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Sustainable Concrete Production: Utilizing Cow Dung Ash and Corn Stalk Ash as Eco-Friendly Alternatives

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Abstract

This study aims to determine whether it is feasible to replace conventional materials used in manufacturing concrete with waste materials, namely cow dung ash and corn stalk ash. This study proposes to assess the possibility of using these agricultural by-products to improve the sustainability of concrete while simultaneously tackling the environmental issues related to the manufacture of conventional concrete. The research aims to assess the mechanical qualities, optimize the mix proportions, and examine the ecological implications of using these substitute materials. This research aims to mitigate environmental challenges like carbon dioxide emissions, resource depletion, and the accumulation of agricultural waste by combining agricultural waste and lowering dependency on traditional cement. The study investigates the use of cow dung ash (CDA) and corn stalk ash (CSA) as alternatives for conventional Portland cement (OPC) in mortar mixes at varying quantities, ranging from 5% to 25% CDA and 2.5% to 10% CSA. Chemical composition reveals that CDA and CSA predominantly comprise O, Mg, Al, Si, P, K, and Ca. The workability, hardened characteristics, and microstructure of CDA and CSA were assessed. Increasing CDA and CSA percentages reduced mortar workability; nevertheless, replacing 8% to 10% CDA and 7.5% CSA maintained compressive, tensile, and flexural strengths comparable to control mixes. However, more significant CDA and CSA proportions resulted in lower mortar strength. For example, 10% CDA-enriched mortar had a compressive strength of 31.77 N/mm^2, a tensile strength of 3.42 N/mm^2, and a flexural strength of 3.61 N/mm^2, whereas 7.5% CSA-enriched mortar had a compressive strength of 28.4 N/mm^2, a tensile strength of 3.04 N/mm^2, and a flexural strength of 3.7 N/mm^2. According to the findings, CDA and CSA can replace OPC by up to 10% and 7.5% in mortar manufacturing, making cementitious material alternatives viable.

Keywords: Cow Dung Ash; Corn Stalk Ash; Strength; Microstructural.

1. Introduction

Construction and building industries, mainly concrete, are crucial for economic development, particularly in emerging markets, but their reliance on natural resources contributes significantly to global CO_2 emissions [1]. Concrete production for road, bridge, tunnel, residential, dam, and flood defenses is 14 billion cubic meters annually, with Portland cement being the primary binder, contributing 8% to global CO_2 emissions [2– 4]. In response, Cement and concrete companies aim to reduce CO_2 emissions by 25% by 2030, aligning with the Paris Agreement's goal of limiting global warming to 1.5°C [2].

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Decreasing carbon dioxide emissions from the cement industry can be achieved through an ecological circle that converts waste materials into valuable commodities. This method conserves natural resources, encourages waste diversion, and supports environmentally sustainable waste management techniques. Studies have explored the viability of supplementary cementitious materials from industrial and agricultural leftovers [5–11]. Waste materials replace traditional concrete manufacturing ingredients with waste resources like recycled aggregates and coconut fibers [12–18]. The concrete industry can reduce its environmental impact by using agricultural waste, such as CDA and CSA, as construction materials. Population growth has increased agricultural waste, which is non-biodegradable and persistent. These materials are easily accessible and economically viable, making them an attractive option for sustainable concrete production. Landfills holding agricultural waste pose contamination hazards, encouraging further study of their use in cement production. Table 1 shows the properties of CSA and CDA.

Table 1. Properties of corn stalk ash and cow dung ash

CSA	CDA
Produced through the burning of stalks	Made by successfully burning dried dung cakes
Improves thermal insulation, strength, and durability	Enhances strength, resistance to abrasion, and resistance to freeze-thaw
It is quickly produced from burning corn stalks.	They are easily obtained from cows' dung.
Good filler material for pavements	Enhances structural quality with pozzolana properties
Relatively dense material	Bulky in nature
Light in weight	Large ash content
Eco-friendly material	Excellent substitute for cement
Improves radiation resistance property of concrete	Lower combustion rate

The literature suggests that dung can enhance the workability and durability of concrete and serve as an additional binder [19]. Researchers investigated the properties of CDA in pozzolana in cement paste and mortar. They sun-dried and calcined cow dung at 400-500ºC. Adding CDA to blended cement paste extended the setting time and increased standard consistency. However, as the ash content and curing time increased, the compressive strength of the modified concrete decreased. Nonetheless, it was concluded that there's no significant disparity between standard concrete and concrete with up to 15% CDA [20].

The study investigated the effectiveness of CDA and glass fiber in concrete. It was found that a mixture containing 8% CDA and 0.5% glass fiber exhibited the highest compressive strengths after 28 days. Additionally, CDA was noted for its lightweight properties, making it a feasible building material [21]. Subsequent research examined CDA concrete's compressive strength with replacement levels ranging from 5% to 30%, showing increased strength with higher replacement levels. However, while CDA performed well at a 10% replacement rate for flooring or structural elements, its utility for applications subjected to high structural loads was limited. Nevertheless, the study proposed CDA as a promising option for sustainable concrete production [22].

Studies investigated CDA and wood ash as additives in fly ash bricks. Results indicated that a 5% replacement of these components enhanced compressive strength, leading to long-term improvements in fly ash brick properties [23]. Additionally, the research explored CDA's potential as a cement substitute in concrete, finding that a 10% replacement rate resulted in the highest observed compressive strength [24].

The research discussed in Venkatasubramanian et al. [25] explores the properties of CDA and coconut fiber on concrete strength. Substituting coconut fiber and CDA in concrete has been found to enhance strength by 55% to 70%, offering cost-effectiveness and waste reduction benefits while preserving environmental integrity. Moreover, in Ramachandran et al. [26], CDA was examined as a supplemental cementitious material for split and compressive strength. Optimal results were observed with a 15% replacement rate after 28 days of water curing. CDA-modified concrete exhibits lower permeability, improved alkalinity retention, and more excellent thermal stability than regular concrete, attributed to its higher silica concentration, as described in Dhaka & Roy [27].

In Ramachandran et al. [28], the utilization of CDA and fly ash in concrete production was investigated, highlighting their potential to reduce CO_2 emissions from cement manufacturing and address solid waste disposal concerns. Concrete exposed to freshwater was examined, emphasizing the importance of compressive strength, split tensile strength, and pH levels. X-ray diffraction and field emission scanning electron microscope analyses revealed that concrete with 15% CDA displayed higher quantities of calcium silicate hydrate, cementitious properties, and a lower bacterial density than ordinary concrete. An experimental investigation on entirely replacing alumina, lime, and CDA for cement concluded that 10 to 20% CDA could serve as a complete cement substitute in concrete [29]. However, integrating CDA necessitated increased water content, leading to a gradual reaction with concrete post-casting. Lime was found to retain and release water during curing. Additionally, a study on potentially using CDA to filter biodiesel from waste oil identified the optimal purification concentration using chemometric analysis, comparing CDA's Fourier transform infrared transmission spectral properties to those of treated water. CDA exhibited structural features akin to current water-based biodiesel purification technologies, rendering it an efficient adsorbent for biodiesel purification through typical water washing technology [30].

In Magudeaswaran & AS [31] study, the use of CDA in brick-making and concrete was investigated. In concrete, varying amounts of 10%, 20%, and 30% CDA were tested, with 10% proving the most effective. Additionally, researchers explored using goat dung ash and CDA as cementitious materials to modify brick characteristics. The study on CDA-stabilized earth bricks revealed that while compressive strength significantly increased with 20% CDA, it decreased notably after 10 minutes of water immersion, even at maximum replacement levels. It was recommended to adhere to building specifications to prevent prolonged direct contact between CDA-stabilized earth bricks and rainwater. The dry and wet compressive strengths of bricks stabilized with 20% CDA were measured at 6.64 and 2.27 N/mm², respectively [32]. In Vishwakarma & Ramachandran [33], the investigation focused on using solid waste and nanoparticles as alternatives for producing green concrete mixtures. The study indicated that these waste elements could serve as admixtures in concrete construction, enhancing workability, strength, and durability while potentially reducing cement costs, environmental pollution risks, and landfill space usage. X-ray diffraction analysis showed the amorphous form of silica when extracted using CDA, with scanning electron microscopy and energy dispersive spectroscopy revealing a particle size of 200 nm. CDA's crystalline structure and chemical composition did not significantly differ from typical Portland cement [34].

Sahin et al. [35] examined the use of CDA as a substitute for cement in concrete. They found that at 56 days, concrete incorporating bovine waste ash exhibited significant increases in compressive strength—96%, 95%, and 94% with 5%, 10%, and 15% replacements, respectively. Additionally, research on the corrosion resistance and seawater resilience of concrete with slag cement showed that a 20–30% replacement yielded optimal corrosion outcomes [36]. Lightweight concrete advantages were explored, highlighting better tensile strain capacity, superior heat resistance, an increased strength-to-weight ratio, a lower coefficient of thermal expansion, and sound insulation properties [37]. Moreover, adding 15% CDA improved durability, reduced permeability, minimal pH drop, and lower microbial growth [38].

Millogo et al. [39] revealed that adobes stabilized with CDA are suitable for construction in wet areas, with cattle manure ash concrete exhibiting higher compressive strength than fly ash concrete. Cattle manure ash showed superior pozzolana activity compared to fly ash, suggesting its potential as a cement substitute, potentially addressing waste disposal concerns [40]. Replacing 15% of cement with cattle manure ash enhanced particle size distribution, particle density, and aggregate structure, improving compressive strength [41]. Additionally, green concrete studies using bovine dung ash found advantages in fresh and hardened characteristics [42].

Utilizing CDA to stabilize alluvial soil for subgrade increased California Bearing Ratio and Unconfined Compressive Strength while reducing volumetric changes, with a suggested maximum ash concentration of 7.5% [43]. Manjunath Patel et al. [44] investigated CDA's performance as an additional material for stable molding and casting, noting maximum improvement at 5% concentration, leading to increased hardness and significant compressive strength enhancement in concrete after 28 days. CDA is a cost-effective means to reduce environmental risks and maintain ecological stability [45].

In a study by Lakshmi et al. [46], fly ash and CDA were used as pozzolana replacements in concrete production, with 5–10% CDA and 15% fly ash improving compressive and tensile properties. Moreover, Kumar [47] found that adding 10% fly ash and 5% CDA to concrete increased compressive strength after 28 days. Regarding plastering, Mbereyaho et al. [48] found that a slurry containing up to 20% CDA could replace cement concrete as a plastering binder for specific structural components. Lastly, Aiyedun et al. [49] emphasized the inclusion of clay with CDA in fire bricks, highlighting CDA's potential as a substitute building material for insulating fire bricks.

Vasu [50] conducted research on CDA and found that a 10% substitution increased the compressive strength of concrete after 28 days, making it stronger and more durable than traditional concrete. Meena & Sood [51] asserted that CDA and fly ash are high-quality, low-cost, environmentally friendly, and long-lasting building materials. The review identifies that the incorporation of fly ash in previous concrete reduces void content and permeability, attributed to the filler effect of fly ash, and the ideal substitution percentages of cement with fly ash range between 10% and 30% when utilized in concrete manufacturing. However, it is noted that higher levels of substitution can adversely affect the hydration process, resulting in lower strength [5, 52]. The findings indicate that the optimal replacement ratio for sugar cane leaf ash or granite dust in ultra-high-performance concrete production is 20%, which results in the best mechanical characteristics. For instance, after 28 days of casting, the compressive strength increased by 12.16% and 8.44% with the addition of sugar cane leaf ash and granite dust, respectively.

Moreover, the study reveals that a 25% replacement ratio of recycled fine aggregates from natural fine aggregate exhibited ultra-high-performance concrete's most favorable mechanical and transport properties [53]. The findings indicate that concrete produced by replacing 25% of cement with fly ash and 10% of coarse aggregates with palm kernel shells and adding 1.2% fibers yields optimal strength. The study suggests that lightweight concrete, which is cost-effective, can be produced by combining fly ash and palm kernel shells. Such an approach can facilitate the construction of affordable housing while conserving raw materials [54, 55]. The study review underscores the potential benefits of incorporating CDA in concrete production, including cost reduction, enhanced compressive strength, and improved durability against specific environmental stressors. However, it also highlights the importance of managing workability challenges associated with higher levels of CDA replacement by adjusting the water content in concrete mixes. The reviewed papers suggest an optimum replacement level of 20% CDA in concrete, which enhances compressive strength compared to conventional concrete mixes [54]. Table 2 presents experimental investigations on replacing cement with CDA in concreting. Additionally, an environmental concern involves the disposal of corn stalks, with studies indicating that burning agricultural waste pollutes the air and depletes nutrients, leading to reduced soil fertility. However, using CSA instead of cement in mixes improved compressive strength compared to regular concrete.

Table 2. Utilization of cow dung ash in concrete

Country	Ref. No.	Material Replaced	Mix Proportion	Studied properties
Nigeria	[20]	Cement	0- 30%	Standard Consistency, Soundness, Setting time, and Compressive strength
India	[21]	Cement	6- 14%	Workability, Setting time, and Compressive strength
India	[22]	Cement	5- 30%	Compressive strength, Consistency limits, Setting time
India	[23]	Fly Ash	5- 20%	Compressive strength and Water Absorption
Nigeria	[24]	Cement	10- 30%	Bulk Density, Workability, and Compressive strength
India	[25]	Cement	2.5- 3.5%	Compressive strength and Tensile strength
India	[26]	Cement	5- 15%	XRD, Compressive strength, Split tensile strength, Rapid chloride penetration (RCPT), FESEM and TGT analysis
India	[27]	Cement	10- 30%	Compressive Strength
India	[29]	Cement	10- 20%	Workability and Compressive Strength
-	[31]	Cement	10- 30%	Compressive strength, Consistency, and Workability
Turkey	[35]	Cement	0- 30%	Compressive strength
India	[38]	Cement	2.5- 15%	Compressive strength, Soundness, setting time, Exposure studies in fresh water, Biofilm characterization, pH degradation, XRD.
China	[40]	Cement	10- 30%	Compressive strength, XRD, EDS, SEM
China	[41]	Cement	15%	XRD, SEM, Compressive strength
India	[42]	Cement	15%	X-ray fluorescence, XRD, Workability, Compressive strength, and water absorption
India	[28]	Cement	15%	pH, Compressive strength, Split tensile strength, XRD and FESEM
India	[45]	Cement	5- 15%	Bulk density, Setting time, Workability, Compressive strength, and Split tensile strength
India	[46]	Cement	0- 30%	Split tensile strength, Compressive strength, and Flexural strength
India	[47]	Cement	5- 12%	Compressive strength, Initial and Final setting time, workability, and Standard consistency
-	[48]	Cement	10- 40%	Shrinkage, Water Absorption (Atterberg), Durability and Weathering resistance
India	[50]	Cement	5- 20%	Slump test, Compaction factor test, and Compressive strength test
India	[51]	Cement	5- 30%	Split tensile strength, RCPT, and Water penetration

Raheem et al. [56] CSA-modified concrete's 28-day cured compressive strength increased by 10%, suggesting promising results for interlocking paving stones. In a study examining the effects of adding 5%, 10%, and 15% CSA to concrete, Hamdy et al. [57] discovered that compressive strength improved compared to conventional concrete. Aksoğan et al. [58] investigated CSA as a cement substitute in concrete, using a 2.5% replacement by weight of cement and conducting experiments at 7, 28, and 180 days. They concluded that adding ash to concrete enhances various engineering qualities by filling voids and creating a more robust concrete structure. Moreover, under sulfate attack, concrete's compressive strength was optimal when cement was replaced with CSA, and thermogravimetric measurements revealed a decrease in CO_2 concentration with CSA [59]. Table 3 presents experimental studies on the substitution of cement by CSA in concrete.

Table 3. Corn stalk ash as an additive

Country	Ref. No.	Material Replaced	% Replaced	Experiments carried out
Nigeria	[56]	Cement	5- 25%	Water Absorption, compressive strength, Abrasion, and Density test
Egypt	[57]	Cement	5- 15%	Slump test, Compaction factor test, and Compressive strength test
Turkey	[58]	Cement	2.5- 5%	Compressive strength, Abrasion, Freeze-thaw, Sulphate resistance and Scanning Electron Microscope
China	[59]	Cement	2- 8%	Compressive strength, XRD, Thermogravimetry and SEM

Limited research has explored concrete modifications using CDA and CSA individually, with results indicating enhancements in definite characteristics. CDA and CSA exhibit pozzolanas' characteristics, making them suitable for creating concrete pozzolanas. Cow dung and corn stalks are prevalent in rural regions of India.

The study aims to modify concrete by partially substituting CDA and CSA and analyzing their impact on concrete strength. Specifically, it focuses on replacing a portion of OPC in mortar manufacturing with CDA and CSA. Unlike previous studies on similar themes, this research delves deeper into studying the effect of CDA on various mortar properties as it replaces OPC. Additionally, it assesses a wide range of parameters, including workability, compressive strength, tensile strength, and flexural strength on M-25 grade concrete, which sets it apart from previous studies that focused on a small number of aspects.

The results of this study are noteworthy and novel, as no previous research on this subject has been undertaken in the location where the study was conducted. By expanding the scope of analysis and investigating multiple parameters, this study contributes to a better understanding of the effects of CDA and CSA substitution in mortar manufacturing.

2. Materials and Methods

2.1. Materials Used

2.1.1. Cement

The OPC utilized in this study had a 43 grade and was sourced in Mohali, Punjab. The cement superiority was assessed per IS 8112-1989 [60]. The physical properties conformed to the requirements necessitated by standard specifications of Indian standards listed in Table 4. The results of specific gravity, fineness, consistency, and setting time of cement tests as per the standard [58–61].

Table 4. Physical properties of cement

Properties	43 grade (OPC)	Standards
Specific gravity	3.15	IS 2720- Part 3
Fineness of Cement	98%	IS 4031- Part 1
Normal Consistency of Cement	30.5%	IS 4031- Part 4
Initial and Final setting time	29 minutes & 549 minutes	IS 4031- Part 5

2.1.2. CDA and CSA

Cow dung and corn stalk samples were collected from agricultural land near Akhnoor in Jammu and Kashmir. The samples were sun-dried for a week and then calcined in a muffle furnace at 800º C and 500º C for two hours, as shown in Figure 1. This particular temperature was chosen as it yielded superior-quality CDA and CSA [41, 62]. After burning, the samples were cooled and processed with a milling machine. Samples with a sieve size of 150 µm were used for cement replacement. Figure 2 shows the resulting CDA and CSA, which are dark gray. Table 5 summarizes the outcomes of Energy dispersive analysis on the CDA and CSA with the physical properties

Table 5. Chemical composition and physical properties of CDA and CSA (wt. %)

Organic ashes	O	Mg	Al	Si	P	K	Ca	Specific weight (g/cm^2)
CDA	38.51	4.64	2.90	27.23	5.58	4.38	16.76	2.80
CSA	46.64	4.39	-	10.31	7.64	16.53	14.53	2.00

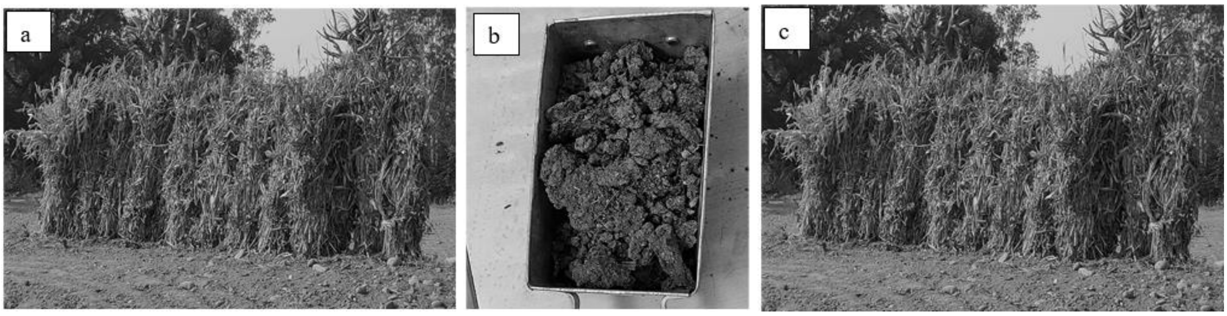

Figure 1. (a) Raw cow dung; (b) Collected cow dung; (c) Raw corn stalks; (d) Collected corn stalks; (e) Muffle furnace

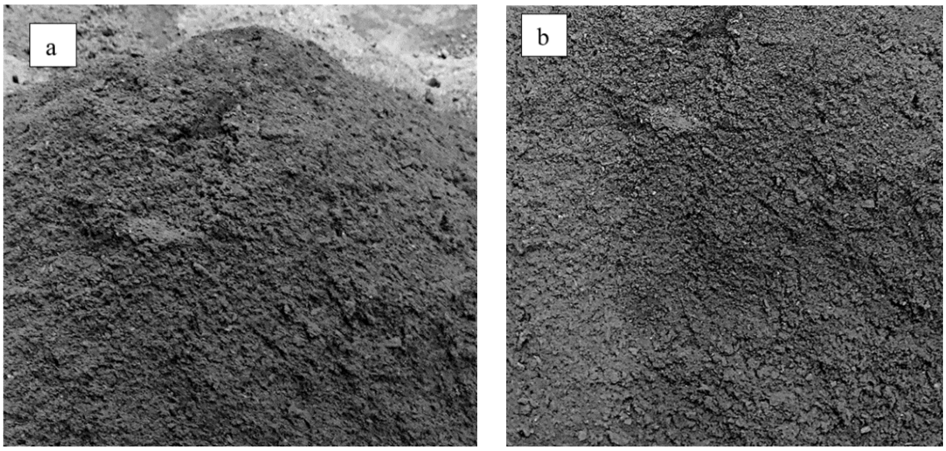

Figure 2. a) CDA; b) CSA

2.1.3. Aggregates

Naturally occurring sands with particle sizes less than 4.75 mm were used as fine aggregates. Coarse aggregates were composed of crushed stones with a maximum length of 20mm. According to the standard, the aggregates were subjected to different tests to confirm their quality [63, 64]. In addition, physical parameters were measured on the fine and coarse aggregate samples, and the findings for their respective standards are shown in Table 6.

Table 6. Physical properties of aggregates

Properties	Coarse Aggregates	Fine Aggregates	Standards
Specific gravity (g/cm^3)	2.67	2.6	IS 2386-3 (1963)
Fineness Modulus	8.09	3.12	IS 383-1970

2.2. Methodology

2.2.1. Mortar Mix Preparation

The mortar mixes were developed with a water-to-binder ratio of 0.44 and a volumetric ratio 1:1:2 (M25) for cement, sand, and aggregates. Because the primary goal of our research was to investigate the impacts of partially replacing 43 Grade OPC with CDA and CSA, we studied various amounts of CDA content (5%, 8%, 10%, 15%, 20%, and 25%) and CSA content (2.5, 5%, 7.5%, and 10%). To test the hardened concrete qualities, 33 cubes, 33 cylinders, 33 beams, and three samples were explicitly created for each mix. Tables 7 to 12 show the mix codes and percentages of OPC, CDA, and CSA used and their corresponding quantities.

Table 7. Proportions and quantities of material for compressive strength properties with CDA

Mix % age	OPC Content (kg)	CDA Content (kg)	Sand Content (kg)	Aggregates Content (Kg)	Water/cement ratio
0%	5.613	-	6.7827	12	0.44
5%	5.332	0.280	6.7827	12	0.44
8%	5.164	0.449	6.7827	12	0.44
10%	5.052	0.561	6.7827	12	0.44
15%	4.771	0.841	6.7827	12	0.44
20%	4.490	1.122	6.7827	12	0.44
25%	4.209	1.403	6.7827	12	0.44

Table 8. Proportions and quantities of material for compressive strength properties with CSA

Mix % age	OPC Content (kg)	CSA Content (kg)	Sand Content (kg)	Aggregates Content (kg)	Water/ cement ratio
0%	5.613	-	6.7827	12	0.44
2.5%	5.472	0.140	6.7827	12	0.44
5%	5.332	0.280	6.7827	12	0.44
7.5%	5.192	0.420	6.7827	12	0.44
10%	5.051	0.561	6.7827	12	0.44

Table 9. Proportions and quantities of material for tensile strength properties with CDA

Mix % age	OPC Content (kg)	CDA Content (kg)	Sand Content (kg)	Aggregates Content (kg)	Water/ cement ratio
0%	8.812	-	10.648	18.972	0.44
5%	8.372	0.440	10.648	18.972	0.44
8%	8.108	0.704	10.648	18.972	0.44
10%	7.931	0.881	10.648	18.972	0.44
15%	7.490	1.321	10.648	18.972	0.44
20%	7.050	1.762	10.648	18.972	0.44
25%	6.609	2.203	10.648	18.972	0.44

Table 10. Proportions and quantities of material for tensile strength properties with CSA

Mix % age	OPC Content (kg)	CSA Content (kg)	Sand Content (kg)	Aggregates Content (kg)	Water/ cement ratio
0%	8.812	-	10.648	18.972	0.44
2.5%	8.592	0.220	10.648	18.972	0.44
5%	8.372	0.440	10.648	18.972	0.44
7.5%	8.151	0.660	10.648	18.972	0.44
10%	7.93	0.881	10.648	18.972	0.44

Table 11. Proportions and quantities of material for flexural strength properties with CDA

Mix % age	OPC Content (kg)	CDA Content (kg)	Sand Content (kg)	Aggregates Content (kg)	Water/ cement ratio
0%	8.316	-	10.048	17.902	0.44
5%	7.900	0.4158	10.048	17.902	0.44
8%	7.650	0.665	10.048	17.902	0.44
10%	7.484	0.831	10.048	17.902	0.44
15%	7.068	1.247	10.048	17.902	0.44
20%	6.652	1.663	10.048	17.902	0.44
25%	6.237	2.079	10.048	17.902	0.44

Table 12. Proportions and quantities of material for flexural strength properties with CSA

Mix % age	OPC Content (kg)	CSA Content (kg)	Sand Content (kg)	Aggregates Content (kg)	Water/ cement ratio
0%	8.316	-	10.048	17.902	0.44
2.5%	8.108	0.207	10.048	17.902	0.44
5%	7.900	0.415	10.048	17.902	0.44
7.5%	7.692	0.623	10.048	17.902	0.44
10%	7.484	0.831	10.048	17.902	0.44

2.2.2. Methods

After conducting numerous tests on the material characteristics of cement, fine aggregates, coarse aggregates, and composition of CDA and CSA. The workability in Figure 3 and hardened properties of the normal, CDA, and CSA-containing mortar specimens in Figure 4 were evaluated using the test methods and types presented in Table 13. These procedures meet Indian norms. The qualities of hardened mortar include compressive strength, tensile strength, and flexural strength. The mortar mixtures were formed into 150 × 150 × 150 mm cubes, a 150 × 300 mm cylinder, and 100 × 100 × 500 mm beams. After molding, the cubes, cylinders, and beams were kept at room temperature for 24 hours. The specimens were then removed from the molds and immersed in water to cure until the test, which took place 28 days later. To investigate the microstructural properties of CDA and CSA samples, we used a scanning electron microscope, Energy dispersive analysis, and X-ray diffraction. Figure 5 illustrates the approach used in the procedure.

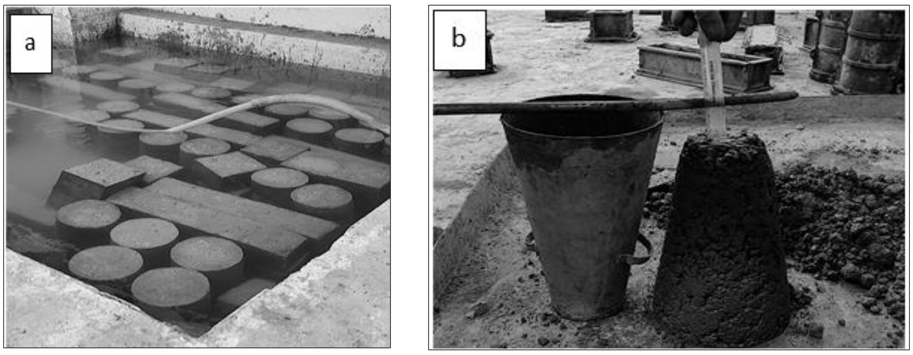

Figure 3. (a) Curing of samples; (b) Slump cone test of mortar

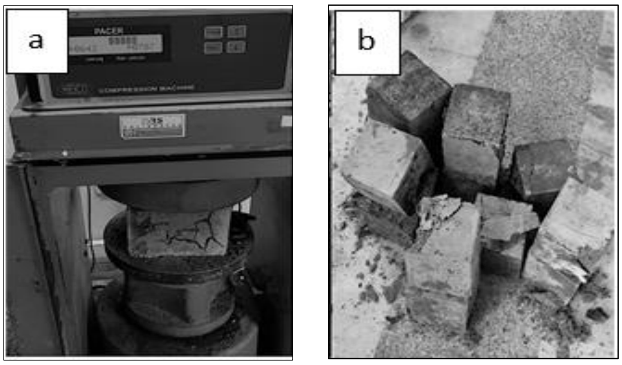

Figure 4. (a) Testing of samples; (b) Crushed samples

Table 13. The fresh, hardened, and microstructural tests of samples

Tests	Properties	Tests Standards	Examined Samples	Curing Ages
Fresh Properties	Workability	IS- 456 [65]	All	-
Hardened Properties	Compressive strength Tensile strength Flexural strength	IS 516- 1959 [66] IS 5816- 1999 [67]	All	28 days
Microstructural Properties	SEM, EDA, and XRD	-	CDA and CSA	-

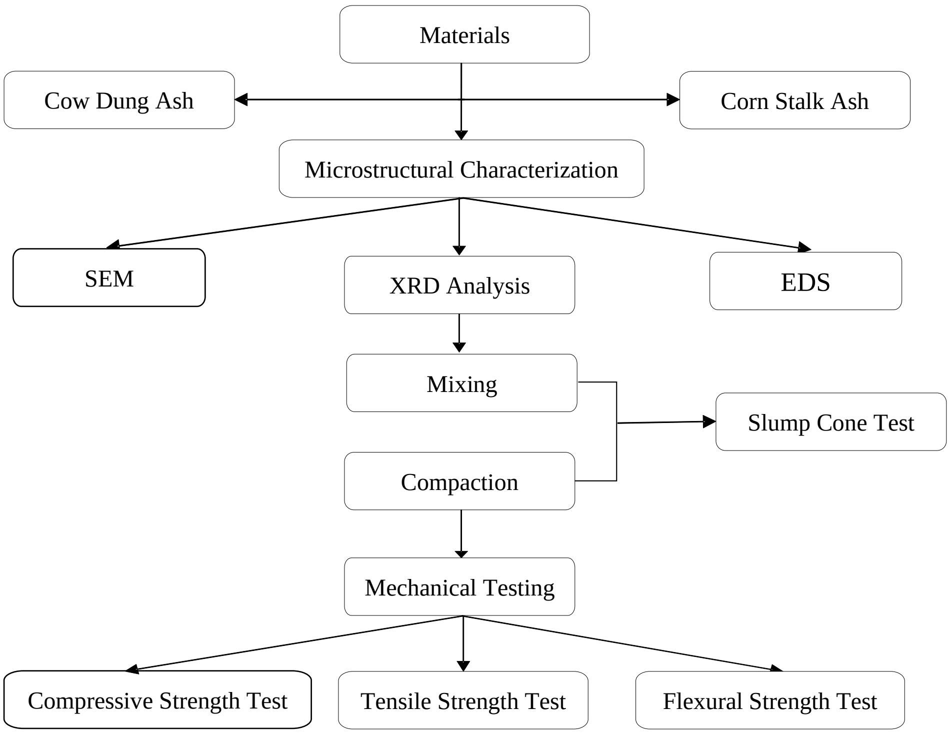

Figure 5. Flow chart showing the collection and selection of the published articles

3. Results and Discussion

This section summarizes the test results and investigates the efficacy of CDA and CSA as partial cement replacements in mortar samples. Our research focuses on how CDA affects workability and hardened properties compared to reference specimens manufactured with regular OPC.

3.1. Effect of CDA and CSA on Workability

The workability of the plastic mortar was determined by assessing its consistency using the slump (Tables 14 and 15). The results clearly show that when the levels of CDA and CSA increased, the slump of the mortar decreased significantly. The most significant slump reductions were noted at CDA replacement levels of 20% and 25% and CSA replacement of 10%, related to the standard mixture. Comparable results were described by [21, 25]. This effect is due mainly to the increased porosity of CDA and CSA particles compared to cement. The porosity structure of CDA and CSA particles results in more excellent absorption of mixing water inside the mixture, especially as the amount of CDA and CSA increases. To compensate for the reduced workability produced by CDA and CSA, a larger superplasticizer is necessary to maintain the optimum workability of the mortar [1].

Table 14. Slump test of Normal and CDA mortar

S. No.	% of ash added	Slump value (in mm)
1.	0%	82
2.	5%	81
3.	8%	81
4.	10%	77
5.	15%	75
6.	20%	72
7.	25%	71

Table 15. Slump test of Normal and CSA mortar

S. No.	% of ash added	Slump value (in mm)
1.	0%	82
2.	2.5%	80
3.	5%	78
4.	7.5%	81
5.	10%	76

3.2. Effect of CDA and CSA on Hardened Properties

Tables 16 to 18 show the cube compressive strength, cylinder tensile strength, and beam flexural strength of mortar specimens after 28 days of curing with varied percentages of CDA. The result shows that increasing the amount of CDA up to 10% resulted in a linear rise in the mortar's compressive and tensile strength, while the specimen with 25% showed the highest drop. Furthermore, increasing the proportion of CDA utilized resulted in a linear drop in flexural strength relative to the regular mix, with the biggest decrement occurring at 10% after the standard blend. Furthermore, Tables 19 to 21 show a linear increase in the mortar's compressive, tensile, and flexural strength as the percentage of CSA employed increased up to 7.5%, with the 10% specimen showing the highest loss. The value of compressive strength at 10% replacement of CDA with cement is 31.77 N/mm^2. This strength value is approximately 11% and 27% more than the value of compressive strength for the control mix and M 25 grade concrete, respectively. As per IS: 456: 2000, the strength for M 25 grade concrete cured for 28 days is 25 N/mm^2 [65].

Table 16. Compressive strength of Normal and CDA mortar cubes

S. No.	% ash added	Compressive strength (N/mm^2)
1	0%	28.61
2	5%	26.6
3	8%	30.60
4	10%	31.77
5	15%	22.47
6	20%	18.56
7	25%	15.72

Table 17. Tensile strength of Normal and CDA mortar cubes

S. No.	% of ash added	Tensile strength (N/mm^2)
1.	0%	3.01
2.	5%	2.93
3.	8%	3.25
4.	10%	3.42
5.	15%	2.5
6.	20%	2.1
7.	25%	1.83

Table 18. Flexural strength of Normal and CDA mortar cubes

S. No.	% of ash added	Flexural strength (N/mm^2)
1.	0%	3.71
2.	5%	3.58
3.	8%	3.5
4.	10%	3.61
5.	15%	3.16
6.	20%	2.93
7.	25%	2.53

Table 19. Compressive strength of Normal and CSA mortar cubes

S. No.	% ash added	Compressive strength (N/mm^2)
1.	0%	26.56
2.	2.5%	26.9
3.	5%	27.5
4.	7.5%	28.4
5.	10%	26.7

Table 20. Tensile strength of Normal and CSA mortar cubes

S. No.	% of ash added	Tensile strength (N/mm^2)
1.	0%	2.78
2.	2.5%	2.83
3.	5%	2.88
4.	7.5%	3.04
5.	10%	2.75

Table 21. Flexural strength of Normal and CSA mortar cubes

S. No.	% of ash added	Flexural strength (N/mm^2)
1.	0%	3.59
2.	2.5%	3.61
3.	5%	3.64
4.	7.5%	3.7
5.	10%	3.59

3.3. Microstructural Properties

3.3.1. X-Ray Diffraction of CDA

The X-ray diffraction (XRD) spectra of CDA at 800°C revealed prominent sharp peaks, as depicted in Figure 6. These peaks signify the presence of crystalline structures oriented at specific 2θ angles, a characteristic that enhances X-ray diffraction due to the structural arrangement. Upon calcination at 800°C, a distinct peak corresponding to quartz emerged at 2θ = 26.920° (d = 3.30931Å), indicating its trigonal, hexagonal crystal lattice. Similarly, peaks at 2θ = 24.285° (d = 3.66209Å) and 2θ = 21.150° (d = 4.19736Å) corresponded to cristobalite, displaying monoclinic crystal structures. These peaks appeared notably sharp due to the ash sample's high crystalline silica content. Additionally, smaller crystalline peaks were observed, such as broad peaks around 2θ = 16.299° (d = 5.43385Å), 2θ = 18.058° (d = 4.90850Å), 2θ = 20.086° (d = 4.41728Å), 2θ = 34.863° (d = 2.57137Å), 2θ = 45.295° (d = 2.00046Å), 2θ = 49.463° (d = 1.84121Å), 2θ = 61.09° (d = 1.51567Å), 2θ = 68.269° (d = 1.37275Å), 2θ = 72.540° (d = 1.30209Å), 2θ = 73.719° (d = 1.28415Å), and 2θ = 81.692° (d = 1.17778Å). These peaks indicate the transformation of crystalline structures into amorphous silica. The crystallinity of CDA is measured at 58.4%, while the remaining 41.6% is amorphous.

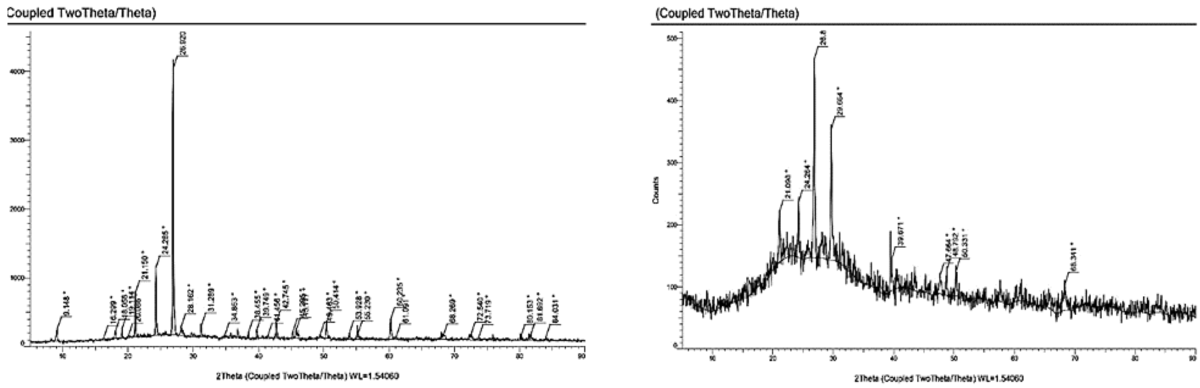

Figure 6. (a) XRD of CDA, (b) XRD of CSA

3.3.2. X-Ray Diffraction of CSA

The X-ray diffraction (XRD) analyses of CSA revealed sharp peaks indicative of crystalline structures at specific 2θ orientations, enhancing X-ray diffraction efficiency. At a calcination temperature of 500°C, sharp peaks of cristobalite were observed at 2θ = 21.098° (d = 4.20763Å) and 2θ = 24.264° (d = 3.66528Å), showcasing monoclinic crystal structures. Additionally, peaks at 2θ = 26.883° (d = 3.31384Å) and 2θ = 29.664° (d = 3.00913Å) indicated the presence of crystalline quartz, displaying a trigonal hexagonal crystal lattice as illustrated in Figure 6. Quartz, characterized by sharp peaks, transitions into amorphous silica, which exhibits broader peaks. CSA predominantly contains amorphous quartz, constituting 75% of its composition, while its crystallinity is measured at 25%. This finding contrasts with a previous study that exclusively identified amorphous silica in CSA at a calcination temperature of 500°C, highlighting a notable difference in observed crystalline peaks [68].

3.3.3. SEM-EDX Analysis of CDA and CSA

The SEM analysis conducted on cow dung ash powder elucidates the alterations in morphology, size, and chemical composition of cow dung ash particles. Examination of the cow dung ash reveals densely packed particles of small grains. The particle size ranges from 10 to 50 µm, exhibiting various geometries such as cylindrical, flakes, feathers, and rod shapes, as depicted in Figure 7. These naturally occurring nano-silica particles can effectively fill voids, presenting the potential for concrete densification within the mortar phase

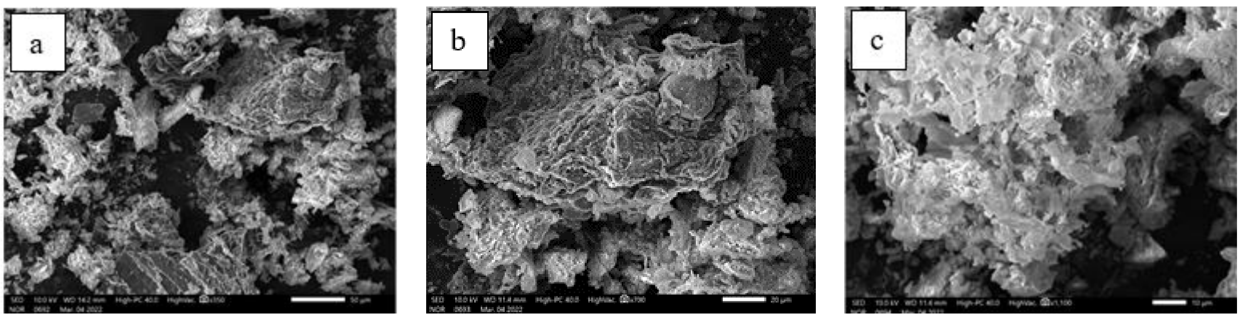

Figure 7. SEM images of CDA

The elemental composition of CDA was determined through Energy Dispersive Analysis (EDA), revealing various elements as summarized in Table 5. Notably, the ash comprises 27.23% silica, with the pure silica particles exhibiting a predominantly spherical shape with agglomerated characteristics, as illustrated in Figure 8. This study underscores CDA, indicating a higher silica content than Ordinary Portland Cement (OPC) and CDA, as detailed in previous research [26]. SEM images of ground CSA are depicted in Figure 9. The particle size distribution of CSA ranges approximately from 10 to 200 µm, showcasing a variety of structures, including cellular, chromatic, spherical, and flaky. Additionally, the ash composition includes 10.31% silica.

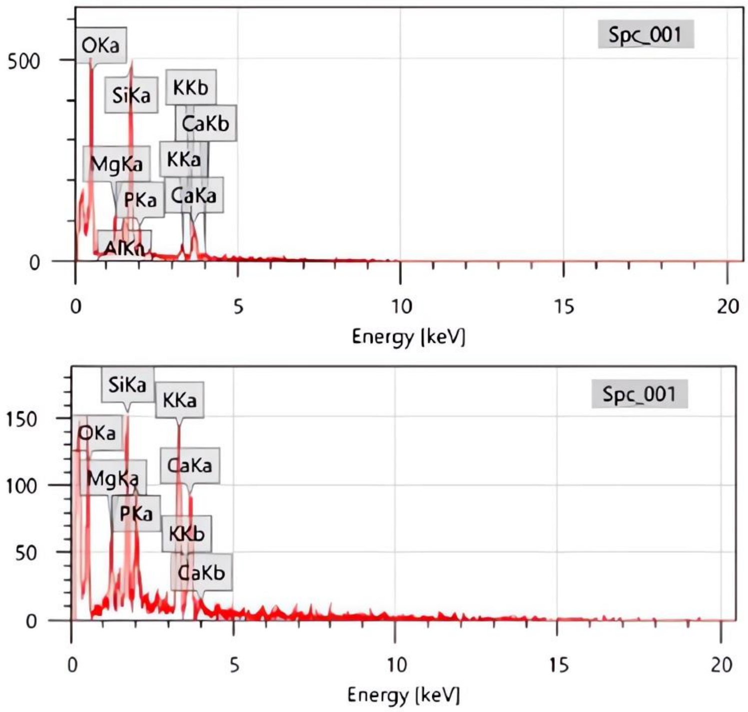

Figure 8. (a) EDS of CDA, (b) EDS of CSA

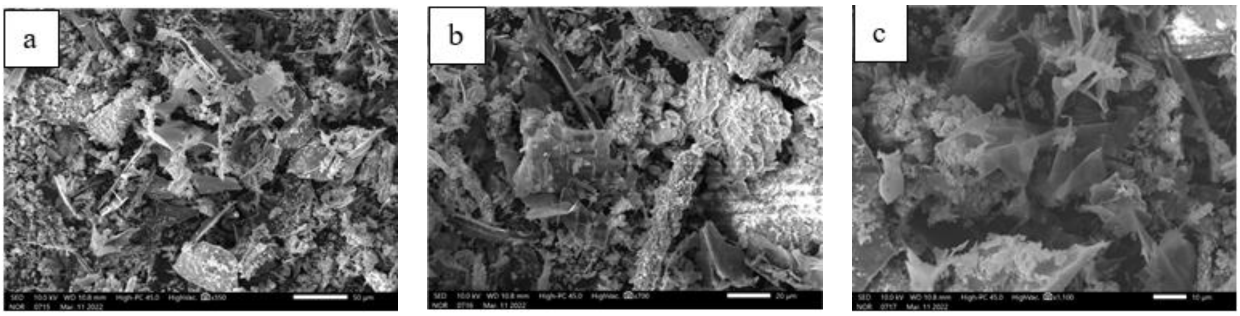

Figure 9. SEM images of CSA

4. Conclusions

The process of making cement entails the release of more hazardous gases, which endanger the environment in various ways. Many studies are being conducted to wholly or partially replace the fine aggregate, coarse aggregate, and cement in concrete. This project attempted to use CDA in varied proportions (5%, 8%, 10%, 15%, 20%, and 25%) and CSA in varying percentages (2.5%, 5%, 7.5%, and 10%) as cement replacement materials in M 25- grade concrete. Using these materials increased the structural characteristics of concrete, including compressive strength, tensile strength, and flexural strength. The study also examined how CDA and CSA affect concrete's workability and hardened properties while investigating their physical and chemical properties.

Moreover, it reduces the environmental impact caused by landfilling or dumping these materials. Replacing traditional materials with CDA and CSA can promote the reuse of waste materials. The methods tested for concrete production can be applied in the construction of various structures such as compound walls, non-load-bearing partition walls, lightly loaded precast members (such as shelf slabs, sill slabs, cut lintels, and sunshades), as well as curb walls and medians of roads. The following conclusions are:

- Increasing the proportion of CDA and CSA in the mortar mix reduces workability compared to the control mix. The mortar mixes containing CDA and CSA had a lower slump value.
- CDA and CSA show higher compressive, tensile, and flexural strengths at 28-day curing periods than standard concrete produced using OPC.
- There was a marked increase in the compressive, tensile, and flexural strengths of 10% CDA and 7.5% CSA.
- SEM and EDA confirmed the presence of nano-silica in CDA and CSA.
- XRD analysis indicates pure silica exists in both crystalline and amorphous phases in CDA and CSA.

Modified concrete containing CDA and CSA showed improved mechanical qualities as the pozzolanic activity increased with age. Pozzolanic processes contribute to forming more calcium silicate hydrate (C-S-H) gel, the primary binder in concrete. This result raises the strength and durability of the concrete over time.

5. Declarations

5.1. Author Contributions

Conceptualization, K.S.; methodology, K.S. and S.A.; formal analysis, A.J. and A.N.; writing—original draft preparation, A.J. and A.N.; writing—review and editing, K.S., S.A., N.A.A., and K.M.A. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in article.

5.3. Funding and Acknowledgements

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5.4. Conflicts of Interest

The authors declare no conflict of interest.

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