Case Studies in Construction Materials 18 (2023) e01790

Contents lists available at ScienceDirect

Case Studies in Construction Materials

journal homepage: www.elsevier.com/locate/cscm

Case study

Evaluation of pozzolanic reactivity of maize straw ash as a binder supplement in concrete

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A R T I C L E I N F O

Keywords:
Maize straw ash
Pozzolanic activity
Pozzolanic reactivity
Agro-waste
Strength properties
Void filler

A B S T R A C T

Cementitious materials, irrespective of their sources, play a vital role in cement hydration reaction in concrete. Hence, it is critical to understand how each supplement affects the early and later age properties of concrete. Maize Straw Ash (MSA), being a material with minimal consideration as a pozzolan for partial replacement of cement, was evaluated based on different researcher's reports. A range of outcomes involving the use of maize straw ash as replacement materials in concrete were examined based on their impact on concrete in the early and later stages, and the findings were presented in addition to assisting in their future use. The impact of pozzolanic material on both mechanical and durability property were analysed, and how certain treatment methods influence the property of concrete in the early and later period. The data revealed that maize straw ash has comparable behaviour when given the same treatment technique before use, ability to increase strength over a long duration compared with other Agricultural waste (agro) materials, and likewise act as a void filler when concrete hardens to improve durability, with the usage of these materials for optimal strength not exceeding 20% replacement, shrinkage control not exceeding 30%, and 10–15% for good workability. At (500–800 °C calcination heat), the pozzolanic reaction produces good results.

1. Introduction

Cement production not only consumes a lot of energy and occurs at high temperatures (about 1500 °C), but it also releases harmful chemicals into the environment, including carbon dioxide (CO_2), carbon monoxide (CO), Sulphur dioxide (SO_2), and Nitrogen Oxides (NO_x) [1]. The high demand for cement for concrete is a major contributor to greenhouse emissions [2] which needs to be curtailed to have a safe environment.

The environmental problems emanating from cement production engineered research into complementary or alternative materials (partially or fully) to reduce cement consumption and CO_2 emissions. Many researchers have investigated the use of various agricultural wastes as supplementary for cement with individual agricultural waste materials showing unique performance with respect to percentage replacement [3].

The following agricultural wastes are utilised as a partial replacement for cement and with the stated optimal content: guinea corn husk ash, rice straw ash, wheat straw ash, elephant grass ash, nano sized sesame stalk ash (2.5%) and rice straw ashes (20%), rice husk

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https://doi.org/10.1016/j.cscm.2022.e01790
Received 22 October 2022; Received in revised form 1 December 2022; Accepted 18 December 2022
Available online 19 December 2022

Table 1
Physical properties of maize straw components from other researchers.

Researchers						Cobs				Leaves			Stalk			
	Specific Gravity	Fineness Modulus	Specific Surface Area (m^2/kg)	Colour	Moisture Content	Average Particle Size \vskip5 \hfill \hbox \rot90 {(μm)	Bulk Density (kg/m^3)	Porosity (%)	Moisture Content	Average Particle Size \vskip5 \hfill \hbox \rot90 {(μm)	Bulk Density (kg/m^3)	Porosity (%)	Moisture Content	Average Particle Size \vskip5 \hfill \hbox \rot90 {(μm)	Bulk Density (kg/m^3)	Porosity (%)
[12]	2.18				6.38	0.56	282.38	67.93	7.92	0.70	81.61	86.06	6.40	0.49	127.32	58.51
[13]	1.80	1.90					795									
[14]	1.95–2.55		272			10–30	800									
[15]					6.91 + 0.07	390.9										
[16]	3.49			Greyish Purple		75										
[17]	2.54															
[18]	2.027–2.102					699–725										

Source: Different Authors Physical Characteristics of Maize Straw Ash.

ash (20%) and olive waste ash (5%) [4], sugarcane bagasse ash (15%) and nano eggshell powder (5%) [5], palm leaf ash (20%) and rice straw ash (20%), cotton stalk ashes (10%) [6]. The concrete made using the materials demonstrated good compressive strength, and durability performance that is comparable to that of normal concrete at optimal percentage replacement. Maize straw ash as observed also aid improved strength development in concrete as its curing age increases. The need for improved cement replacement material necessitated the use of maize straw ash, which is a class of maize stalk, straw, and cob. Maize straw ash exhibits great pozzolanic properties with improved late strength and durability when used in concrete. The existing disposal method of maize straw is open air combustion of the leftover after livestock, rodents and cattle have fed over a period. In general, pozzolanic materials can activate hydrated calcium hydroxide ($Ca(OH)_2$) to produce hydrated calcium silicate (CSH-gel), an important component in the strength of hydrated cement mixes [7].

According to [8], chemical and physical characteristics alone do not provide the best results for pozzolanic material, other factors, including water-cement ratio, pozzolan type and content, cement type, age, water lowering admixtures must be taken into account through an experimental programme.

Mechanical compressive strength of coconut fibre improves after treatment by immersion in boiling water. Surface treatment with sodium hydroxide (NaOH), called mercerisation, of agricultural waste like pineapple fibre, coconut fibre, has shown great improvement in their chemical composition, compared to natural condition. However, immersion in potassium hydroxide (KOH) and Calcium hydroxide ($Ca(OH)_2$) produces inefficient improvement in mechanical properties [9].

The pozzolanic state of maize straw ash can be improved with acid leaching pre-treatment, as evidenced by [10], calcination within temperature below 800 °C for enhanced reactivity and sizing within 5–10 μm for highly reactive ash [4].

Also, different pozzolanic materials exhibit different mechanical and durability characteristics in concrete and improper application or preparation produces major setbacks like the high loss of ignition, reduced workability, and a strength activity index below 75% [11]. Even though he recorded low strength activity index, several scholars confirmed that pozzolans influenced the workability, compressive strength, and durability performance of concretes. In support of this, it was confirmed that pozzolanic activity extends beyond the 28-day compressive strength properties of supplementary cementitious materials.

This study aims to review the effect of the pozzolanic activity of maize straw ash from various sources on the mechanical and durability properties of concrete for building purposes. Also, the study is expected to provide information relating to the treatment that is adaptable for maize straw ash when used as a partial replacement for cement and the overall performance of concrete. The optimal content of maize straw ash and its merit compared to other ashes/pozzolans are explored in this study.

2. Methods

This study was carried out by reviewing several published research articles focusing on the use of ashes from agricultural wastes for the development of cementitious binders. The properties of the ashes were documented and also explored their potential influence on concrete. The reactivity of maize straw ash was explored and also compared with other related ashes.

Although research works focusing on the use of maize straw ash as a partial replacement of cement is somewhat limited, however, this study explored the trend of its use, its physical and chemical reactivity, pozzolanic reactivity, effect on mechanical and durability behaviour at early and late curing phase in concrete. Finally, the rate of strength gains relative to other researchers compared to individual control samples over their duration was evaluated using the compressive strength of concrete made utilising corn cob ash and corn stalk ash.

3. Physical and chemical composition of maize straw ash

3.1. Physical composition

The physical properties of maize straw ash concrete and mortar are greatly influenced by the physical characteristics of mineral admixtures, such as particle size, specific surface area, and specific gravity.

The particle size distribution, particle shape and pressing determine the porosity according to [19]. Table 1 above shows the physical characteristics of maize straw ash as reported by various researchers. The particle size can control the rate at which heat is transferred [15]. Particle size reduces with increasing burning time [20,21]. Maize straw ash after harvesting maize is usually wet, consequently requiring it to be dried through the sun and then ground before calcination to obtain the needed ash. The ash quality is usually a product of applied/calcined temperature [22] since an uncontrolled temperature will produce ash that is characterised by a crystalline phase which may reduce the benefits for use as supplementary material in concrete because it is best in the amorphous phase.

There is an increase in water absorption with rising maize straw ash, as well as a decrease in density as maize straw ash increases [23,24]. The addition of silica in pozzolanic materials causes increased water absorption [25], which is also corroborated by [26] that this further decreases the swelling index and improves mechanical strength and mortar flow.

It can be postulated that each component of the maize straw ash has a unique response when used in concrete, this is evident in the higher density record in cob ash compared to the leaves and stalks since the cob is more compact and likewise in other characteristics like the moisture content and porosity which are some of the factors that affect concrete workability and strength. Pozzolanic additives improve concrete’s chemical resistance to sulphate ion-containing solutions by reducing porosity and increasing density [27].

Table 2
Chemical composition of maize straw ash samples from previous researchers.

Chemical Constituent	[10] Natural	[10] Treated Treated	[30] Corn Straw Ash	[31] Corn Stalk	[32] Corn Cob	[11] Corn Cob	[33] Corn Cob Ash	Corn Cob Ash	[34] HSCA	[34] Ordinary RCA	[35] Corn Straw Ash	[36] Corn Stalk	[17] Corn Cob Ash	[16] CCA
SiO_2	62.5	94.2	67.392	64.80	66.36	38.8	67.41	63.73	35.51	38.33	38.49	37	67.23	59.66
Na_2O			0.195		0.41	0.9	0.9	0.1				0.25	0.37	0.34
MgO			1.944	5.06	2.06	2.1	4.56	2.06	9.77	5.01	5.72	7.35		1.68
Al_2O_3			0.771	9.42	7.48	7.9	15.08	6.31	0.29	0.22	3.98	2.37	6.34	4.92
P_2O_5	3.0	0.9	1.170				2.5	0	9.27	4.53	0.24			
K_2O	17.2	0.3	5.547	6.5	4.92	23.5	5.81	2.05	23.95	27.58	22.46	15		15.48
CaO	8.7	0.4	3.267	4.95	11.57	1.8	13.71	4.01	8.99	7.83	10.39	13	10.75	1.86
TiO_2	0.5	0.1	0.071				0.06	0			0.21			
MnO	0.5	–	0.250				0.03	0			2.07			0.01
Fe_2O_3	0.9	0.2	0.839	2.88	4.44	7.4	6.15	1.97	0.35	0.47	0.82	1.19	5.33	Nil
CuO			0.011											
ZnO			0.027											
Rb_2O			0.006											
SrO			0.011											
SO_3	2.6	1.6		0.65	1.07	0.6	1.24	1.07	2.65	1.72	3.59	1.32	1.04	
Cl				1.50					2.25	3.02	3.48			
ROx				4.24										
LOI	4.0	2.3		1.54		10.8	12.2	1.47	5.3	11.4	6.60	22.50		
Cr_2O_3											0.04			
$SiO_2 + Al_2O_3 + Fe_2O_3$	63.4	94.4	69.0	77.1	78.28	54.1	88.64	72.01	36.15	39.02	43.29	40.56	78.9	64.58

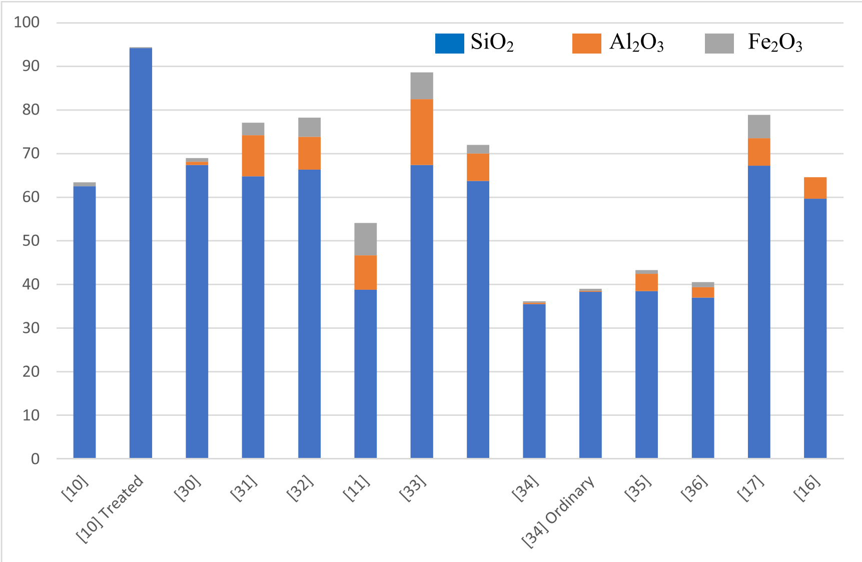

Fig. 1. Combination of the major pozzolanic compounds from different researchers.

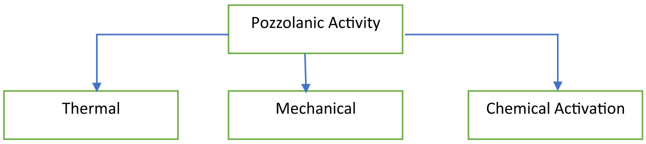

Fig. 2. Pozzolanic activation.

3.2. *Chemical composition*

Maize straw ash differs in chemical composition with different regions and soil profiles, the chemical composition in Table 2 depicted diversity in different areas and places with treatment levels from various researchers worldwide. This chemical composition is a major determinant in the pozzolanic reactivity of maize straw ash and other agro materials. According to [16], the source and processing technique of maize straw ash have an impact on its characterisation. Apart from diversity among various researchers, the availability of replacement material with awareness is crucial.

The main substance that governs pozzolanic activity is the amount of SiO_2 [22] which is rather high as seen in Table 2. The mixture of SiO_2, Al_2O_3, and Fe_2O_3 has a significant impact on the final strength. Materials with less than 70% (ASCE Requirement for pozzolan) in a total of the listed chemical combination demonstrate poor reactivity and produced lower compressive strength even at later ages. According to [28], treating maize straw removes components like K_2O and also increases the quantity of silicon oxide in ashes as seen in Fig. 1. Free lime can delay expansion and reduce the compressive strength of cement-based composites, which could seriously deteriorate the built environment. A surplus of sulphates causes an expansive effect by forming secondary ettringite, which can cause the matrix of a cement-based composite to disintegrate or crack and thereby lose strength [29].

4. Pozzolanic activity

The pozzolanic activity measures the degree of reaction over time or the rate of interaction between a pozzolan and Ca^{2+} or calcium hydroxide ($Ca(OH)_2$) in the presence of water [37].

There are many ways to study pozzolanic activity, but the two most common ones are impedance spectroscopy and measuring electrical conductivity [22]. Thermal, mechanical, and chemical activation are the three methods used to activate the pozzolanic activity of natural pozzolans [38] (Fig. 2). As seen in Fig. 2, each of the method affects the pozzolanic activity coupled with the processing duration compared to unprocessed pozollanic material.

The composition, microstructure, and pozzolanic properties of the material may be influenced by the combustion temperature. As a result of the investigation, it has been determined that various types of biomass ash respond differently to different combustion temperatures [39]. Maize straw ash exhibits different colours at distinctive calcination temperatures. Maize straw after drying is brown in colour, it produces grey and black ash, with blackish colour for calcination at 400 °C owing to the presence of unburnt/partial calcination and grey colour at temperature above 500 °C. The temperature necessary for the amorphous and crystalline states is what thermal activation is all about. Maize straw ash calcined at 500 °C for 2 h produces best pozzolanic activity with minimum amount of

Table 3
Mechanical properties of different straws from different researchers.

Researcher	Replacement Material	Compressive Strength	Tensile Strength	Flexural Strength	Treatment	Observation	Review
	Elephant Grass Ash						
[47]	20% Cement replacement with Elephant Grass Ash	35 N/mm^2 with control at 20% replacement			BET value increased from 42.1 m^2/g to 44.3 m^2/g and expressly to 72.6 m^2/g for hot washing & HCl leaching procedures respectively	Prior treatment improves SiO_2 content and decreases loss on Ignition by leaching of metallic oxides	No changes in compressive strength, Young's Modulus, and water absorption of 20% cement replacement with control
[48]	Rice Husk Ash ground at 180, 270 and 360 min used at 20% cement replacement	Lower Day 1–3 strengths compared to control by all samples, Higher day 28 – 180 days by all samples compared to control. 360 min ground sample has the highest compressive strength from day 7 till 180days above all and control.	20% replacement has a higher tensile strength on all days above control. 360 min grinding has the highest tensile strength	All samples have higher flexural strength than control on all days. The 360 min have the highest flexural strength	Ground sample in 180, 270 and 360 min.	Specimen with 360 min of grinding exhibits higher shrinkage than control. 180 min grinding has the lowest shrinkage compared to control	The addition of microfine particles would increase the drying shrinkage
[49]	Guinea Corn Husk Ash as partial replacement of cement at 5%, 10%, 14%, 20% and 25%	Lower compressive strength with the addition of maize husk ash above 5% level replacement.			Burning to 600 °C, allowed to cool and ground and sieved.		Optimal replacement level of 5–10%
[50]	Wheat straw ash as a partial replacement for sand at 3.6%, 7.3% and 10.9%	Comparatively to the control, the compressive strength increased by 9%, 35%, and 87%, respectively.	Increased tensile strength as wheat straw ash increased	Increase in flexural strength with replacement of wheat straw ash by 9%, 35% and 71% respectively			Transformation of large pores into small pores and reduction in the porosity
[20]	Sugarcane Bagasse Ash in replacement from 0% to 30% with increasing order of 5%	Compressive strength reduction with increasing sugarcane bagasse ash, with 50% strength reduction when 30% replacement is incorporated					10% replacement gives a compressive strength higher than control. 25% maximum replacement as peak when incorporating bagasse ash.

unburnt carbon [40]. By reducing the loss of ignition, thermal processing enhanced pozzolanic performance. Mechanical activation is concerned with the dissolution of reactive SiO_2 from the pozzolan, and chemical activation is concerned with the interaction with the solution of the chemical compound. It reduces the loss of ignition and increases the specific surface area to improve the strength and durability of blended cementitious systems [41]. Maize straw ash is chemically reactive most at 500 °C, as reported in Chapelle and Fratini tests concluded. It produces 159.5% higher than the prescribed standard minimum (330 mg/g) [40].

The chemical composition, chemical reactivity index, and mineralogical components of natural pozzolans all influence their pozzolanic activity [42].

4.1. Pozzolanic reaction

The pozzolanic reaction is a straightforward acid-base reaction using Calcium Hydroxide (Portlandite) and Silica Acid (Orthosilicic Acid), it is a lengthy procedure that takes around 28 days to finish [43].

In Chemical form,

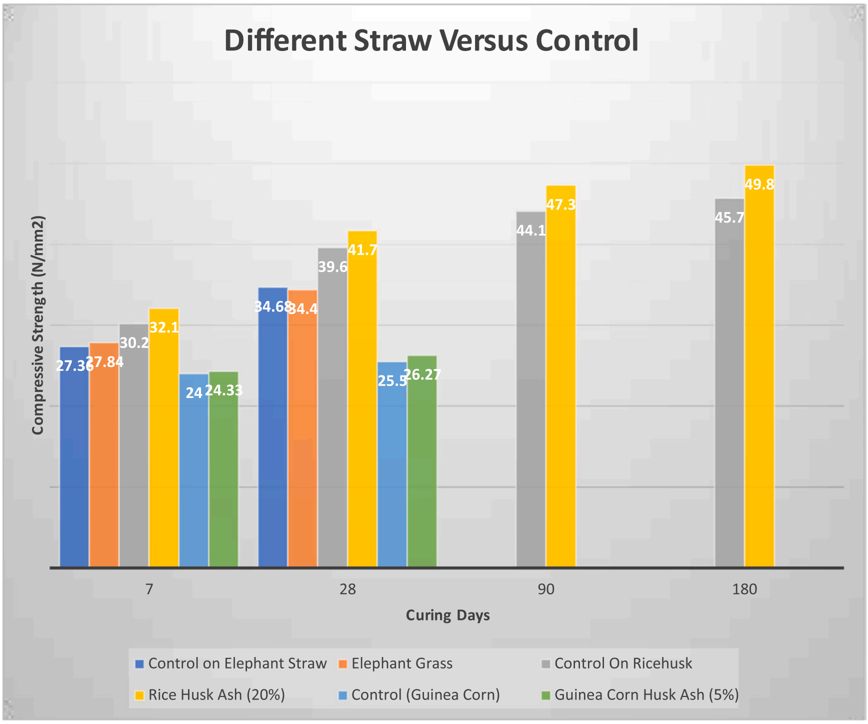

Fig. 3. Response of some agro materials on compressive strength with optimum replacement.

$Ca(OH)_2 + 2H_4SiO_4 = Ca(H_3SiO_4)_2 + 2H_2O$

Also written as:

CH + SH → C-S-H

Or.

$Ca(OH)_2 + 2(SiO_2 \cdot H_2O) = CaO \cdot 2SiO_2 \cdot 2H_2O + H_2O$

Calcium Silicate Hydrate has a lower density than portlandite and pure silica, which causes swelling of the reaction products, which is visible in poorly crystalline silica aggregates and can seriously damage mortar structures due to the resulting volumetric expansion, which often reduces sandcrete strength [23]. However, there is conclusive evidence that calcining pozzolanic material to an amorphous state (500–800 °C) [22] will avoid damage and transform amorphous silica into highly reactive silica, as long as the temperature does not exceed 900 °C, which generates non-reactive crystalline silica [10,33].

4.2. *Chemical reactivity*

The most important component in determining a material's pozzolanic potential is reactive silica. Its capacity to interact with readily available calcium hydroxide and produce cementitious hydration products [29]. A material with poor reactivity with cement mineralogical compound can be enhanced by utilising a very fine grain size and additives that can dissolve the reactive silica. Reactive silica, grain type, and specific surface area are all important factors in determining chemical reactivity [42].

4.3. *Microscopic analysis*

In big agglomeration form, maize straw ash with 20% substitution has the largest C-S-H production concentration, functioning as a bridge between the particles [43].

4.4. *Impact of pozzolanic activity on mechanical property of concrete*

4.4.1. *Influence on compressive strength*

The effect of pozzolanic activity is more pronounced on tensile strength than on compressive strength [34] attributed higher compressive strength due to the presence of Mg content, on the contrary [44], indicated that the presence of incompletely combusted straw ash has a detrimental influence on compressive strength. In support of this, incomplete combustion and pozzolanic activity will result in lower compressive strength than when a fully combusted ash or highly reactive ash is used within 28 days. This justified the lower strength of 7 days and higher strength of both 28 and 180 days compressive strength by Aksoğan, Binici [36]. The resulting compressive strength at the early stage is determined by the reactivity of the pozzolan, and the quantity of maize straw ash added. Kamau, Ahmed [45] result on compressive strength of partial replacement of 5% has a lower compressive strength when compared to both the control and 10% replacement which is evidence of lower reactivity of the pozzolanic material. When early-stage high compressive strength is required, highly reactive pozzolan will be required but when the immediate strength is not of importance, a low reactive pozzolan can be a substitute, provided the maize straw ash quantity is within 20% of cement.

4.4.2. Influence on hydration heat

Pozzolanic activity lowers hydration heat by replacing cement with pozzolanic activity, which increases the produced heat during hydration [46] (Table 3).

Researchers concluded that agro materials with pozzolanic properties can be used as a partial replacement for cement. As observed in Table 3, Individual agro material responds differently with replacement percentage. The use of individual agro materials and their compressive strength within 28 days show they can improve the overall strength of concrete. As seen in Fig. 3, There is always a percentage replacement that produces better concrete strength than the control. However, there is a need for understanding the behaviour of individual agro material before its usage. Rice husk ash can improve strength when the replacement is within 20%, unlike guinea corn ash which can only replace 5% of cement in concrete for better strength.

4.5. Impact of pozzolanic activity on durability

Durability refers to a material's capacity to withstand the impacts of extensive usage, drying, wetting, heating, freezing, thawing, corrosion, oxidation, and volatilisation over an extended period without substantial degradation [51]. Maize straw ash with high silica content exhibits great performance over a long time.

4.5.1. Action on chemical attack and resistance to freeze-thaw

The addition of maize straw ash improves resistance against abrasion [52], chemical attack and acid permeability but with a reduction in compressive strength. Due to changes in composition and structure, the influence on sulphate erosion resistance of cement-based materials varies. The addition of maize straw ash might boost calcium hydroxide consumption by interacting with the sulphate ion. And, when paired with the preceding data, it could be determined that additional aluminate products induced expansion and cracking, resulting in a drop in compressive strength. With the addition of calcined ash and aluminate products, the peak intensity of ettringite rose. When 4% of the cement was replaced, the cement was more resistant to sulphate attack and had greater compressive strength than the control. Under sulphate assault, maize straw ash enhances the composition and compactness of cement-based products to some amount [31]. As 2.5% and 5% of the cement was substituted with maize straw ash, the concrete was more resistant to repeated freeze-thaw cycles and hydrochloric acid [18]. The increase in ash content significantly increases sodium sulphate resistance of concrete [52]. The strength deterioration factor can be improved when maize straw ash is submerged in Na_2SO_4 solution thereby reducing its elongation even though there is weight loss after a chemical attack [14].

4.5.2. Permeability

The ease and ability of gas or fluid to pass through concrete or the rate at which water under pressure can flow through voids of concrete. Maize straw ash exhibits a good pozzolanic reaction in filling up pores with gel produced from secondary hydration of cement. The coefficient of water absorption of CCA specimens was 8% lower than that of control specimens at 7.5% replacement but was 126% higher at 30% replacement [11]. The decrease in water absorption up to 10% substitution is due to the pore-filling action before the onset of pozzolanic reactivity [14].

4.5.3. Drying shrinkage

Drying shrinkage for specimens under natural dry conditions (0 per cent replacement) is faster in the first 3–7 days, which is the strength development period. However, because the hydration and pozzolanic processes are completed, 20 per cent substitution with maize straw ash has the largest drying shrinkage, consuming the most water and creating the most C-S-H colloid. The higher content of maize straw ash increases its affinity for water. The quantity of maize straw ash greatly affects the concrete produced and the demand for water [43].

4.6. Influence of chemical treatment on pozzolanic reactivity using sodium hydroxide and sodium silicate

Chemical treatment decreases loss on ignition and drastically reduced K_2O content by 21%. Reaction with NaOH shows that there is an increase in silica dissolution, but this is only applicable provided the concentration of NaOH does not exceed 3 mol/L. Simultaneously, as the concentration of Sodium Hydroxide solution increases, so does the sodium silicate modulus.

As the concentration of the NaOH solution increased, the amount of alkali that came into contact with the silica from the MSA increased, increasing the rate of silica dissolution; however, the sodium silicate modulus decreased as a result of the rise in alkali content [30]. It will be challenging to chemically process silica particles in large quantities [53]. However, in agreement with [16], the treatment impact is not evident when pozzolanic activity is measured over a short period since it is a reaction that takes time to achieve and is largely reliant on the reactive state of the utilised pozzolan [54].

Other treatment methods include water soaked, alkali treated (NaOH, CaOH or KOH), bleaching by hydrogen peroxide, NaClO and acid hydrolysis using sulphuric acid and HCl, enzyme treated and Tetramethyl ammonium hydroxide (TMAOH) post treated [55].

4.6.1. Pozzolanic activity index

The pozzolanic activity which is the ability of the material to react with calcium hydroxide is highly affected by grinding, thermal processing, and chemical treatment.

Grinding agro waste ash increases the pozzolanic activity index by more than 75%, leading to a 50% increase in compressive strength [41]. According to [56], the pozzolanic activity index of Maize Straw Ash is 96.8%, CaO reduction is 93.2%, and Chapelle activity is 856.3%, with an ideal burning temperature of 500 °C.

The indication of appropriate maize straw ash burning enhances the chemical composition and percentage composition of SiO_2, Al_2O_3, and Fe_2O_3 in a pozzolan, which becomes globally acceptable when larger than 70% [33].

4.6.2. Electrical conductivity of maize straw ash pozzolan

The electrical conductivity of pozzolan shows the behaviour of its reaction between amorphous silica and CH to give C-S-H gels.

Ashes from agricultural waste should be burned at a temperature between 500 and 700 °C, and thermal processing increased the effectiveness of pozzolanic reactions by reducing ignition loss. Chemical treatment enhanced the strength and durability of blended cementitious systems by increasing the specific surface area of agricultural waste and decreasing the loss of ignition.

Pozzolanic action takes a long time to complete; to establish the expected strength, the curing age must be a minimum of 56 days. The resulting ash is partially replaced in cement at 5% intervals to get the desired strength. After 96 days, the resultant strength offers an excellent report that comprises the early strength and the pozzolanic activity of substituted ash.

5. Macrostructural and mechanical influence of maize straw ash on concrete

5.1. Physical parameters

According to [57] on test for porosity between the cotton plant ash, mustard plant ash, pigeon pea plant ash, and maize plant ash shows that maize plant ash had the highest porosity. The porosity of a material rises as the amount of trapped air grows; in the instance of maize plant ash, the larger porosity (94.34%) contributed to a stronger tendency to adsorb water.

When maize straw ash is used as a partial replacement of cement in concrete, its effect on fineness, soundness, consistency, the initial setting, final setting, and residue on sieve sizes vary, depending on the quantity applied.

The fineness tends to reduce when maize straw ash quantity increases and increases when maize straw ash quantity reduces. The soundness increases with increasing maize straw ash content and vis-versa. The consistency tends to be the opposite as it was observed that an increase in straw ash content reduces the consistency. The initial and final setting time increases with maize straw ash and likewise. The residue on 45 μm increases with maize straw ash increase [32].

5.2. Effect of maize straw ash on radiation shielding effect

Depending on the reactivity state of the pozzolan, when the pozzolan has low reactivity, the compressive strength after 28 days is inadequate. When employing agricultural material, the predicted strength is highly dependent on the pozzolanic reactivity which is often determined by the amount of silica and Calcium Oxide in the material.

There is a progressive loss of strength when compared to the control, however, maize straw ash is unusual in that it has a higher strength to lower density ratio than conventional concrete [23]. Pozzolanic concrete improves compressive strength in two ways: as a filler by boosting the radiation shielding effect, resulting in stronger concrete when filling voids, and as a consequence of the pozzolanic reaction [36]. As a result, there will be a reduction in cement demand or usage at that time [58]. According to [43], 20% replacement with maize straw ash produced a high compressive strength at 28days but 10% replacement produces the highest shear strength but lesser than the control.

Maize straw ash incorporated without a blend of other agro material shows the same result as described by [23] on a mix of rice straw ash and maize straw ash. The chemical composition of the current alumina and silica in the material influences the strength development.

5.3. Effect of maize straw ash on density

An increase in ash content leads to a decrease in the density of concrete produced [59]. Because CSH is denser than portlandite and pure silica, an alkali-silica reaction can develop in concrete over time between the alkaline cement pore water and the weakly crystalline silica aggregates [58]. A 10% replacement within 7 and 28 days shows a decrease in density by 1.2% and 3.2% respectively.

5.3.1. Workability

The amount of water required for satisfactory workability rises when maize straw ash is present. The application of maize straw ash to concrete produces stiffer concrete, and the bigger the increment, the stiffer it becomes [60]. This means that workability reduces

Table 4
Maximum strength obtained by some researchers when using maize straw ash as a partial replacement of cement.

Author	Days	Percent	Control	1%	3%	4%	5%	6%	8%	9%	10%	12%	Method used
	3	4	32			32.5		30.5	25				
[63]	7	6	47			38		41	36				Computer Simulation
	28	8	55			49		50.5	50.5				
[64]	7	9	22.35							25.08		26.8	
	28	12	33.37							37.44		38	
[65]	3	5	15				16				18		
	7	10	23				24				26		
	28		28.5				32.5				34		
[66]	7	5	20.7								17.8		
	28	10	26.2								23.1		
	56	15	25.3								26.9		
	90		27.7								28.3		
[34]	7	1	41.3	38.9							39.6		
	28	3	43.55	47.1							41.3		High Silica Corn Ash
	56	10	46.5	47.5							43.6		
[67]	3		34.9		34								
	28		42.5		36								
	112		54		45.5								
[68]	7	10	16.22								14.7		
	28		24.04								22.7		
	56		27.76								27.2		
	90		34.06								36.1		

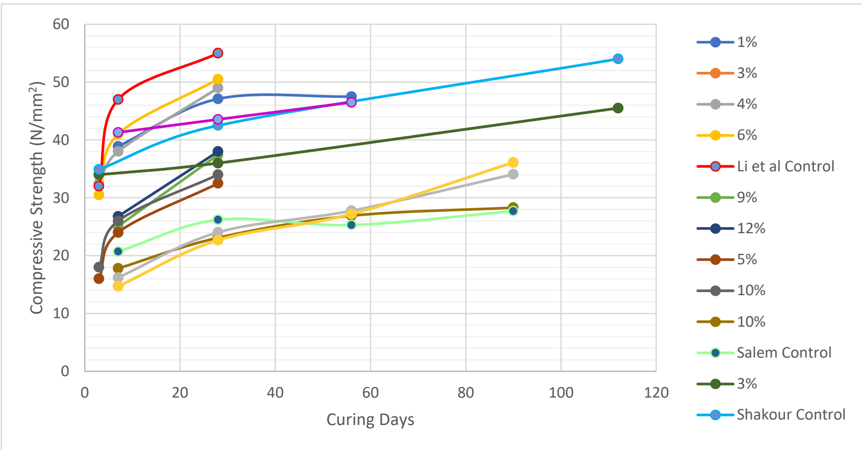

Fig. 4. Maize straw ash with varying percentages of cement replacement on compressive strength.

with increasing silica content and the concrete slump decreased as the maize cob ash percentage increases [61].

As the ratio of ternary cementitious materials (TCM) grew, the workability of fresh concrete declined. The findings of this study showed that the agricultural materials studied could work well as a binder in cementitious composites [59]. A contrary result was discovered by [11], that an increase in workability with increasing maize straw ash. The reason for different results can be deduced from the replacement quantity. It was discovered that the content of Silica in the used maize straw ash has lower than 40% and the combination of the aluminate and ferrous with silica content has lower than acceptable 70% value.

5.4. Effect of maize straw ash on setting time

With an increase in maize straw ash, the setting time of concrete containing that material increases [62]. This will shorten the time it takes to transport ready-mixed concrete over long distances before use [33].

5.5. Effect of maize straw ash on compressive strength

Corn Straw Ash produces better concrete than the control over a longer period because its strength increases with time despite having a lower initial strength. Table 4 depicts the rate at which compressive strength increases when maize straw ash is added. Maize straw ash, when used in the right amount, over time can produce better concrete. In 65 days or more, 10% replacement becomes

Table 5
Impact of maize straw ash and maize cob ash on mechanical property of concrete.

Author	Material and Sandcrete Percent Reduction	Application	Water Cement Ratio	Mix Ratio	Processing of Materials	Max Curing Days
[23]	Maize Straw Ash and Rice Husk Ash	Sandcrete - 40%	0.5	1:6	Sun Drying – Pre-Burning – Burning – Grinding - Sieving	28
[35]	Maize Straw Ash and Palm Oil Fuel Ash	0–30% POFA 0–30% MSA	0.58			56
[43]	Maize Stalk Fly Ash in the preparation of Cemented Coal Ganguage Backfill	0, 10, 20, 30 and 40 20% - Highest Compressive Strength 10% - Highest Shear Strength	0.55		Maize Straw Fly Ash was Spread out. - Oven Dried (80°C for 24 h)	28 Drying Shrinkage (180days)
[24]	Maize Stalk Ash for paving stones	0–25% 10% - Increased strength compared to control at 28days Density - decreased with increasing ash content Water absorption - rate increased with maize stalk ash Abrasion Resistance – increased with an increasing amount of corn stalk ash				10% Maize Stalk Ash is recommended and cured for 28d for higher strength
[49]	Guinea Corn Husk Ash	0%, 5%, 10%, 15%, 20% and 25% by weight replacement for cement	0.65	1:2:4		5–10% replacement is recommended with 5% strength greater than the control sample.
[69]	Guinea Corn Husk Ash as a partial replacement of cement, on mechanical properties of lateritic concrete	20% 0–10% gives an increase in workability, increase in GCHA reduces porosity	0.3–0.45 decreases slump height 0.45 – 0.7 increases slump height. 10% - Optimum	5 mm fine aggregate size and 10 mm coarse aggregate size	Burning at 650 °C	20% - gives optimal strength of 18.78 N/mm^2 at 0.51water/cement ratio which is higher than control of 17.61 N/mm^2 at 0.7 water/cement ratio.
[70]	Corn husk Ash	0,5,10,15,20% and 25% replacement for stabilisation of soil bricks			SiO_2, Al_2O_3 and Fe_2O_3 are in small quantities, (Uncontrolled combustion.)	20% ash has the highest compressive strength. 5% for maximum dry density and 10% for highest optimum moisture content.
[33]	Corn Cob Ash	Less than 20% recommendation for untreated to prevent porous and permeable concrete compared to control. The presence of Potassium oxide negatively affects cement hydration thereby producing low compressive strength and high chloride ion penetration.				Improved durability
[14]	Corn Cob Ash	Partial replacement of cement from 0% to 30% replacement	0.6	1:2:4		A gradual reduction in a slump from 25 mm to 2 mm at 0–30% replacement, respectively.
[10]	Maize straw ash on mortars	Partial replacement with and without treatment using citric acid at room temperature for 48 h followed by washing using deionized water to remove acid Increased compressive strength result achieved.			Treatment increases amorphous silica concentration.	7 and 28days An increase in specific surface area is associated with K_2O removal by acid leaching
[71]	Maize Straw Ash	Replacement of Cemented coal gangue backfill with maize straw ash with different amounts of 0%, 10%, 20%, 30% and 40%.	0.55			There is an initial decrease in compressive strength then an increase with substitution amount and 40% exhibits the highest uniaxial compressive strength.
[72]	Maize Cob Ash		0.44–0.56			

(continued on next page)

Table 5 (*continued*)

Author	Material and Sandcrete Percent Reduction	Application	Water Cement Ratio	Mix Ratio	Processing of Materials	Max Curing Days
		Replacement of cement at 0–20% by weight				Compressive strength, flexural strength, and tensile strength all declined as maize cob ash content increased.
[68]	Corn Cob Ash	Partial Replacement of cement with 0, 10,20, and 30 of corn cob ash	0.4–0.55			10% replacement has higher strength than control at 90days of curing.
[60]	Corn Cob Ash	Partial replacement of cement in 0%, 4%, 8%, and 12% by weight for M20 concrete	0.55	M20		Concrete becomes stiff with an increase in corn cob ash, compressive strength increases with curing age.

stronger than the control, as seen in Table 4, most of the researcher's 10% replacement has better strength compared to the control. The percentage replacement, which is established by the pozzolanic activity of the used maize straw ash, has a significant impact on the increase in strength. What gives the substance its increased strength is the later occurring pozzolanic reactivity of the ash from maize straw as seen in Fig. 4. On the other hand [24], found that the compressive strength decreased after 56 days as compared to the outcome at 28 days. Even though there was no record of the amount of water used, he hypothesised that this would be due to the pozzolanic activity of maize stalk ash, which might have caused a pore in the concrete and led to lesser strength because the water would have evaporated.

In all samples, the strength of maize straw ash concrete is lower than control, according to Fig. 4, although it is still within acceptable limits. As the strength increases over time, the concrete has a high compressive strength. The increase in strength is attributed by the delayed pozzolanic properties of maize straw ash.

For the use of maize straw ash and corn cob ash, used agricultural material must have pozzolanic activity in addition to meeting the requirement of 70% SiO_2, Al_2O_3, and Fe_2O_3. Table 5's data from most researchers demonstrate that good concrete can be made from maize straw ash, particularly when the water/cement ratio is between 0.45 and 0.55, as reported by most researchers, and at the same time, the partial replacement is within 10%. Better concrete is made when maize straw ash is ground for a longer period [53].

6. Conclusion and recommendation

The problems of increasing cost of construction materials and environmental pollution issues emanating from poor waste management are part of the motivations for research development for sustainability. The current study focused on the evaluation of pozzolanic reactivity of maize straw ash as a binder supplement in on concrete. Several research articles relating to the use of maize straw ash in cementitious composite were reviewed and analyzed. The following conclusions were drawn form the study:

i. The use of agro waste for cementitious applications can be considered when the total dominant oxides (Silicon Oxide, Aluminium Oxide, and Iron Oxide) together is 70% or above. Overall, it has been shown that the pozzolanic reactivity is majorly affected by calcination, grinding, sieving and treatment with chemicals. NaOH of 2% (w/v) at 120 °C and Citric acid improves the Silica Content and thereby produce better concrete.
ii. The strength development at maturity (maximum curing) is associated with the level of reactivity of maize straw ash. However, low reactivity will not be a concern if early strength of concrete is not important. The use of maize straw ash can aid long-term strength performance in concrete. This will provide greater strength to help the concrete regain its lost integrity over time and the gel produced by maize straw ash will fill up pores produced with time which will improve the concrete produced at a later age rather than creating a void that could have reduced the integrity of the concrete at later age.
iii. In terms of water absorption in concrete containing maize straw ash, a mix ratio of 1:1.5:3 (M20) and 1:2:4 (M15) exhibited optimal water absorption rate with a 10% maize straw ash content, while a mix ratio of 1:3:6 (M10) can accommodate 15% replacement for optimal performance of concrete. The recommendation of 10% gives a stronger strength over a longer period when used without treatment or consideration of high silica ash.
iv. Apart from the major role of the chemical composition in pozzolanic reactivity, the presence of the following contaminants like K_2O, and P_2O_5 will greatly reduce the strength of concrete produced but can be removed with chemical treatment. However, excessive and unreactive CaO will reduce concrete strength produced.
v. Future studies should focus on maize straw ash's potential for use in areas with salting issues, as well as its potential to stabilise laterite soil and clay with blended cement and prevent concrete cracking.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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