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Impact of polypropylene fibre and cow dung ash proportions on compressive strength of concrete

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Integrating polypropylene fibre (PPF) and cow dung ash (CDA) into concrete presents a promising avenue for sustainable building materials. Cow dung ash contributes to environmental sustainability by reducing carbon emissions and pollution, while PPF enhances fracture resistance, mechanical strength, and durability against water infiltration and chemical attacks. This study investigates the combined use of PPF and CDA as additives in concrete, focusing on optimizing their mix ratio to enhance compressive strength. Concrete mixes were prepared using Grade 43 ordinary Portland cement, river sand as fine aggregate, and coarse aggregate, with varying proportions of CDA and PPF. Compressive strength testing was conducted for 3 days, 14 days, and 28 days after casting. The results indicate that a mix containing 1.0% PPF and 10% CDA yielded the highest compressive strength across all testing durations, with specific values of 20.5 MPa at 3 days, 28.7 MPa at 14 days, and 35.2 MPa at 28 days, surpassing other combinations. This study provides valuable insights into the use of CDA and PPF as sustainable construction materials, demonstrating their potential to improve concrete performance and promote environmentally friendly building practices.

KEYWORDS: **Cow dung ash; Polypropylene fibre; Compressive strength; Consistency test; Slump test.**

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1. Introduction

The construction sector is of great importance globally, playing an essential role in national development and economic growth. As building projects increase, especially in emerging countries, the demand for concrete is expected to rise due to its exceptional strength and widespread availability compared to other materials [1]. Concrete is a composite material made up of aggregates combined with fluid cement that gradually hardens through a process called curing. It is the primary material used in construction for various structures such as buildings, bridges, pillars, dams, foundations, pipelines, and poles. However, concrete's high density categorizes it as a heavyweight material, and it exhibits reduced toughness, making it prone to cracks and showing lower strength compared to polypropylene fibre-reinforced concrete (PPFRC) [2]. Moreover, the concrete sector is the largest consumer of natural resources and has a significant impact on worldwide carbon dioxide (CO2) emissions originating from the manufacturing process of Portland cement, the main adhesive in concrete production. Portland cement alone contributes to approximately 8% of global CO2 emissions, with an annual production volume of four billion tons [3–5]. Consequently, concrete and cement manufacturers are actively involved in initiatives to promote ecologically sustainable concrete alternatives [6]. Additionally, efforts are being made to reduce the formation of micro-cracks, improve resistance to acids and alkalis, and enhance the mechanical properties of concrete [7].

In the last two decades, several studies have focused on supplementary cementitious materials (SCMs) derived from agricultural byproducts and industrial sources, such as fly ash, silica fume, rice husk ash, and blast furnace slag [8,9]. Some recent research has specifically looked at the potential of cattle dung ash (CDA) as a supplementary material due to its high silicon dioxide concentration and pozzolanic properties. Cow dung typically contains nitrogen, carbon, hydrogen, oxygen, potassium, phosphorus, and calcium [10,11]. In India, where a substantial amount of cow manure is produced annually, there is enough supply to produce CDA on an industrial scale. Studies have investigated the impact of different cattle manure ash (CMA) particle sizes, produced at varying temperatures, on concrete compressive strength. Positive compressive strength was observed when 15% of the cement was replaced with CMA. Additionally, adding up to 10% of CDA to a mixture has been recommended to improve its compressive strength [12,13].

Various studies have also explored the effects of polypropylene fibres (PPFs) on concrete properties. PPFs are cost-effective, readily available, and have the capacity to enhance toughness, strengthen structures, minimize the propagation of small fractures, and improve resistance to chemicals [14]. Research has shown that incorporating PPFs into concrete increases its ability to withstand compression at temperatures below 300 °C. It has also been observed that the maximum compressive strength of fine aggregate (FA) is achieved when using 0.5% PPF by weight of FA, with additional research indicating that increasing the PPF content up to 2% can further improve strength [15].

The research aims to investigate the effect of using PPF as a partial replacement for sand and CDA as a partial replacement for Ordinary Portland Cement (OPC) on concrete's compressive strength. Before determining compressive strength, various tests were conducted, including consistency tests for cement and CDA, sieve analysis for coarse and fine aggregates, setting time tests for cement and CDA, workability assessments, water absorption tests, and specific gravity measurements of aggregates. This study is significant as it explores a novel area of research, and the findings are original as no previous research has been conducted on this specific topic.

2. Materials

Cow dung ash is used as a cementitious substance, and polypropylene fibre is used as a substitute for fine aggregate in concrete mixes to reduce construction expense and to enhance the mechanical properties of concrete, such as its ability to withstand compression and its durability. Additionally, the material is environment friendly.

2.1. Cement

Cement OPC G43, manufactured by JK Cement Ltd. was used **(Fig. 1a)**. The composition of the cement was evaluated based on IS 8112:2013 [16]. It had a maximum final setting time of 356 min and an initial setting time of 36 min. The cement used in this study conforms to the BIS standard IS 269:2015, exhibiting a fineness of 2850 cm2/g and soundness values of 1 mm for Le Chatelier and 0.08% for autoclave testing. These properties applied to all percentages of Cow dung ash (CDA) replacement: 5%, 10%, and 15%.

2.2. Polypropylene fibre (PPF)

In recent years, PPF has become a popular thermoplastic polymer due to its exceptional characteristics, cost-effectiveness, and ease of processing. Polypropylene, a type of monofilament fibre made from a new synthetic polymer was used. The used PPF is white, 12 mm long with a diameter of 18 µm as shown in **Fig. 1(b)**.

2.3. Cow dung ash (CDA)

The physical characteristics of the ash include its bulkiness, high ash concentration, and low burning ratio. The cow dung ash used in this project is obtained from Radha Energy Cell, Ludhiana. It was subjected to heating at 500 °C and passed through a 300 µm sieve to facilitate its use as cement replacement, as a result, cow dung ash appeared grey as depicted in **Fig. 1(c)**. The weight (%) distribution of the chemical composition of CDA as per company data is: SiO_2-69.65, Al_2O_3-4.27, Fe_2O_3-2.99, MgO-2.22, CaO-12.55, SO_3-1.36, K_2O-2.94, Na_2O-0.57, P_2O_5-1.48, Mn_2O_5 -0.63 and TiO_2-0.33 respectively.

Fig. 1(a) OPC cement, (b) polypropylene fibre and (c) cow dung ash.

2.4. Fine aggregate

River sand was filtered through a 4.75 mm sieve to ensure uniform size was used. The sand was thoroughly inspected to meet the standards specified in IS: 383:1970 [17]. The physical properties of the sand sample are as per the required guidelines. The measured specific gravity was 2.67, and the water absorption was 1.01%, as per the IS:383:1970 standard.

2.5. Coarse aggregate

Coarse material ranging from 20 mm (passing) to 10 mm (retained) was used. According to IS:383-1970 [17], the measured specific gravity of the material was 2.68, and its water absorption was 0.81%.

2.6. Mortar mix preparation

A volumetric ratio of 1:3 for cement to sand and a water/cement ratio of 0.45 were employed to prepare mortar mixes. The primary objective was to investigate the influence on concrete compressive strength by replacing ordinary Portland cement (OPC) with cow dung ash (CDA) at proportions of 5%, 10%, and 15%, and river sand with polypropylene fibre (PPF) at proportions of 1%, 2%, and 3%, to determine the optimal combinations. A total of 36 mortar cubes, each with dimensions of 70.6 × 70.6 × 70.6 mm3 were prepared. At least three samples for each blend were prepared. **Table 1** presents the mix codes, ranging from CDA0 to CDA15 including the percentages and quantities of OPC and CDA, the amount of sand and water for each mix.

Table 1. Details of mortar mix codes.

S. No.	Mix Codes	OPC Content		CDA Content		Sand	Water
		(%)	(kg)	(%)	(kg)	(kg)	(kg)
1	CDA0	100	1.8	0	-	5.4	0.756
2	CDA5	95	1.71	5	0.09	5.4	0.792
3	CDA10	90	1.62	10	0.18	5.4	0.828
4	CDA15	85	1.53	15	0.27	5.4	0.936

3. Methods and testing

About 45 mortar cubes were prepared, including 9 control cubes with a standard mortar mix and 36 cubes with varying proportions of CDA (5%, 10%, and 15%). Additionally, cubes consisting of 100% CDA were also prepared. Ninety concrete cubes with dimensions of 150 × 150 × 150 mm3 were prepared to examine their compressive strength properties. This set included 9 conventional cubes and 81 cubes with varying concentrations of CDA (5%, 10%, and 15%) replacing cement, and PPF (1%, 2%, and 3%) replacing sand. These cubes were tested after 3, 14, and 28 days as per IS:2250:1981 standards [18].

Tests were conducted to assess the consistency and quality of cement and CDA, their setting times, density, and the water absorption capacity of aggregates. The workability of concrete mixes incorporating PPF and different concentrations of CDA was evaluated using slump tests. Furthermore, the water absorption percentage of the concrete cubes was determined. The compressive strength testing was conducted using a hydraulic compressive testing machine (Associated Instruments Manufacturers India Pvt. Ltd. (Aimil)), a sophisticated apparatus designed to evaluate the compressive strength and behaviour of materials under uniaxial loads. The machine features a robust load frame made of high-strength steel, a hydraulic power unit to generate the necessary pressure, an actuating cylinder to apply the load, and precision load cells to measure the exerted force. Dis-placement transducers, such as linear variable differential transformers (LVDTs), were utilized to accurately gauge specimen deformation. The data acquisition system recorded and processed real-time data from the load cell.

4. Results and discussion

4.1. Sieve analysis of cement and CDA

The fineness of both the cement and CDA was evaluated using an IS-90-micron sieve as per IS: 460 (part 1-3):1985 standards [19]. The sieve analysis results are presented in **Table 2**, providing the fineness measurements obtained through dry sieving. For each material, a sample weight of 100 g was used. The residue weights recorded in the first row of the table were 8 g for cement and 7 g for CDA, corresponding to residue percentages of 8% and 7%, respectively. The average residue percentages were calculated to be 7.33% for cement and 6.33% for CDA. Both values fall within the specified limit of 10% as per the standards [19], indicating acceptable fineness limit for concrete applications.

Table 2. The sieve analysis of cement and cow dung ash.

S. No.	Wt. of sample, W (g)	Wt. of residue, R (g)	% of residue =($\frac{R}{W} \times 100$)	Average % of residue	Specified Limit (%)
			Cement		
1	100	8	8	7.33	10% as per with IS: 460:(part 1-3)-1985
2	100	8	8		
3	100	6	6		
			Cow dung ash		
4	100	7	7	6.33	10% as per with IS: 460:(part 1-3)-1985
5	100	6	6		
6	100	6	6		

4.2. Consistency analysis

The consistency limit procedure, also referred to as the Atterberg limits, determines the critical water contents at which fine-grained soils transition between liquid, plastic, and semi-solid states. The liquid limit (LL) is determined by adding water to a soil sample and using a Casagrande cup or cone penetrometer to measure the water content at which the soil flows to close a groove after a specified number of drops. The plastic limit (PL) is identified by rolling soil threads until they crumble at a diameter of 3 mm, with the water content at this point being recorded. The shrinkage limit (SL) is defined as the water content at which further drying does not result in a reduction in volume. These limits are crucial for soil classification and for predicting soil behaviour under varying moisture conditions. **Table 3** presents the standard consistency of OPC 43 grade cement with various levels of CDA replacement. It indicates consistency percentages for CDA replacement rates of 0%, 5%, 10%, and 15%, with values of 28%, 32%, 34%, and 38%, respectively. However, **Fig. 2** provides a graphical depiction showing the correlation between CDA content (%) and consistency limit and notably, the lowest and highest consistency limits recorded are 28% and 38%, respectively.

Table 3. Standard consistency of OPC 43 grade cement with various levels of CDA replacement.

S. No.	% Replacement	Wt. of cement (g)	Wt. of CDA (g)	Total water added (g)	Consistency (%)
1	0	300	0	78	28
2	5	285	15	96	32
3	10	270	15	102	34
4	15	255	45	114	38

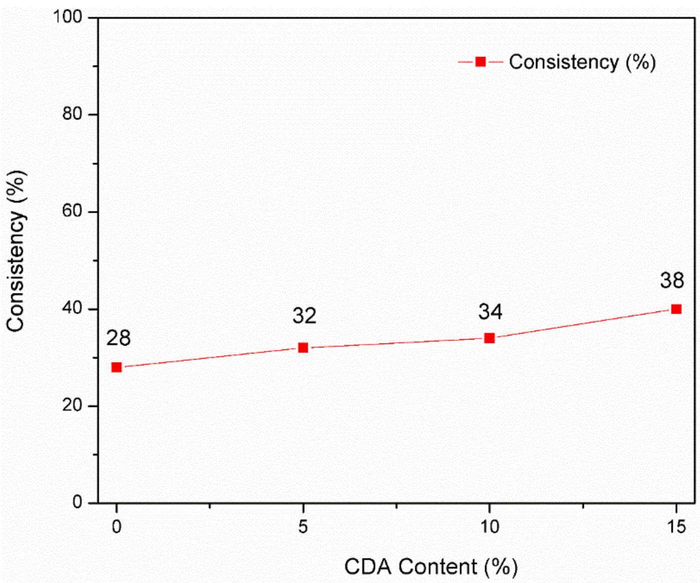

Fig. 2. Standard consistency of OPC 43 grade cement with various levels of CDA replacement.

4.3. Setting time analysis

Fig. 3 illustrates the setting times of OPC 43 grade cement with varying levels of CDA replacement. The data on initial and final setting times for CDA percentages of 0%, 5%, 10%, and 15% is as per IS 4031(Part 5)-1988 standards. Initial setting times progressively increase from 36 to 70 min with higher CDA replacement levels, while final setting times similarly extend from 356 to 451 min, respectively. The graph distinctly portrays those higher levels of CDA replacement led to prolonged setting periods for the cement, highlighting the influence of CDA on the setting characteristics of OPC 43-grade cement mixes. The results highlight the significant effect of CDA on the setting characteristics of OPC 43-grade cement mixes. The incorporation of CDA slows down the hydration process due to its pozzolanic nature, which reacts more slowly with calcium hydroxide compared to the primary cement components. This delayed reaction extends both the initial and final setting times, thereby influencing the workability and early strength development of the cementitious material.

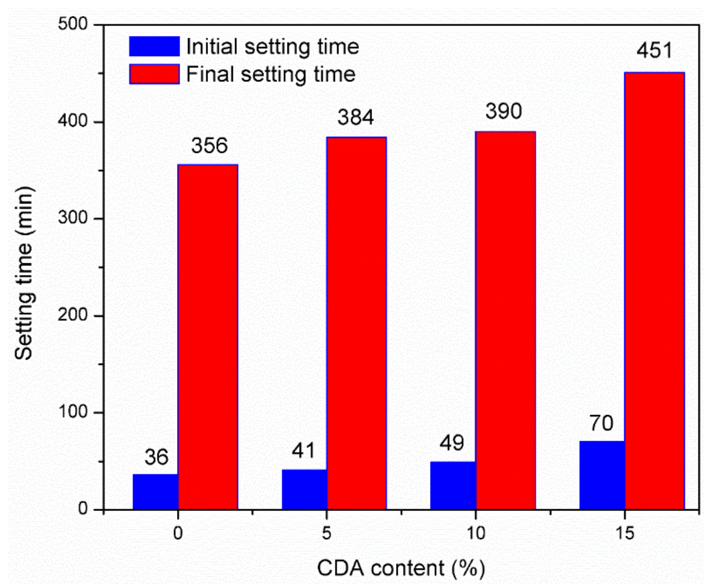

Fig. 3. Setting time of OPC G43 cement with grade varying level of CDA.

4.4. Sieve analysis of fine aggregate

The results of the sieve analysis of fine aggregate (FA) are displayed in **Table 4**, presenting data on cumulative percentage passing and other metrics as per IS 383-1970 standard [17]. The analysis revealed that 100% of the material passed through the 10 mm sieve, with 0% retention, indicating no coarse material is present.

Table 4. Sieve analysis of fine aggregate.

Wt. of fine aggregate (W) = 1000 g					
IS Sieve size	Wt. of FA (g)	% retained	Cumulative % retained	% passing	Permissible percentage passing as per IS 383:1970
10 mm	0	0	0	100	100
4.75 mm	52	5.2	5.2	94.8	90-100
2.36 mm	35	3.5	8.7	91.3	85-1 00
1.18 mm	55	5.5	14.2	85.8	75-100
600 µm	67	6.7	20.9	79.1	60-79
300 µm	475	47.5	68.4	31.6	12-40
150 µm	275	27.5	95.9	4.1	0-10
75 µm	30	3.0	98.9	1.1	-
Pan	11	1.1	100	0	

Fig. 4 presents a gradation curve illustrating the correlation between sieve size in mm and the cumulative percentage passing, providing a visual summary of the particle size distribution. These results, analyzed per IS 383-1970 criteria, offer valuable insights into the quality and suitability of the fine aggregate for concrete applications, ensuring compliance with established standards for particle size distribution.

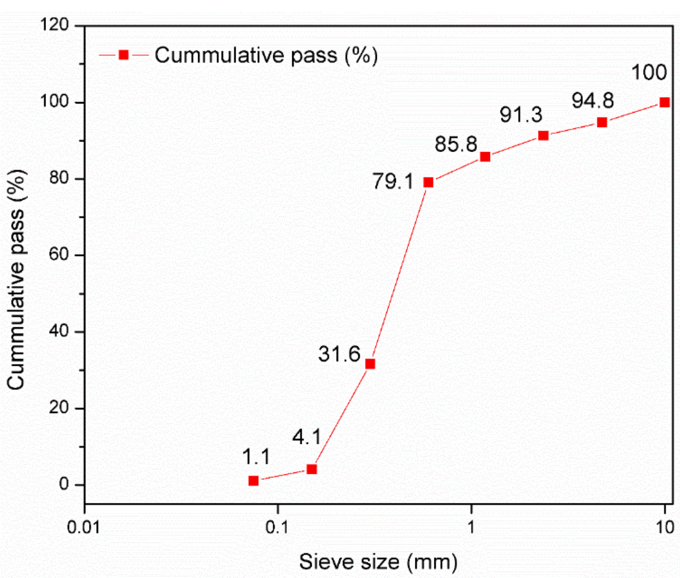

Fig. 4. A typical gradation curve for fine aggregates (FA).

Moreover, the sieve analysis was performed on coarse aggregate as shown in **Table 5.** This table provides the percentage retention, cumulative retention percentages, weight of retained coarse aggregate, and percentage passing as per IS 383-1970 standard. Notably, the pan sieve indicates complete passage of the coarse aggregate, with 0% retention and 100% passing. **Fig. 5** graphically illustrates the percentage passing at different sieve sizes. Complete passage is observed at the smallest size, 4.75 mm. This graphical representation provides a clear summary of the particle size distribution of the coarse aggregate samples, thereby facilitating the assessment of their suitability for concrete applications.

Table 5. Sieve analysis of coarse aggregate.

Wt. of coarse aggregate (W) = 5000 g					
IS sieve	Wt. of CA (g)	% retained	cumulative % retained	% passing	Permissible % passing as per IS 383-1970
20 mm	710	14.2	14.2	85.8	85-100
16 mm	2150	43	57.2	42.8	-
12.5 mm	1415	28.3	85.5	14.5	-
10 mm	610	12.2	97.7	2.3	0-20
4.75 mm	115	2.3	100	0	0-5
Pan	0	0	100	0	-

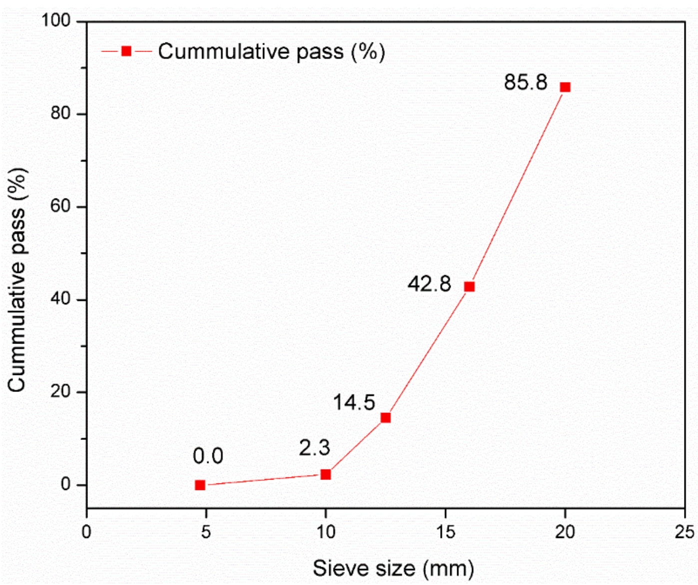

Fig. 5. Gradation curve for coarse aggregate.

4.5. Specific gravity and water absorption tests

The fine aggregate and coarse aggregate were tested for water absorption and specific gravity as per IS: 2386 (Part-3)-1963 standards [20]. The specific gravity and water absorption of fine aggregate are summarized in **Table 6.** An initial sample weight of 2000 g was used for the measurements. Based on these measurements, the water absorption was calculated to be 1.01%, the apparent specific gravity was 2.75, and the specific gravity was 2.67. Similarly, the water absorption and specific gravity of a coarse aggregate sample weighing 1000 g were measured. These measurements led to the determination of the specific gravity (2.68), apparent specific gravity (2.7), and water absorption (0.8%). These values confirm the suitability of the aggregates for use in concrete applications as per the specified standards.

Table 6. Specific gravity and water absorption of fine and coarse aggregate.

Specific gravity and water absorption results of fine aggregate	
Wt. in g of sample taken	2000
Wt. in g of saturated and surface-dry sample (A)	500
Wt. in g of the pycnometer with the sample and filled with distilled water (B)	1910
Wt. in g of pycnometer filled with distilled water (C)	1595
Sample wt. after oven drying (D)	495
Sp. gravity = {D/[A - (B-C)]}	2.67

Apparent specific gravity = {D/ [D – (B - C)]}	2.75
Water absorption (%) = 100 × [(A-D)/D]	1.01
Specific gravity and water absorption results of coarse aggregate	
Wt. in g of sample taken	1000
Wt. of aggregate and basket in water (A)	2855
Wt. of empty basket in water (B)	2235
Wt. of the dried aggregate in the air with wet surface (C)	990
Wt. of oven-dried aggregate in the air (D)	984
Specific gravity = D/[C – A + B]	2.68
Apparent specific gravity = [D/D - (A-B)]	2.7
Water absorption (in %) = 100 × [(C-D)/D]	0.8

4.6. Compressive cube results of mortar mix cubes

The compressive strength of cement-mortar cubes with varying levels of CDA replacement for 3, 14, and 28 days of curing is presented in **Table 7**. The table shows % CDA, cube area, water content, cube wt., cube density, crushing load and average compressive strength. **Fig. 6** reveals that after 3 days of curing, cubes with 0% CDA content exhibited the highest compressive strength of 25.9 MPa, whereas those with 15% CDA content showed a reduction to 20.40 MPa. After 14 days of curing, the compressive strength of cubes without CDA remained robust at 40.23 MPa, with a slight decrease to 38.81 MPa observed at 15% CDA content. However, after 28 days of curing, the highest compressive strength was achieved with 10% CDA content, measuring 47.77 MPa. Further increase in CDA content up to 15% shows a negligible decline in the compressive strength (47.26 MPa). The inclusion of CDA as a partial replacement for cement in mortar significantly influences the material's properties. Initially, the presence of CDA tends to reduce early compressive strength due to the slower pozzolanic reaction compared to the hydration of ordinary Portland cement (OPC). However, as curing progresses, the pozzolanic activity of CDA enhances the long-term strength and durability of the mortar. CDA contributes to the formation of additional calcium silicate hydrate (C-S-H), which improves the matrix's density and strength. This delayed strength gain is evident in the increased compressive strength observed at later stages of curing. The optimal CDA replacement level appears to be between 10% and 15%, where the benefits of enhanced pozzolanic activity outweigh the initial reduction in strength, resulting in a significant overall improvement in the mechanical properties of the cement mortar.

Table 7. Compressive strength of cement mortar mix (1:3) cubes with different CDA proportions after 3, 14 and 28 days of curing.

S. No.	% CDA in cement	Cube area (mm^2)	Water content (ml)	Cube wt.(kg)	Cube Density (kg/m^3)	Crushing load (kN)	Avg. Compressive strength (MPa)
For 3 days							
1	0	4984.36	252	0.73	2074.48	129.09	25.9
2	5	4984.36	264	0.69	1960.23	127.75	25.63
3	10	4984.36	276	0.68	1931.82	123.46	24.77
4	15	4984.36	312	0.62	1761.89	101.68	20.40
For 14 days							

5	0	4984.36	252	0.73	2084.29	200.52	40.23
6	5	4984.36	264	0.70	1988.64	203.31	40.79
7	10	4984.36	276	0.69	1960.23	196.08	39.34
8	15	4984.36	312	0.67	1903.41	193.44	38.81
For 28 days							
9	0	4984.36	252	0.71	2017.64	231.62	46.47
10	5	4984.36	264	0.69	1960.81	237.41	47.63
11	10	4984.36	276	0.67	1903.97	238.10	47.77
12	15	4984.36	312	0.59	1776.63	235.56	47.26

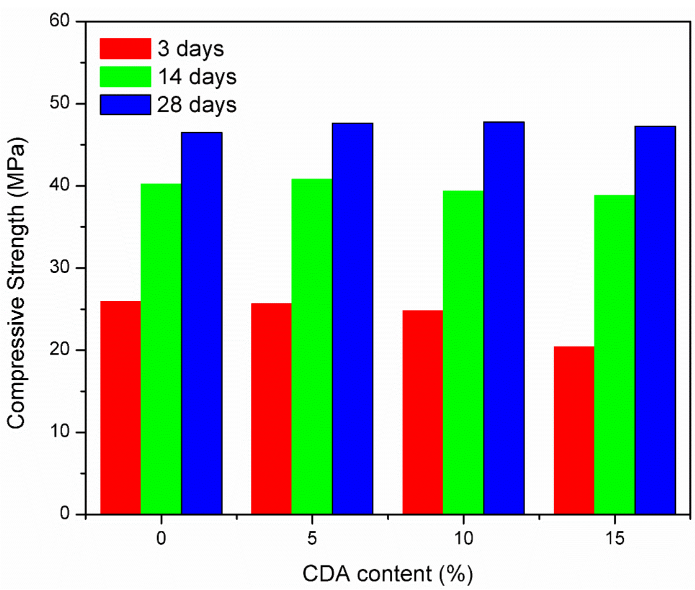

Fig. 6. Comparison of compressive strength of cement mortar mixes with different CDA proportions.

4.7. Workability test

Workability, assessed by the slump cone test as per IS: 1199–1959 [21], SP: 23-1982 [22], and IS 7320-1974 [23] standards. The test exhibits distinctive characteristics across various combinations of CDA and polypropylene fibre (PPF). **Fig. 7** presents a bar graph illustrating slump values against various combinations of CDA and PPF contents. The graph highlights the highest slump value of 46 mm for the mix without CDA or PPF additions and the lowest slump value of 19 mm for the mix containing 15% CDA and 3% PPF. As the percentages of CDA and PPF increase, the slump values generally decrease, indicating a reduction in workability. Specifically, with 15% CDA and 3% PPF, the slump value reached its minimum, demonstrating a significant decline in the concrete's flowability under these conditions.

The observed reduction in slump values with increasing CDA and PPF percentages can be attributed to several factors. CDA, being a pozzolanic material, tends to increase the water demand of the mix due to its finer particle size and higher surface area compared to ordinary Portland cement (OPC). This results in lower workability as the mix becomes more cohesive and less fluid. Similarly, the addition of PPF, which is known to enhance the mechanical properties of concrete by providing improved tensile strength and crack resistance, also contributes to a reduction in workability. The fibres create a network within the concrete matrix, increasing its stiffness and reducing its ability to flow. Therefore, while CDA and PPF positively influence the strength and durability of concrete, their combined effect necessitates adjustments in the mix design, such as the incorporation of superplasticizers or adjustments in water content, to achieve the desired workability.

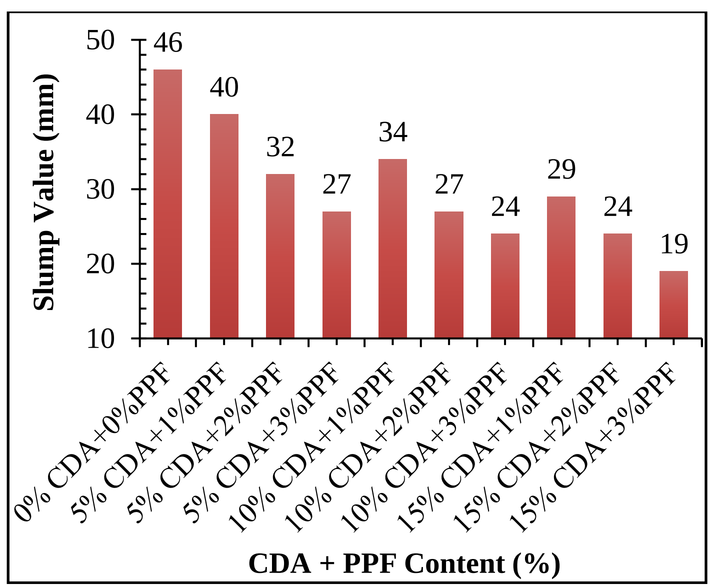

Fig. 7. Slump test results for the combination of CDA and PPF.

4.8. Compressive cube results of concrete cubes

Table 8 provides comprehensive data on the compressive strength of concrete cubes incorporating various ratios of CDA and PPF as substitutes for cement and river sand. The data was compared to normal concrete, which exhibited a compressive strength of 26.39 MPa after 28 days of curing. All tests were conducted as per IS:456-2000 standard [24] to ensure accuracy and reliability. At 3 days of curing, the highest compressive strength of 13.37 MPa was observed with the combination of 10% CDA and 1% PPF, demonstrating the significant influence of CDA and PPF ratios on early strength development. This trend is visually supported by **Fig. 8**, which graphically depicts the compressive strength patterns, highlighting the dominance of the 10% CDA and 1% PPF combination, along with notable strengths such as 11.50 MPa for 5% CDA and 1% PPF, and 8.33 MPa for 10% CDA and 3% PPF.

After 14 days of curing, there was a substantial improvement in compressive strength, with the highest value of 25.04 MPa again attained with the 10% CDA and 1% PPF combination. The results after 28 days of curing show the highest compressive strength of 29.23 MPa with the same combination, indicating its continued effectiveness over time. Conversely, the lowest compressive strength at this stage was 15.3 MPa, noted in the mix with 15% CDA and 3% PPF.

Fig. 8 further highlights this trend, with a bar chart illustrating the consistent performance of the 10% CDA and 1% PPF combination across various curing durations, alongside other significant strengths such as 24.17 MPa for 5% CDA and 2% PPF, and 19.87 MPa for 10% CDA and 3% PPF. This graphical representation provides an extensive overview of the compressive strength variations depending on the different CDA and PPF ratios after 28 days of curing, underscoring the considerable impact of these additives on the development of concrete strength.

The observed results can be justified by the pozzolanic activity of CDA, which contributes to the formation of additional calcium silicate hydrate (C-S-H) in the cement matrix, enhancing long-term strength and durability. PPF, on the other hand, improves the tensile strength and crack resistance of the concrete, contributing to overall mechanical performance. The optimal combination of 10% CDA and 1% PPF appears to provide a balanced enhancement of compressive strength and durability. At the same time, higher levels of CDA and PPF may lead to excessive water demand and reduced workability, thus negatively impacting the strength development. Therefore, carefully optimizing CDA and PPF ratios is crucial for achieving the desired improvements in concrete properties.

Table 8. Compressive strength results of normal and designed concrete cubes at 3,14 and 28 days of curing.

S. No.	% CDA in cement	% PPF in Fine Aggregate	Cube area (mm^2)	Water/cement	Cube wt. (kg)	Cube density (kg/m^3)	Crushing load (kN)	Cube strength (MPa)
Control Mix								
1			22500	0.45	8.35`	2616.30	230.18	10.23
2			22500	0.45	8.43	2497.78	531.45	23.62
3			22500	0.45	8.41	2491.85	593.78	26.39
For 3 days								
4		1	22500	0.45	8.2	2429.63	258.75	11.50
5	5	2	22500	0.45	7.81	2302.22	275.18	12.23
6		3	22500	0.45	7.77	2314.07	253.58	11.27
7		1	22500	0.45	8.17	2420.74	300.83	13.37
8	10	2	22500	0.45	8.0	2370.37	249.75	11.10
9		3	22500	0.45	7.79	2308.15	187.43	8.33
10	15	1	22500	0.45	8.06	2388.15	232.43	10.33

11		2	22500	0.45	7.87	2331.85	209.25	9.30
12		3	22500	0.45	7.46	2210.37	175.70	7.80
For 14 days								
13		1	22500	0.45	8.11	2402.96	516.83	22.97
14	5	2	22500	0.45	7.72	2287.41	543.83	24.17
15		3	22500	0.45	7.65	2266.67	509.18	22.63
16		1	22500	0.45	8.03	2379.26	563.40	25.04
17	10	2	22500	0.45	7.88	2334.81	533.25	23.7
18		3	22500	0.45	7.63	2260.74	477.08	19.87
19		1	22500	0.45	8.02	2376.30	414	18.4
20	15	2	22500	0.45	7.86	2328.89	376.43	16.73
21		3	22500	0.45	7.47	2213.33	317.25	14.1
For 28 days								
22		1	22500	0.45	8.08	2394.07	605.7	26.92
23	5	2	22500	0.45	7.92	2346.67	621	27.60
24		3	22500	0.45	7.86	2328.89	522.90	23.24
25		1	22500	0.45	8.02	2376.30	657.68	29.23
26	10	2	22500	0.45	7.94	2352.59	595.35	26.46
27		3	22500	0.45	7.88	2334.81	468.68	20.83
28		1	22500	0.45	7.94	2352.59	491.40	21.84
29	15	2	22500	0.45	7.73	2290.37	411.75	18.3
30		3	22500	0.45	7.55	2237.04	344.25	15.3

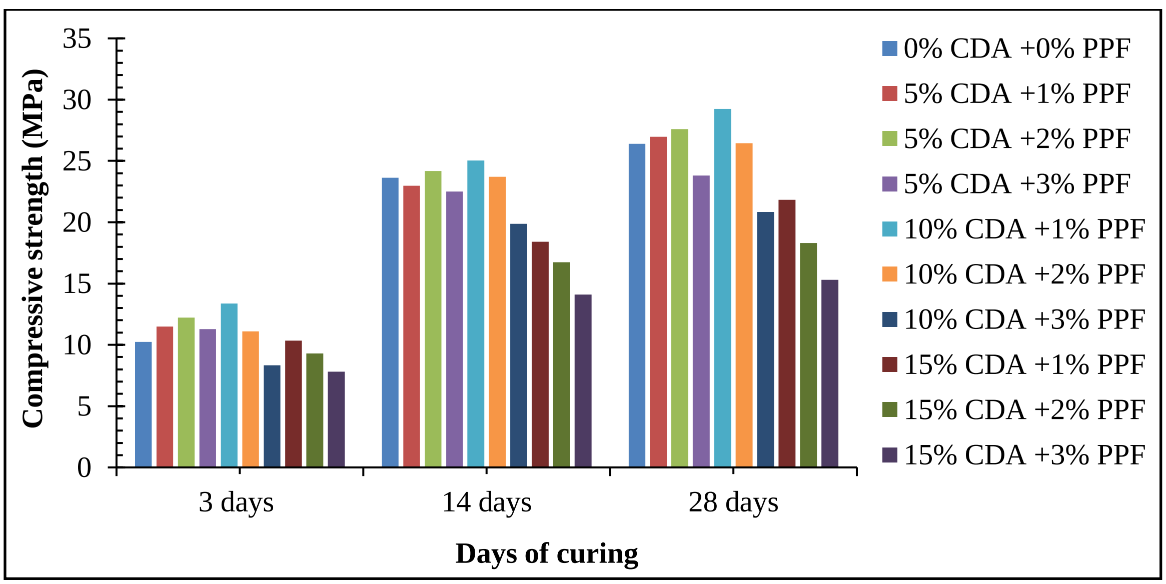

Fig. 8. Comparison of compressive strength of normal cubes and cubes cast with different CDA and PPF proportions.

4.9. Water absorption tests of concrete with varying proportions of CDA and PPF

Water absorption percentages of concrete cubes with varying proportions of CDA and PPF were determined by following IS: 1124:1974 standard [25]. **Table 9** presents a comprehensive examination of the water absorption data at different curing durations. After 3 days of curing, the highest water absorption percentage was recorded at 4.83% for the combination containing 10% CDA and 3% PPF, while the lowest was 2.62% observed for the combination without CDA or PPF additions. After 14 days, the highest water absorption percentage increased to 4.93% for the combination of 15% CDA and 3% PPF, whereas the lowest was 2.28% for the mixture comprising 5% CDA and 1% PPF. Finally, after 28 days, the highest water absorption percentage was 4.86% for the combination of 15% CDA and 3% PPF, while the lowest was 2.21% for the mix without any additives.

These findings indicate that the inclusion of CDA and PPF affects the water absorption properties of concrete over time. The increased water absorption observed with higher percentages of CDA and PPF can be attributed to the porous nature of CDA, which increases the overall porosity of the concrete matrix. Additionally, PPF, while improving tensile strength and crack resistance, can also create microchannels within the matrix that facilitate water ingress. Consequently, the optimal balance of CDA and PPF is crucial to maintain the desirable properties of concrete while mitigating excessive water absorption. This variation in moisture absorption capabilities underscores the importance of optimizing the proportions of CDA and PPF to enhance the durability and performance of concrete.

Table 9. Water absorption of concrete cubes with different proportions of CDA and PPF.

S. No.	% CDA in cement	% PPF in Fine Aggregate	Water Absorption (%)		
			3 Days	14 Days	28 Days
1	0	0	2.62	2.43	2.21
2	5	1	2.70	2.28	2.70
3		2	2.91	2.88	2.00
4		3	4.39	4.38	4.28
5	10	1	3.90	3.86	2.46
6		2	4.34	4.19	4.22
7		3	4.83	4.13	4.24
8	15	1	2.97	3.09	2.87
9		2	3.83	3.56	3.79
10		3	4.55	4.93	4.86

5. Conclusions

The integration of increasing percentages of CDA and PPF in concrete led to a noticeable decrease in workability. This reduction is attributed to the increased surface area and rough texture of CDA and the fibrous nature of PPF, which both demand higher water content for effective mixing. At a composition of 10% CDA and 3% PPF, the concrete exhibited a significant increase in water absorption. This phenomenon can be ascribed to the porous structure of CDA and the presence of organic components that enhance the water absorption capacity of the concrete matrix. Substituting cement with 5% and 10% CDA and sand with 1% and 2% PPF resulted in an improvement in com-pressive strength. However, when CDA replacement exceeded 10% and PPF replacement surpassed 2%, a decline in compressive strength was observed. This decline can be linked to excessive porosity and reduced cohesiveness at higher replacement levels. The combination of 10% CDA and 1% PPF demonstrated the highest compressive strength at 29.23 MPa. The optimal combination, balancing both strength and workability, was identified as 10% CDA and 2% PPF. Increasing CDA concentration in concrete requires more water to maintain workability. Conversely, PPF integration decreases water demand due to its workability-maintaining properties and hydrophobic nature, which helps to reduce the water-cement ratio. Based on the findings, it is recommended to use up to 10% CDA and 2% PPF. The most advantageous results were recorded at the combination of 10% CDA and 1% PPF. The inclusion of CDA and PPF in concrete offers several benefits, including enhanced cracking resistance, improved durability, increased compressive strength, and extended service life of concrete structures such as roads and floors. Additionally, these materials contribute to lightweight concrete properties, providing cost-effective and sustainable solutions for building applications.

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Data availability

Raw data of the research article is available with the authors and will be provided as per a request from the journal.

Ethical approval

Not applicable.

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