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In-Depth Analysis of Concrete Treated With Cow Dung Ash Exposed to Freshwater

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Abstract:

Concrete constructions located in close proximity to a water environment, whether they are directly or indirectly exposed, experience both physical and chemical transformations. The ingress of water into the permeable concrete prompts the need for implementing appropriate modifications to the visible concrete. Cow dung ash has pozzolanic properties that have the potential to provide high-quality concrete constructions. The primary objective of this research is to investigate the properties of M30 grade concrete mix, namely regular concrete and concrete treated with CDA. The preparation of concrete was conducted by including CDA as a partial substitute for OPC at a rate of 15%.Following a curing period of 28 days, the specimens were further subjected to immersion in fresh water for durations of 56, 90, 180, and 365 days. The results indicated that there was a considerable improvement in pH levels, compressive strength, split tensile strength, and overall durability. X-ray diffraction analyses were conducted to determine the crystalline structures, while Field Emission Scanning Electron Microscope investigations were undertaken to examine the structural morphology of the concrete specimens. Both investigations demonstrated the existence of a higher quantity of calcium silicate hydrate and cementitious products in concrete that was treated with CDA. A lower bacterial density was detected on concrete surfaces that were changed with CDA in comparison to those that were not modified (referred to as NC).

Keywords: Strength and Durability of Concrete Composed of Cow Manure, microscopic, pozzolanic

1.0 INTRODUCTION

Concrete is often regarded as being the second most commonly used building material on a global scale. Various types of concrete structures may be seen inside aquatic environments, such as tanks, pillars, dams, foundations, pipelines, poles, and other similar entities [1]. The concrete buildings that are exposed to fresh water are subject to ongoing degradation issues, perhaps resulting from freeze-thaw deterioration. The observed outcomes of this phenomenon include the generation of internal pressures inside the capillaries and pores of the concrete, leading to notable expansion, cracking, and scaling of concrete's structures. The degradation of fresh water due to many factors such as cement hydration products, alkali-aggregate interactions, crystallization, frost action, corrosion, erosion, and more, poses a significant challenge for concrete structures [2,3]. There are many factors that contribute to the decline in strength and rise in permeability in concrete buildings, rendering them more vulnerable to subsequent attacks and destruction [4]. The concrete industries are not only employing significant amounts of raw materials, such coarse aggregates, sand, and water, but also consuming billions of tons of Ordinary Portland Cement (OPC). These activities are deemed environmentally unfriendly due to their high energy consumption and the subsequent emission of greenhouse gases (GHG), which contribute to the phenomenon of global warming. The preservation of energy is a crucial measure in addressing the challenges posed by the energy crisis and environmental deterioration. According to a study [5], the expenditure on energy in the majority of cement manufacturing facilities is above 25% of the overall production expenses. The production of novel materials and components as building materials contributes to the development of energy-efficient structural materials [6]. The use of everyday waste for the development of new recycling green building materials enhances the attributes associated with green building [7]. Recycled materials provide commendable environmental attributes [8]. In contemporary times, there has been a notable surge in the production of garbage, resulting in a pressing issue concerning its proper disposal. Waste buildup is mostly seen in places with high population density, when a significant portion of these items are left as stockpiles, disposed of improperly as rubbish, or deposited illegally as scrap materials in specific locations. The use of cement, sand, and coarse aggregates as substitutes for waste materials is mostly confined to the construction sector [9]. Cow dung ash (CDA) has pozzolanic properties, making it a viable candidate for use as a pozzolana in the manufacturing of concrete. In the context of India, it has been observed that a solitary bovine creature is capable of generating an estimated 30 kilograms of dung on a daily basis, resulting in an annual production of roughly 12 metric tonnes. There exists an ample supply of raw materials necessary for the production of cow dung ash on an industrial scale. The distribution of cow manure is widespread across India, particularly in rural regions. In the context of small and medium-scale industries, it is estimated that a quantity of around 3.5 metric tons of raw cow dung is required to yield 1 metric ton of cow dung ash. The objective of this research is to investigate the impact of fresh water on the strength, durability, and microstructural features of concrete buildings that have undergone modifications including the partial substitution of cement with cow dung ash (CDA). Microbes also have an impact on concrete buildings immersed in fresh water, as they establish colonies on the concrete surface, as well as inside its pores, capillaries, micro-cracks, and subsequently cause damage. The phenomenon of bacterial adhesion to concrete surfaces in various infrastructure components such as bridges, tanks, pipelines, and cooling towers has been relatively understudied. According to the literature, it has been suggested that the use of dung might potentially enhance work ability and durability, or serve as an extra binding agent [10]. The individual referred to as "Pam" In a study conducted by Fom et al., an examination was made on the compressive strength of bricks stabilized with a mixture of cement and cow dung. Additionally, the researchers analyzed the compressive strength of lateritic soil blocks treated with cow dung, comparing it to that of conventional lateritic blocks. The findings indicated that the lateritic soil blocks treated with cow dung exhibited a greater compressive strength when compared to the usual lateritic blocks [11]. Yalley and Manu conducted an investigation on the strength and durability characteristics of earth bricks that were stabilized with cow dung [12]. Cow dung is well recognized as a natural antiseptic and inhibitor of microorganisms. Additionally, when included into concrete buildings, it serves as an insect repellant and effectively hinders the penetration of UV rays. In recent years, several researchers have undertaken efforts to enhance concrete constructions by including cow dung, since it has been shown to enhance their strength and overall quality. The corrosion of concrete and its resistance to fresh water were examined by an investigation of slag concrete, wherein a replacement rate of 20-30% yielded the most favorable corrosion outcomes [13]. In the Indian context, it is customary to use cow dung as a waterproofing agent. This practice involves combining one part cow dung with five parts soil, measured by weight. The resulting mixture is transformed into a smooth paste by adding water, and afterwards applied to seal surface fissures [14]. The study conducted by Sirri et al. (15) examined the chemical properties and pozzolanic effects resulting from the partial substitution of cement with Cattle Waste Ash (CWA). The researcher discovered that substituting 5%, 10%, and 15% of cement with CWA resulted in the most favorable outcomes in terms of 56-day compressive strengths. According to the farmer, a group of students from Prasetiya Mulya Business School in Indonesia have successfully created construction bricks using cow dung as a primary ingredient. These bricks consist of 75% cow manure and have been shown to be not only 20% lighter than traditional clay bricks, but also possess a compressive strength that is 20% stronger [16]. Tchamdjou et al. (year) elucidated the significance of lightweight concrete, highlighting its several benefits including a greater strength-to-weight ratio, improved tensile strain capacity, reduced coefficient of thermal expansion, and enhanced heat and sound insulation properties (citation). Several studies have also documented activities related to the antibacterial corrosion of concrete in the existing literature. The existence of micro-cracks in concrete does not result in a substantial loss of strength. However, it is important to note that the presence of moisture might potentially create conditions conducive to the development of microorganisms inside the concrete. Several research organizations in India are now doing investigations on the antibacterial properties of concrete modified with various admixtures, such as fly ash and superplasticizer, with the aim of preventing biofouling [18]. Prior research has shown that within the category of M30 grade concrete mixes, namely those with varying levels of CDA replacement by OPC (2.5%, 5.0%, 7.5%, 10.0%, 12.5%, and 15.0%), a 15% replacement of CDA has demonstrated notable improvements in strength, permeability, pH decrease, and microbial growth. This finding was reported in a previous study [19]. This research was designed to conduct a one-year comparative analysis of normal concrete (NC) and concrete modified with calcium dihydroxide (CDA) at a 15% replacement rate of ordinary Portland cement (OPC). The objective was to investigate the mechanical properties, durability, microstructural characteristics, and antibacterial activities of both concretes in a fresh water environment.

2.0 MATERIALS AND PROCEDURES

2.1 SPECIMEN PREPARATION

Two distinct varieties of concrete mixture, namely regular concrete (NC) and concrete enhanced with CDA by a 15% substitution of Ordinary Portland Cement (OPC) with CDA, were developed in accordance with the specifications outlined in IS 8112:1989. The collection of cow excrement was followed by a drying process under sunshine. Subsequently, the dried cow dung was subjected to combustion to yield ash, which was then passed through a mesh with a size of 425µ [20]. The water exhibited a consistent nature, while the proportion of super plasticizer was adjusted in accordance with the specified criteria. Table 1 displays the composition of the mixes used in the production of NC and concrete modified CDA specimens for all mix variations. The compressive strength, split tensile strength, and rapid chloride permeability test (RCPT) were conducted on a cube measuring 150×150mm, a cylinder measuring 150×300mm, and another cylinder measuring 100×200mm. These tests were carried out using the technique outlined in IS 516 (IS 516-1959, IS 9103:1999 [21,22]) and the RCPT was conducted according to ASTM C1202 [23]. The compaction of the concrete mixture was performed using the internal vibration technique in order to prevent the expulsion of entrapped air from the concrete mixture during the casting process (Reference 24). The specimens were retrieved from the aquatic environment at intervals of 7, 28, 56, 90, 180, and 365 days in order to conduct additional analyses.

2.2 ENVIRONMENTAL EXAMINATIONS IN FRESH WATER

2.1. Samples' preparation

The two distinct forms of building materials mixture, specifically regular concrete (NC) and building materials modified with CDA through a 15% substitution of Ordinary Portland Cement (OPC) with CDA, were formulated in accordance with the guidelines outlined in IS 8112:1989. The bovine excrement was gathered, subjected to the process of desiccation under the sun's rays, incinerated to yield the resultant ash, and subsequently filtered through a mesh with a pore size of 425 micrometers [20]. The water remained consistent, and the proportion of super-plasticizer was adjusted according to the specified criteria. Table 1 displays the composition of the mixtures used for the specimens of NC and concrete modified CDA, encompassing all mix variations. The compressive strength, split tensile strength, and rapid chloride permeability test (RCPT) were conducted on a cube measuring 150×150mm, a cylinder measuring 150×300mm, and another cylinder measuring 100×200mm. The testing procedures followed the guidelines outlined in IS 516 (IS 516-1959, IS 9103:1999 [21,22]) for compressive strength and split tensile strength, and ASTM C1202 [23] for the RCPT. The compacted state of the concrete combination was achieved through the utilization of the interior vibration technique, which was employed to prevent the expulsion of entrapped air from the concrete mixture during the casting process [24]. The specimens were retrieved from the aquatic environment at intervals of 7, 28, 56, 90, 180, and 365 days in order to conduct additional analysis.

2.2. Investigations of exposure in fresh water

After 24 hours, all cube and cylinder-shaped concrete samples were taken out of their molds and stored for 28 days in a drying tank in the lab that was kept at a temperature of 28 ± °C [25,26] (Fig. S-1). The specimens were put right into the concrete tank with fresh water after being moved from the drying tank. For a one-year study, the fresh water was reused every 15 days. After 56, 90, 180, and 365 days, the items were taken out. The samples were analyzed after being exposed. Their pH levels (both on the outside and inside) were measured, as well as their mechanical properties (compressive and split tensile strength), durability (RCPT) studies, microstructural properties (X-ray diffraction studies {XRD} and Field Emission Scanning Electron Microscope {FESEM}), and antibacterial activities (TBC).

3.0 Post-exposure assessments

3.1 pH measurement investigation

Ambient and internal pH measurements were conducted on NC and concrete samples that had been modified with CDA. The specimens were cured for 28 days, and subsequently exposed to fresh water for durations of 56, 90, 180, and 365 days. The surface pH was determined using the WTW Sen Tix −3110 electrode, while the interior pH was measured using the Hanna HI-2211 electrode.

3.2. Analysis of Mechanical characteristics

The compressible strength (as per IS 516) and split tensile force (as per IS 5816) test results of concrete specimens exposed to fresh water for durations of 56, 90, 180, and 365 days had been contrasted to those of specimens treated for 7 and 28 days. Both tests were conducted utilizing an automatic compression testing machine with a capacity of 3000kN, employing varying levels of operating pressure.

3.3. Tests on durability

The research included the implementation of the Rapid Chloride Permeability Test (RCPT) in order to assess the chloride resistance of both Normal Concrete (NC) and concrete that had been treated with Calcium-Deficient Apatite (CDA). The study used cylindrical specimens measuring 200×100mm that had been cured for 28 days. These specimens were then exposed to fresh water for durations of 56, 90, 180, and 365 days. The electrical conductivity of the specimens was determined in accordance with the ASTM C 1202–97 standard [27]. The specimens, which had a thickness of 50mm and a diameter of 100mm, were securely affixed between two reservoirs using an epoxy bonding agent. One of the reservoirs, connected to the positive terminal of the DC source, was filled with a solution of 0.3N NaOH. The other reservoir, connected to the negative terminal of the DC source, contained a solution of 3% NaCl. The experimental configuration was maintained during a duration of six hours in order to observe and measure the quantity of electric current that traversed the specimens during the experiment.

Table 1
Mix details of normal and CDA modified concrete.

Mix Proportion	**Grade of Concrete: M30 - Water/Cement Ratio: 0.44**								
	Free water	Cement	CDA	Total Binder	Fine Agg. (River sand)	Coarse Agg.			Super plasticizer (Weight %)
Normal Concrete	0.44	1	–	1	2.18	3.12			0.01 (1% of Cement)
CDA Modified Concrete (15% by weight of total binder)	0.44	0.85	0.15	1	2.18	3.12			0.015 (1.5% of Binder)
Details of Mix per m^3 of Concrete	Free Water (Kg)	Cement (Kg)	CDA	Total Binder (Kg)	Fine Agg. (River sand)	Coarse Agg. (Kg)			Admixture (Kg)
						Total C. A	20 mm (50%)	12 mm (50%)	
Normal Concrete	160.6	365	–	365	794.97	1139.54	569.77	569.77	3.65
CDA Modified Concrete	160.6	310.25	54.75	365	794.97	1139.53	569.77	569.77	5.48

3.4. Properties of microstructures

The X- Ray diffraction experiments were conducted using the Rigaku (9 kW) smartLab X-ray diffractometer, with Copper (Kα) serving as the target material. The NC and concrete specimens, which had been treated with CDA for 28, 56, and 365 days, were then crushed to produce a fine powder. The unknown crystalline compounds were analysed and identified using the Bragg-Brentano method. The scanning increment was 0.02°, the data collection duration was 1 second, and the measurement range spanned from 10° to 80° in 2θ Cu Kα. The X-ray tube voltage and current were set at a constant value of 30 kV and 100 mA, respectively. The JCPDS database, a standard database for X-ray powder diffraction pattern, was utilised to identify the phases of several crystalline phases in both NC and concrete that were modified with CDA. The study utilised Field Emission Scanning Electron Microscopy (FESEM) to examine cylindrical specimens of Normal Concrete (NC) and concrete treated with Calcium Dihydroxide (CDA) for durations of 28, 56, and 365 days. The surface morphology of the specimens was studied using a Carl Zeiss microscope at 20 kV. Every specimen chosen for the analysis was covered with a layer of gold to facilitate the transmission of electricity.

3.5 Antimicrobial actions

We measured the bacterial density of cube concrete specimens exposed for 56, 90, 180, and 365 days in fresh water of North Carolina and concrete amended with CDA. The Total Viable Count (TVC) of bacterial aerobic bacteria was calculated by culture methods with nutritional agar (NA) (Hi Media-M001). By culture in Pseudomonas Agar (PSA) (Hi Media-MM119), Manganous Agar (MnA) (Hi Media-M771), Cyanophycean Agar (CA) (Hi Media-M699), Czapek Dox Agar (CDA) (Hi Media-M1170) and improved Postgate [28], the average number of various microbes including Pseudomonas sp., Manganese-oxidizing microbes, algal fungal organisms, and anaerobic sulfate-reducing bacteria in the biofilm was determined. To remove loosely clinging cells, the concrete specimens were taken out of fresh water and gently rinsed. Cube species' biofilm was spread into 70 millilitres of sterile phosphate buffer (0.0425 g KH_2PO_4, 0.19 g $MgCl_2$ per litre) using a sterile brush. A 0.1 ml sample of each dilution of the bacterial cell suspension was produced and plated onto the appropriate media. After 24–48 hours of 32 °C incubation, the bacterial density was calculated [29].

4.0 Results and conclusion

4.1. Results of pH

For NC and concrete modified with CDA, the pH decrease was examined as both the surface and internal pH after 28 to 365 days in fresh water. It was discovered that both the internal and surface pH of the two specimens showed a tendency towards lowering. Concrete amended with CDA showed smaller pH lowering throughout all days when compared to NC (Table 2). This might be because extra free lime (CaO) from cement combined with CDA to generate calcium silicate hydrate (CSH) when it leached from the NC and in concrete treated with CDA.

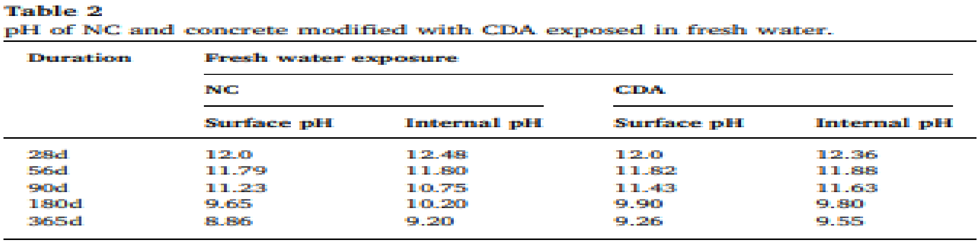

Table 2
pH of NC and concrete modified with CDA exposed in fresh water.

Duration	Fresh water exposure			
	NC		CDA	
	Surface pH	Internal pH	Surface pH	Internal pH
28d	12.0	12.48	12.0	12.36
56d	11.79	11.80	11.82	11.88
90d	11.23	10.75	11.43	11.63
180d	9.65	10.20	9.90	9.80
365d	8.86	9.20	9.26	9.55

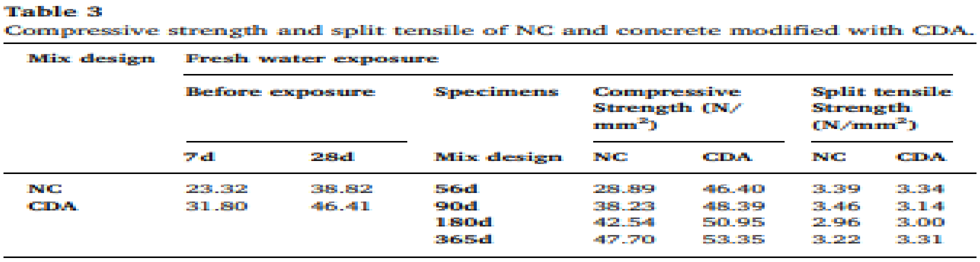

Table 3
Compressive strength and split tensile of NC and concrete modified with CDA.

Mix design	Fresh water exposure						
	Before exposure		Specimens	Compressive Strength (N/mm^2)		Split tensile Strength (N/mm^2)	
	7d	28d	Mix design	NC	CDA	NC	CDA
NC	23.32	38.82	56d	28.89	46.40	3.39	3.34
CDA	31.80	46.41	90d	38.23	48.39	3.46	3.14
			180d	42.54	50.95	2.96	3.00
			365d	47.70	53.35	3.22	3.31

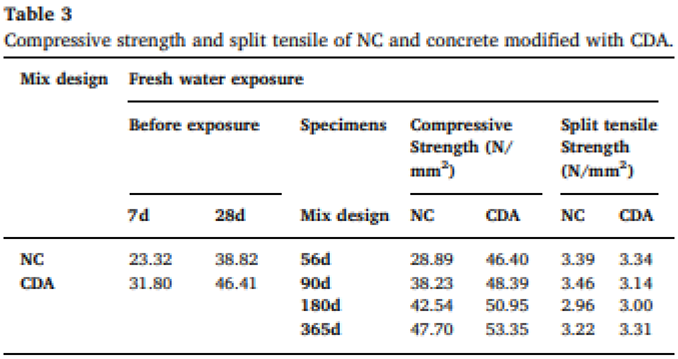

Table 3
Compressive strength and split tensile of NC and concrete modified with CDA.

Mix design	Fresh water exposure						
	Before exposure		Specimens	Compressive Strength (N/mm^2)		Split tensile Strength (N/mm^2)	
	7d	28d	Mix design	NC	CDA	NC	CDA
NC	23.32	38.82	56d	28.89	46.40	3.39	3.34
CDA	31.80	46.41	90d	38.23	48.39	3.46	3.14
			180d	42.54	50.95	2.96	3.00
			365d	47.70	53.35	3.22	3.31

In contrast, concrete amended with CDA showed 31.80 N/mm2 for 7 days and 53.35 N/mm2 for 365 days. For NC, these values were 23.32 N/mm2 and 47.70 N/mm2. Concrete that had been treated with CDA was found to be stronger than NC. Between 56 and 365 days, the split tensile strength of the concrete treated with CDA (3.34 – 3.31 N/mm2) and NC (3.39–3.22 N/mm2) varied. The average results indicated that strength increased, decreased, and then increased again at a greater age (Table 3). Graphs S-1 and S-2 show the standard deviation of the average results for split tensile strength and compressive strength, respectively.

5. Discussion

The aim of this research was conducted to determine the importance of recycling readily available resources with inexpensive material to accomplish the key characteristics of concrete, including its mechanical, workability, and durability. Cow dung ash was not utilised for severe structural loads, but rather as an additional cementitious material for floor applications or as a building component [30]. A benefit of cow dung modified concrete that provides low heat conductivity and light weight was described by Ojedokun et al. [31]. 15% of the Ordinary Portland Cement (OPC) cow dung ash (CDA) was substituted in the concrete buildings. It was contrasted with normal concrete (NC) grade M30. A comparison investigation was conducted between NC and concrete modified with CDA to determine the mechanical, durability, microstructural, and antibacterial activities of the two specimens after they were exposed to fresh water for 56, 90, 180, and 365 days. Concrete that has been altered with CDA and NC were compared for differences in pH lowering. Since pH is influenced by external elements including carbonation, free chloride ions, microorganisms, and other meteorological circumstances, it was raised on the surface of the concrete [32]. In this investigation, NC showed a greater pH reduction than CDA-modified concrete. This is also a result of the cement's free lime (CaO) reacting with CDA and producing additional calcium silicate hydrate (CSH), which increases the strength of CDA-modified concrete [20]. However, when unreactive free lime is exposed to fresh water, it leaches out of normal concrete (NC). After 365 days in fresh water, the concrete treated with CDA exhibited significantly higher strength in both compressive and split tensile tests compared to NC. After 365 days, the RCPT values in the concrete amended with CDA exhibited a better result, indicating reduced durability. Additional research was done using XRD and FESEM to determine the morphological and chemical composition changes for NC and CDA-modified concrete. The presence of more calcium silicate hydrate, as indicated by the XRD data, indicates that the concrete treated with CDA has more strength than NC. The strengthening process in concrete modified with CDA is caused by the production of a silicon dioxide peak and the presence of calcium silicate hydrate from 56 to 365 days [33]. Because nanosilica appears to be dispersed uniformly in concrete treated with CDA rather than NC, the FESEM analysis showed that the concrete changed with CDA had superior structures than the NC. When CDA was added to concrete instead of NC, which acts as a filler and lowers porosity, FESEM examination revealed a needle-like structure of calcite production [34]. When comparing concrete changed with CDA to NC, the order of bacterial density was lower in the former. Overall, this study compares the effects of using CDA on modified concrete to NC concrete and finds that the former performs better in terms of pH deterioration, strength, durability, and lower bacterial density.

This study was performed for significance of recycling of available resources with low cost material to achieve the major properties of concrete such as workability, mechanical and durability properties. Cow dung ash was used as supplementary cementitious materials for floor applications or as a building component but not for high structural stresses [30]. Ojedokun et al. explained an advantage of cow ding ash modified concrete that offers lightness of weight and low thermal conductivity [31]. The concrete structures were modified by partially replacing 15% of cow dung ash (CDA) of Ordinary Portland Cement (OPC). It was compared with M30 grade of normal concrete (NC). Both the specimens were exposed in the fresh water and withdrawn after 56, 90, 180 and 365 days and a comparative study of NC with concrete modified with CDA was done to find out its mechanical, durability, microstructural and antimicrobial activities in fresh water. The difference in pH reduction was compared with NC and concrete modified with CDA. pH was increased on concrete surface as it depends on the exposure conditions of the environment and gets affected by external factors such as carbonation, free chloride ions, microorganism and other climatic conditions [32]. In this study, compared to cow dung ash (CDA) modified concrete, more pH reduction was observed in NC. This is also because of the reaction of free lime (CaO) of the cement with CDA and the formation of more calcium silicate hydrate (CSH), thereby strength of CDA modified concrete has been increased [20]. But in normal concrete (NC), unreactive free lime has been leached when it is exposed to fresh water. The compressive strength and split tensile strength showed appreciably high strength in concrete modified with CDA than NC after 365 days of exposure in fresh water.

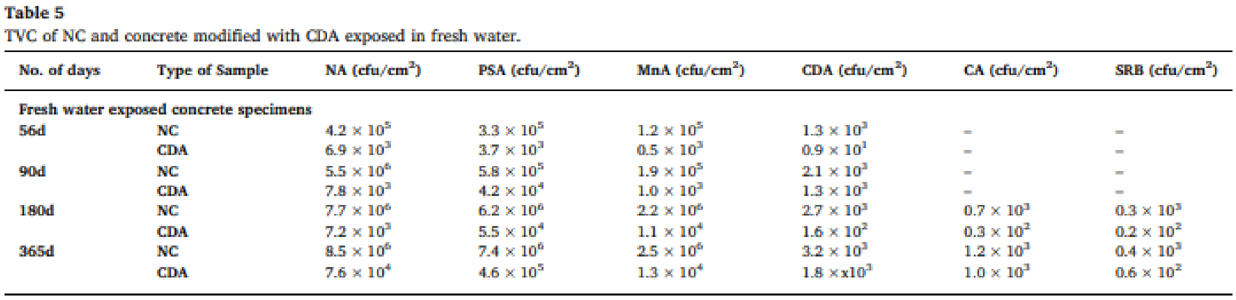
Table 5
TVC of NC and concrete modified with CDA exposed in fresh water.

No. of days	Type of Sample	NA (cfu/cm^2)	PSA (cfu/cm^2)	MnA (cfu/cm^2)	CDA (cfu/cm^2)	CA (cfu/cm^2)	SRB (cfu/cm^2)
Fresh water exposed concrete specimens							
56d	**NC**	4.2×10^5	3.3×10^5	1.2×10^5	1.3×10^3	–	–
	CDA	6.9×10^3	3.7×10^3	0.5×10^3	0.9×10^1	–	–
90d	**NC**	5.5×10^6	5.8×10^5	1.9×10^5	2.1×10^3	–	–
	CDA	7.8×10^3	4.2×10^4	1.0×10^3	1.3×10^3	–	–
180d	**NC**	7.7×10^6	6.2×10^6	2.2×10^6	2.7×10^3	0.7×10^3	0.3×10^3
	CDA	7.2×10^3	5.5×10^4	1.1×10^4	1.6×10^2	0.3×10^2	0.2×10^2
365d	**NC**	8.5×10^6	7.4×10^6	2.5×10^6	3.2×10^3	1.2×10^3	0.4×10^3
	CDA	7.6×10^4	4.6×10^5	1.3×10^4	$1.8 \times x10^3$	1.0×10^3	0.6×10^2

The RCPT values showed a better result in after 365 days in concrete modified with CDA, which indicated less durability. Further the studies were performed to know the changes in chemical composition and morphology by XRD and FESEM for NC and concrete modified with CDA. XRD results showed the presence of more calcium silicate hydrate which is sign of enhanced strength in concrete modified with CDA than NC. The formation of silicon dioxide peak and presence of calcium silicate hydrate from 56 to 365 days are responsible for strengthening process in concrete modified with CDA [33]. The FESEM study revealed the better structures in concrete modified with CDA because of presence of nanosilica seems to be homogenous in dispersion in concrete modified with CDA than NC. FESEM analysis showed needle like structure of calcite formation in concrete modified with CDA than NC which act as filler and reduce porosity [34]. The order of bacterial density was in decreased in concrete modified with CDA compared to NC. Overall, this study evaluates better results on concrete modified with CDA compare to NC with respect to pH degradation, strength, durability and less bacterial density.

6. Conclusion

This study focuses on the efficient utilisation of waste materials and the conservation of energy. The use of CDA has the capacity to enhance the durability and sustainability of high-performance concrete. The reduction of cement usage is crucial both economically and environmentally. The fresh water exposed concrete, which was modified with CDA, exhibited superior performance in terms of pH, mechanical characteristics, durability, and antibacterial activities. Future studies can be conducted to prepare extensive comparative investigations on the chemical deterioration and biodeterioration of concrete modified with CDA, focusing on its improved qualities.

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