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Performance Evaluation of M20 Concrete with Cementitious Substitutes under Saline Water Curing: A Study on Compressive Strength

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ABSTRACT: This study assessed M20 grade concrete with Cow Dung Ash as a partial cement replacement, under saline water curing. Concrete mixes were created with 5%, 10%, and 15% CDA replacements and tested for compressive strength at 7, 14, and 28-days using both portable water and synthetic sea water. Results showed a strength gain with higher CDA under normal water curing, with a maximum compressive strength of 33.4 MPa as a result from 15% CDA. However, compressive strength decreased with higher CDA under saline water curing, with a maximum of 28.3 MPa from 5% CDA. This decline was likely due to structural degradation and incomplete hydration from halides. The study concluded cow dung ash is a practical and sustainable resource in freshwater environments but had limitations under aggressive saline environments. This research also promotes using agro-waste in concrete and furthered knowledge on the importance of curing conditions on the performance of materials.

KEYWORDS: Cow Dung Ash (CDA), M20 Concrete, Cementitious Substitutes, Compressive Strength, Saline Water Curing, Sustainable Concrete

I. INTRODUCTION

While the global demand for environmentally friendly construction practices has increased, the global demand for sustainable alternatives to Ordinary Portland Cement (OPC) has increased as well. OPC production is energy-intensive and known for being a contributor to global CO₂ emissions [1]. The inclusion of supplementary cementitious materials (SCMs) such as fly ash, silica fume, or agricultural waste adopts sustainability and the principles of the circular economy, which are currently high on the agenda, to mitigate some environmental footprint of concrete production and use [2], [3]. Among several choices, CDA, an agro-waste byproduct, has emerged as a viable option based on its pozzolanic properties and filler properties which can modify concrete's microstructure and its long-term strength [4]. Previous work indicates that CDA can partially replace OPC while either maintaining or improving with respect to compressive strength under normal curing conditions [5]. The performance of such concrete in saline environments, however, has not been fully explored. Saline curing may occur in coastal or arid areas that lack freshwater for curing where aggressive ions such as chloride and sulphate may result in durability problems [6].

This study assesses the compressive strength performance of M20 grade concrete with CDA at replacement rates of 5%, 10%, and 15%. Concrete samples were cured in potable water and saline water for 7, 14, and 28 days. The aim of this research was to study the outcome of CDA on compressive strength from a saline exposure, and whether CDA was a suitable material for coastal construction. The findings from this research help contribute to sustainable concrete design, as we now have a better understanding of how the combination of cementitious substitutes and aggressive curing regimes will influence durability. This research was motivated from previous studies, and will be helpful in further narrowing the knowledge gap related to CDA concrete durability in sulphate chloride environments.

II. OBJECTIVE OF THE STUDY

1. To develop M20 concrete mixes using fly ash, silica fume, and cow dung ash to partially replace cement at different percentages.
2. To immerse the concrete samples in saline water and monitor the difference in compressive strength over various curing periods.
3. To compare the compressive strength test results of the substitute-based concrete versus conventional concrete, exposed to the same saline curing conditions.
4. To determine the best percentage and type of cement substitute that can provide similar or more strength than M20 concrete.
5. To investigate the potential for curing concrete with saline water by testing in coastal/H₂O scarce regions.
6. To encourage use of environmental and sustainable options that have waste and by-product materials within civil construction.

III. LITERATURE REVIEW

Supplementary cementitious materials are often used in lieu of part of cement in concrete to decrease cement, increase workability, mechanical properties, and durability, and for environmental benefits [3]. The substitution of natural aggregate in concrete has a change in ratio, and cement replaced by associated slag cement with fly ash. Slag and fly ash are both effective supplementary elements when enhancing cement-based concrete [7]. There is an increasing recognition internationally regarding the need for supplementary cementitious materials, which has resulted in an increase in research on alternatives including fly ash, silica fume, and slag. Each of these materials has established pozzolanic properties that suggest they can act as substitutes for ordinary Portland cement [8], [9]. Fly ash is formed from coal ignition, fly ash is frequently used in concrete as an alternative to cement. One investigation discussed performance of cement containing fly ash and activated fly ash in terms of strength properties [10].

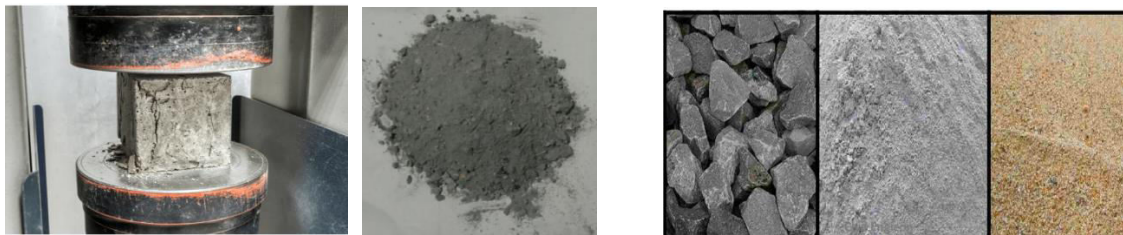
The investigation demonstrated that concrete made with fly ash had increased compressive strength, in comparison to conventional concrete; particularly high strength was achieved with activated fly ash [11]; it is also evident that fly ash has a potential to enhance concrete mechanical properties [12]. Silica fume, an industrial byproduct that is widely recognized for its ability to enhance the strength and durability of concrete, has been studied in combinations that include GGBS, fly ash and silica fume as a component replacement of cement in concrete; the results indicated that mineral admixtures may have varying effects on concrete strength and durability [13]. The use of supplementary cementitious materials in ready-mixed concrete has increased globally for environmental and economic reasons [14]. The study made note that a range of aspects should be considered such as compressive strength, workability, setting time, and heat of hydration.

The construction industry is now facing the problem of implementing sustainability into their processes of production, either by finding or adopting new products and materials that are environmentally friendly or by helping mitigate CO₂ emissions to the atmosphere [15]. Geopolymer concrete is being developed as a sustainable alternative (with less CO₂ emissions) to traditional cement-based concrete [16]. Research has shown that fly ash-based geopolymer binders can be formulated to make mortar and concrete with similar physical properties as cement mortar and cement concrete [17]. This research paper will investigate the utilization of fly ash, ground coarse explosion heater slag or GGBS and metakaolin as an alternative material exemplar in the development of geopolymer concrete, which is a ternary blend. This research study explored the application and effects of fly ash, ground granulated blast furnace slag and metakaolin as alternative maintenance materials in geopolymer concrete examined [18]. The research also investigated the potential of sourcing waste products, such as fly ash and ceramic powder, as substitute materials of geopolymer concrete, which is being identified as a possible building material towards a sustainable future [19]. Similarly, in addition to fly ash, GGBS, and silica fume, agricultural waste, such as cow dung ash, is now attracting attention as a potential source of cementitious material [20], [21]. The study concluded that incorporating waste products, such as fly ash and ceramic powder, into geopolymer concrete is potentially a sustainable building material [19][22].

IV. MATERIAL AND METHODOLOGY

The materials chosen for this investigation were used to make M20 grade concrete with CDA as a partial replacement for cement, and cured in both river (potable) water and saline water. The testing procedures used are based on the relevant Indian Standard codes: Compressive strength test in accordance with IS 516:1959 [23], sieve analysis of cement in accordance with IS 4031 (Part 1):1988 [24], and aggregate testing in accordance with IS 2386 (Part 1):1963 [25].

Fig: 1. Concrete Cube Fig: 2. Cow Dung Ash Fig: 3. Materials (Aggregate, Cement, Sand)



Cement (OPC): Cement was used as the main binder in the mix. The total amount used was 24 kg; a portion of cement was replaced with cow dung ash (CDA) in some mixes at 5%, 10%, and 15%. Cement used had a specific gravity of 3.12.

Sand (Fine Aggregate): Clean, well-graded river sand was considered the fine material, and we used a total amount of 36 kg. The material passed all sieve analysis testing methods, and its specific gravity is equal to 2.6.

Coarse Aggregate (CA): 20 mm size crushed stone aggregate was used as the coarse material, with a total quantity of 72 kg. The aggregate used had a specific gravity of 2.67 and met standard grading.

Cow Dung Ash (CDA): Cow dung ash used in this work was collected and processed through drying and sieving, and it was chosen for this work due to its use as a partial cement replacement in the mix. Total CDA used across the different mix designs (5%, 10%, and 15% replacement) was approximately 10 kg. CDA is a pozzolanic material and part of the sustainability elements in construction.

Water: The concrete was mixed using potable water, and the cement-water ratio was 0.5. A total of 24 kg was utilized in sample preparation alone. Additional water was applied for curing.

Salt Water: salt water was made by mixing 35 grams of sodium chloride (NaCl) with one litre of normal water, which was approximately 40 kg in weight for curing. This salt water had a exact gravity of 1.020 with a pH of 6.70 and chloride ions at 1560 mg/L. This salt water was used to cure concrete samples to determine its effect on compressive strength with replacement of cement with CDA.

Materials Used in Concrete

For this study, the ingredients used were OPC at total quantity of 24 kg, sand at 36 kg, and coarse aggregate size of 20 mm was used in a total quantity of 72 kg. The mixing and sampling water incorporated in the study was 24 kg, and to replicate saline curing conditions, a total of approximately 1.5 kg of sodium chloride (NaCl) was added to the curing water. CDA, was used as a partial replacement material for around 10 kg of the cement used in the concrete mixes. The materials used were measured and mixed to find the compressive strength of an M20 grade concrete when there were different water curing methods involved.

Mixing Process of Material

1. In this study, we produced and tested a total of eighteen concrete cubes utilizing cow dung ash as a substitute for 5%, 10%, and 15% of the cement. Six cubes were made from the same concrete mix for each sample which included 8 kg of cement, 12 kg of sand, and 24 kg of coarse aggregate. The water to cement ratio was 0.5 for making the samples. To replace the cement, 5%, 10%, and 15% of the 8-kg of cement was replaced with cow dung ash. 2. For curing, we used 40 kg of water, in which salt water was made with 35 grams of salt mixed in one litre of regular water.

V. RESULT AND DISCUSSION

The manufacture M20 grade concrete utilizing CDA based cement replacement in the following proportions: 5%, 10%, and 15% replacement of cement. Then the compressive strength was investigated after it cured for 7, 14 and 28 days in both normal water and salt water. With regards to the compressive strength testing, it was noted that all concrete samples cured in normal water achieved compressive strength at the later periods of time, and that the compressive strength of the concrete samples increased with the % of CDA in the mixture proportion, until it achieved compressive strength. The highest compressive strength (33.4 MPa) of CDA at 15% after twenty-eight days of usual water curing was also the trend, which indicated that CDA will provide good beneficial materials for strength if used in the correct proportions and the components were cured in the appropriate conditions.

The results of the compressive strength investigation were then examined with salt water curing. The salt water curing also showed a decrease in compressive strength as CDA percentages increased. The only exception being that 5% CDA (salt water) still showed reasonable compressive strength at 28 days (28.3 MPa). However, if the percentage of CDA was increased to 10% and 15%, then the compressive strength using salt water curing was substantially decreased (24.6 MPa and 22.0 MPa respectively at 28 days). It was beyond a doubt that the salt water had an adverse effect on compressive strength development using either 10% or 15% CDA replacement. Overall discussions clearly indicated that CDA replacement was a feasible additive to concrete mixes (up to 15%) with normal water curing. However, with the effect of salt water on concrete performance, it was clear that CDA was unfavourable for concrete mixes with the increased replacement.

Table: 1. Material - Partial Replacement of Cement (%)

%	CDA	CEMENT	W/C RATIO
5%	5	95	0.5
10%	10	90	0.5
15%	15	85	0.5

The above table shows the proportions which were taken in the experiment where CDA was partially replacing cement. This analysis was done using three levels of replacing cement. These levels included 5%, 10%, and 15%. Each percentage has a different amount of cement being used, while the total amount of binder being used by weight was the same, and therefore had to reduce the mass of cement down to account for replacing a portion with CDA. The W/C ratio was constant in each mix at 0.5 to achieve the same workability. For example, in the 5% mix, 5% CDA and 95% cement were used. For 10% CDA, 90% cement, and for 15% CDA mix, 85% cement was used. The table presents a starting point to determine how CDA replacement at varying replacement levels affect concrete compressive strength.

Table:2. Observation Table for Cow Dung Ash with Normal Water (Compressive Strength)

CDA	7 DAYS	14 DAYS	28 DAYS
5%	18.8	22.8	30.0
10%	19.3	24.3	31.9
15%	20.6	26.5	33.4

The compression strength of the concrete samples with different percentages of CDA was tested in a study. Samples were cured in normal (fresh) water. Curing was conducted at 7, 14 and 28 days periods to determine the compressive strength. As can be seen in this table, with each increasing percentage of CDA, also increased compressive strength values. The compressive strength values after curing at the 5% CDA replacement were 18.8 MPa after curing for 7 days, 22.8 MPa after the 14 day curing period, and 30.0 MPa after the 28 days of curing. At the 10% CDA replacement condition, the compressive strength value was much greater than the compressive strength value at 5% CDA, at 31.9 MPa for the 28 day curing period. The maximum of the compressive strength values occurred at 15% CDA in which the 28 day compressive strength was 33.4 MPa. These results indicate that CDA positively impacts strength development over time, given the curing is in normal water.

Table:3. Observation Table Cow Dung Ash with Salt Water (Compressive Strength)

CDA	7 DAYS	14 DAYS	28 DAYS
5%	16.20	20.20	28.30
10%	15.10	18.50	24.60
15%	13.40	16.50	22.00

This table displays the compressive strength data for concrete samples made with Cow Dung Ash and cured with salt water. Additionally, the strength was measured at 7, 14 and 28 days. Unlike the behaviour observed with normal water, the results indicated the strength diminished with increased portion of CDA. At the replacement of 5% CDA, samples had compressive strength of 16.2MPa at 7 days, 20.2MPa at 14 days, and 28.3MPa at 28 days. For 10% CDA, compressive strength dropped to 24.6MPa by 28 days for 10% CDA and continued to 22.0MPa at 15% replacement. The results suggest that inclusion of salt water affects compressive strength development particularly with increasing levels of CDA replacement. The data demonstrates the effect of water quality in curing concrete and its impact on strength development.

Fig :4. Curing Period 7 Days

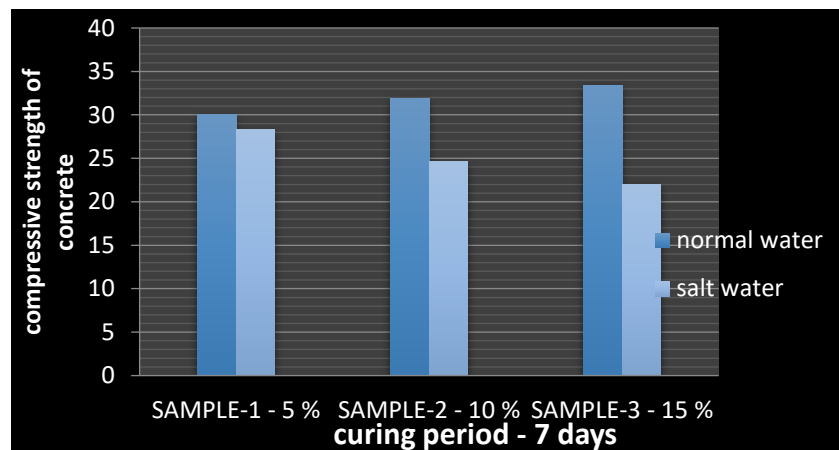


Fig:5. Curing Period 14 Days

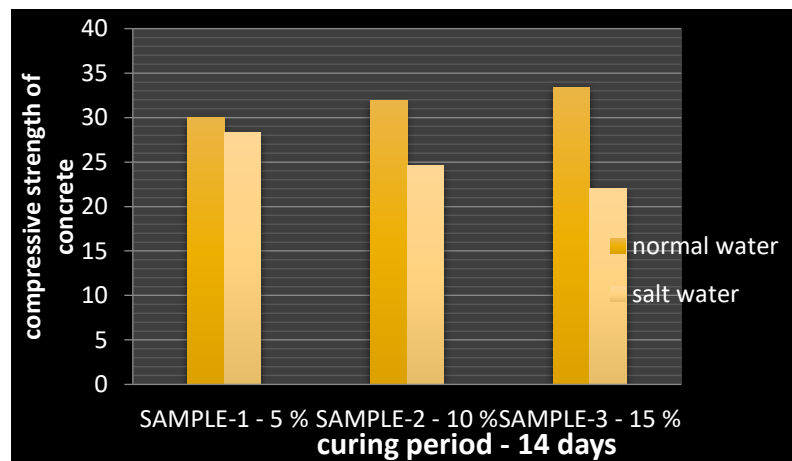
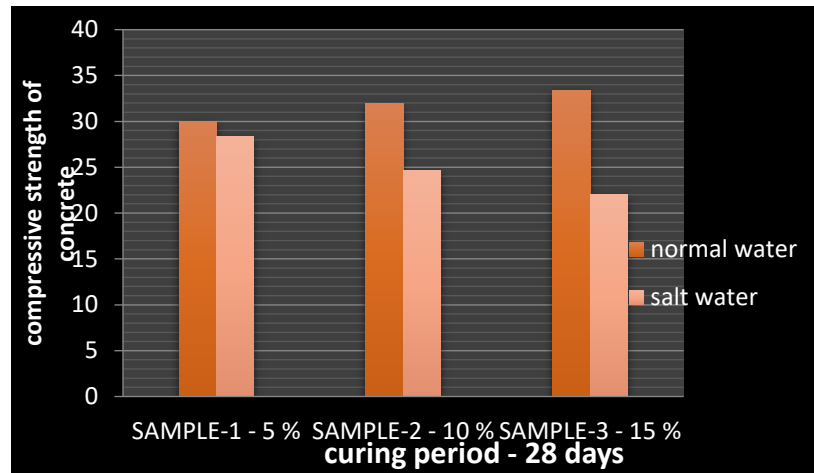


Fig:6. Curing Period 28 Days



VI. CONCLUSION

This research evaluated the possibility of using CDA as a substitute in part of cement in M20 grade concrete, with the main objective being compressive strength in normal water curing and saline (salt) water curing. A total of three levels for cement substitution were studied; 5%, 10%, and 15%. The experimental results indicated that CDA had a positive impact when used as partial cement replacement material when cured in normal water, and as the cement replacement percentage was increased, the strength was consistently upgraded, resulting in 33.4 MPa at 15% replacement after 28 days curing length. In conclusion, it can be said that CDA can contribute to strength generation and is considered ECM for its pozzolanic properties and filler aspects which slowly densify concrete microstructure. In comparison, the samples cured in salt water exhibited a declining trend in compressive strength as CDA percentage increased. Even though the 5% CDA displayed a quality strength of 28.3 MPa at 28 days, the performance reduced with increasing replacement percentages, 24.6 MPa at 10% CDA and 22.0 MPa at 15% CDA. The observed decrease in performance could be due to chloride ions in the saline water which could either limit the hydration of the cement or induce porosity and micro cracking which would lead to a decrease in strength of the matrix. The overall findings suggest that CDA is an alternative sustainable material to cement, and if desired, could be used to enhance stronger material under curing conditions, but the extent of CDA as an alternative in saline environments is limited and warrants further consideration. The study illustrated the dual importance with respect to consideration of material and curing conditions in designing durable and high-performance concrete mixes. The findings support using CDA within conventional concrete applications that are supplied fresh water, while suggesting for future research to consider applications of CDA with aggressive environmental influxes such as marine or saline.

Recommendation for Further Studies

1. Research could address surface treatments or surface additives that might combat the adverse effects of curing concrete in pore water containing salts.
2. Research into aspects of long-term durability, including permeability, corrosion resistance, and sulphate attack resistance of CDA under marine environments would be necessary.
3. Microscopic or microstructural analyses (e.g., SEM, XRD) could show deeper understanding of the bonding and hydration of CDA-based mixes.
4. Field testing can take place in coastal and/or saline-prone environments to boost real-world quality and provide verification of laboratory data.

Limitation

1. This study only limited their findings to compressive strength; they did not evaluate the tensile or flexural strength of the composites.

2. The only SCM assessed as a fractional replacement of cement was CDA and it was not combined with other SCMs.
3. The testing was done under controlled laboratory conditions which may not provide an accurate representation of field behaviour.
4. CDA's effects on reinforcement corrosion under salt water conditions was not measured.

VII. FUTURE SCOPE

The increasing demand for environmentally friendly and low-cost alternatives to cement means that CDA could be a good solution for sustainable construction. Certainly, possibilities for its application could be further expanded by optimizing its treatment and blending with other industrial wastes. This study clearly supports applications of CDA for mass concrete, non-structural elements, and rural infrastructure where freshwater resources can be difficult to obtain. Furthermore, applying agro-waste alternatives such as CDA could mitigate a significant amount of carbon emissions associated with a large construction sector, whilst also providing an avenue for organic waste utilization and treatment.

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