.58% which is greater than the ASTM specification for pozzolans. Tumba et al. (2018a) carried out a chemical analysis of CCA. The test revealed that CCA is a pozzolanic material as it met the pozzolan requirement stipulated by ASTM C618 and can be classified under class N natural pozzolans.

Table 1 presents CCA's physical and chemical composition as investigated by various authors. The specific gravity (SG) of CCA, as shown in table 1, ranges from 1.07 to 2.27. Still, according to the ASTM C618 specification for natural pozzolans, the specific gravity recommended for pozzolans ranges from 1.9 – to 2.44 (Neville, 1995). In addition, the chemical composition of CCA by various authors in Table 1 revealed that CCA has a high amount of silica, the constituent responsible for concrete strength. Furthermore, the variation in CCA's oxide composition in Table 1 is due to the source of the corn cob and the methods used by each author in processing the CCA.

Table 1 Physical and chemical composition of corn cob ash

Researchers	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**M_gO**	**SO_3**	**K_2O**	**Na_2O**	**LOI**	**SG**
Tumba et al. (2018a)	59.54	6.53	4.93	5.96	2.32	1.04	6.67	0.43	9.37	-
Ikponmwosa et al. (2015)	44.60	1.42	0.025	6.70	0.025	0.004	0.30	0.050	0.16	2.18
Kamau et al. (2016)	38.8	7.9	7.4	1.80	2.1	0.59	23.5	0.9	10.8	-
Abubakar et al. (2021)	66.4	7.5	4.4	11.6	2.1	1.1	4.9	0.4	-	2.27
Owolabi et al. (2015)	64.90	10.79	4.75	10.24	2.08	2.53	4.23	0.43	-	1.05
Oyebisi et al. (2017)	64.50	6.48	4.03	16.23	1.99	1.06	-	0.90	5.95	2.05
Suwanmaneechot et al. (2015)	63.91	4.01	3.95	4.13	2.91	0.88	12.12	-	-	-

3.2 Effect of corn cob ash on concretes workability

Concrete workability is the ease with which concrete is placed. Assefa (2019) investigated the suitability of CCA in producing lightweight concrete. Cement was replaced by CCA at 0% to 35 % at an interval of 5%. All the percentage replacement was tested for workability using the slump test. They observed that the slump value decreases as the percentage of cement replacement with CCA increases. They concluded that cement could be replaced by CCA up to 20% as the 20% slump value is still within the specified limit. Tumba et al. (2018a) studied the effect of sulphate and acid on concrete with cement replaced by CCA at 5% to 20% replacement levels. The workability of the self-compacting concrete was determined through slump tests, v-funnel, and blocking ratios. The slump and blocking ratios test result showed that the concrete workability reduces with increased CCA content. They reported that all the concrete mixes are within the range of acceptable values for the slump test except the blends with 15% and 20% CCA, while 5% replacement is suitable for the blocking ratio test. And for the V funnel test, the flow time increased as the CCA content increased. Ikponmwosa et al. (2015) partially replaced cement with CCA in concrete production from 10% to 40%. The concrete workability decreased from 79mm to 42mm. i.e., the slump changed from true to shear slump. They opined that the decrease in the workability was because of the large surface area of CCA, making the concrete demand more water to make it workable.

3.3 Effect of Corn Cob Ash on Strength Properties of Concrete

The compressive strength of concrete is determined by the quality and properties of aggregate and cement used, the concrete mix ratio, the water-cement ratio, the curing period and the handling process. Similarly, the content of CCA in a concrete mix as a partial substitute for cement influences the concrete's strength. Ikponmwosa et al. (2015) studied the strength properties of CCA concrete. The researchers investigated the effect of CCA on concrete compressive strength and flexural strength. The Cement was substituted with CCA at 0%, 10%, 20%, 30%, and 40%. The concrete mix ratio used was 1:2:4, with a water-cement ratio of 0.65. They observed that the optimum flexural and compressive strength occurred at 10% CCA content. The study recommended that concrete with 10% CCA content as a partial replacement of cement in concrete production should be used in low-cost housing construction. Price (2014) investigated the effect of the partial replacement of cement with CCA on concrete's thermal and mechanical characteristics. The cement was replaced at 0% to 20% at 5% intervals. They reported that at 90 days of curing, the compressive strength of the mortar increased to 10% replacement level and afterwards began to reduce above 10%. That is, 10% cement replacement with CCA was found to have the optimum strength (35.9Mpa). Tumba et al. (2018a) also replaced cement with CCA at 0% to 20%. The concrete cubes were cured in water, magnesium sulphate (MgSo4), and hydrochloric acid (HCl) for 7, 14, and 28 days. The result showed that 5% replacement is the optimum percentage replacement level as it offered better compressive strength. They further reported that the strength of the concrete increases with the curing age while the strength reduces as the percentage replacement of cement with CCA increases. In addition, the strength deterioration factor reduces as the CCA content increases. They opined that CCA improves the durability of concrete and can be used as a partial replacement for cement in self-compacting concrete. The result from the experimental investigation of Assefa (2019) revealed that the compressive strength of all the concrete reduced as the CCA increased. Still, the compressive strength of up to 15% replacement of cement with CCA falls within the requirement of C-25 concrete. Also, they reported that the cubes decreased in weight and became lighter as the percentage replacement of cement with CCA increased. In the study of Augustine and Michael (2016), cement was substituted with CCA at 0% to 25% in steps of 5%. The cubes were cured for 7 and 28 days and tested for compressive and flexural strength. The experimental result showed that the concrete strength decreased with an increase in the percentage of CCA content. The compressive strength of 0% CCA concrete at 28 days of curing was 27.04N/mm2 and decreased to 17.33N/mm^2 at 25% CCA. The flexural strength decreased from 10.79N/mm^2 for 0% per cent replacement to 5.72N/mm^2 for 25% replacement. They concluded that a 10% replacement of cement with CCA is optimum and suitable for building walls and other mild construction works. Singh et al. (2018) studied the effect of increased temperature on CCA concrete (M25 grade). Cement was replaced with CCA at 0%, 100%, 150%, 20% and 25%. The cast cubes were cured for 28 days and heated in a furnace at four different temperature levels, 150^{0}C to 600^{0}C, for 2hrs and tested. They detected that the compressive strength of all the percentage replacements increased up to 300^{0}C temperature and decreased above 300^{0}C temperature. They observed that the increase in strength up to 300^{0}C might be due to the increase in the hydration process, while the reduction of strength was due to the evaporation of the chemically bound water. They concluded that 10 % replacement at 330^{0}C temperature has the optimum strength. Anowai et al. (2020) partially replaced cement with CCA in varying percentages of 10%, 20% and 30% by weight in the production of Sandcrete Blocks. The Sandcrete block samples made with 10% and 20% replacements of OPC with CCA achieved compressive strengths of 4.05N/mm^2 and 2.65N/mm^2, which is within the specified by NIS:87 (2004) for sandcrete block. They recommended that OPC be partially replaced with 10% and 20% CCA in sandcrete block production for load-bearing and non-load-bearing walls, respectively. Shaikh et al. (2020) replaced cement with CCA at steps of 5% to 20%. The cubes were tested for strength at 28 days of curing. They reported that 5% replacement of cement with CCA has the maximum compressive strength (24Mpa) and split tensile strength. The compressive strength at 5% was 7% more than the control mix. And split tensile strength was 1.52% more than the control mix. Also, an experimental study was carried out by Owolabi et al. (2015) on the effect of corncob ash as a partial substitute for cement in concrete. The result revealed that at 5% cement replacement with CCA, the compressive strength was 21.44N/mm^2 at 28 days of curing. Bala et al. (2015) replaced cement with CCA in concrete production. Cubes of size 150x150x150mm were cast with cement and replaced with CCA from 0%-12% in steps of 3%. The cast cubes were tested for compressive strength at 28 days of curing. The 3% replacement for cement was found to be optimum, having a compressive strength of 29.4N/mm^2 at 28 days of curing, while the minimum strength (18.6N/mm2) was obtained at 12% replacement of cement with CCA. They recommended that superplasticizers and accelerators be used to improve the durability and strength properties of the concrete. Olafusi et al. (2018) studied CCA characteristics as pozzolans. They opined that the reduction of the compressive strength of concrete as CCA content increases could be due to the aggregation of CCA in the hardened concrete.

Table 2 presents various authors' optimum percentages of CCA for cement replacement. As recommended by the authors, the optimum ratio of CCA ranges from 3% to 15% for compressive strength and 10% for tensile strength. The recommendations of some of the authors revealed the advantages of CCA concrete. These include low-cost housing construction, lightweight concrete, self-compacting concrete, block production and building walls.

Table 2 Optimum percentage of corn cob ash by various authors

Author	**The optimum percentage of CCA**		**Recommendations**
	Compressive	Flexural/Tensile	
Ikponmwosa et al. (2015)	10%	10%	Suitable for low-cost housing construction
Price (2014)	10%	-	
Tumba et al. (2018b)	5%	-	self-compacting concrete
Assefa (2019)	15%		Suitable for Lightweight concrete
Augustine and Michael (2016)	10%	10%	suitable for building walls, beams and other mild construction works
Bala et al. (2015)	3%	-	
Anowai et al. (2020)	10-20%	-	concrete block production for load-bearing and non-load-bearing
Olafusi et al. (2018)	5%	-	
Shaikh et al. (2020)	5%	5%	
Owolabi et al. (2015)	5%	-	

4. Limitations and Further Research

The review is limited to CCA's physical and oxide composition and its effect on concrete's workability and strength properties. However, from the study, the tensile properties of CCA concrete were addressed by a few authors. Also, more investigation is needed to be carried out on the effect of corn cob from various sources, the effect of fineness on the pozzolanic characteristics, and the strength and durability properties. Furthermore, further research on CCA should address the microstructural properties of CCA concrete as it influences the strength and durability properties of concrete.

5. Conclusions

The use of corn cob ash as a partial replacement for cement was investigated by reviewing the literature. The properties of CCA and its effect on concrete strength and workability were studied. From the review, CCA is a suitable pozzolanic material for cement replacement in concrete production as its oxide composition satisfies the ASTM C618 requirement for pozzolans. However, the pozzolanic property of CCA is determined by the burning temperature, time and fineness. These properties, in turn, influence concrete strength. CCA concrete gains strength slowly, and at an earlier age, the strength is lower than that of ordinary Portland cement but increases later. Also, the strength increases with the curing period, a property of pozzolan as they gain strength with time. Furthermore, the workability of CCA concrete reduces as the CCA percentage increases, thereby requiring additional water for the concrete to become workable.

Therefore, from the review, it can be concluded that CCA could be used as a supplementary cementing material in concrete, from 5% to 10% replacement, without sacrificing the workability and strength properties of the concrete. Additionally, its utilization as cement replacement will help to enhance sustainable concrete production and promote environmental conservation.

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