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Effectiveness of Coconut Shell Ash for Corrosion Control in Concrete – An Experimental Approach

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Abstract

This study evaluates the performance of coconut shell ash as a corrosion-controlling agent in concrete. Reinforced concrete specimens with different dosages of coconut shell ash were cast and further exposed to an accelerated corrosion process. The corrosion activity was monitored with the help of the most commonly adopted electrochemical techniques viz - half-cell potential and Tafel extrapolation technique. The test results indicated that adding 5% coconut shell ash by the weight of cement in concrete hindered the corrosion activity and resulted in a decreased corrosion rate. The compressive strength of concrete with coconut shell ash was also enhanced compared to concrete without coconut shell ash. Thus, using coconut shell ash as an additive in concrete can be considered an eco-friendly solution as it helps resolve the issue of disposal of agricultural waste material and controls the corrosion activity in concrete.

Major findings: *The experimental results indicate that incorporating 5% Coconut Shell Ash (CSA) by weight of cement into concrete effectively reduces corrosion and enhances compressive strength. As a waste agricultural byproduct, CSA offers an environmentally friendly solution for agricultural waste disposal while mitigating corrosion in concrete.*

Keywords: *Admixture, Coconut Shell Ash, Corrosion Control, Reinforced Concrete*

1.0 Introduction

Reinforced Concrete (RC) is the most common and popular construction material because of its high durability, fire resistance and affordability as compared to structural steel. Over the past few decades, the construction of RC structures is increasing all over the world. However, damages to RC structures still occur due to overloading, ageing, poor construction quality, corrosion of reinforced steel, exposure to high

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temperatures, chemical reactions, etc. In coastal regions, corrosion of steel embedded in concrete is the foremost reason for the deterioration of RC structures. Due to the presence of a passive layer formed by oxides on the surface, the steel rebars remain protected in the concrete containing a highly alkaline environment. But, due to the reaction of either chloride ions or carbon dioxide, this protective layer was disrupted resulting in the initiation of corrosion[1,2]. Thus, the quality of concrete surrounding the steel rebars plays a very crucial role in controlling the corrosive environment. To prevent corrosion and to enhance the life of RC structures, several methods have been established such as the application of protective coating to steel reinforcement, cathodic protection, coating to the concrete surface, alternative reinforcement and use of corrosion inhibitors. Because of the low cost, easy process of application and adequate corrosion resistance[3], the method of use of corrosion inhibitors is gaining popularity in the construction industry. According to the National Association of Corrosion Engineers (NACE)[4], a corrosion inhibitor is a substance that decreases the rate of attack by the environment on a metal, when added to an environment. The inhibitors do not interact directly with the metal surface, but retard the corrosion either by removing aggressive constituents from the environment or by developing favourable conditions in the environment for the formation of protective precipitates.

The corrosion inhibitors are broadly classified into three categories viz. (i) based on the method of application, (ii) based on the protection mechanism and (iii) based on their contents. Based on the application methods, the inhibitors can be either added as an admixture into concrete in the fresh state or can be spread over the surface of hardened concrete in the form of coating. Such inhibitors are called migrating corrosion inhibitors[5]. From the literature, it is observed that for more than a decade, inorganic and synthetic chemical-based corrosion inhibitors such as chromate, nitrate and nitrite inhibitors have been widely used in practice. However, several concerning problems are also reported such as amplification of corrosion rates for low dosage, toxicity, leaching across concrete cracks as well as skin and eye irritation because of their toxicity[6,7]. These issues regarding the use of chemical-based corrosion inhibitors resulted in the development of environment-friendly corrosion inhibitors derived from natural resources or based on plant extracts[8]. Coconut shell is one of the important natural resources and current research work aims at evaluating the performance of CSA as an additive in concrete for control of corrosion.

The coconut tree is one of the most significant cultivated palm trees as it is the most beneficial plant in the world. The global coconut production was around 63.7 metric tons in the year 2021, with India, Philippines, Indonesia, Sri Lanka and Brazil being the main contributors to coconut production. Though the coconut industry in India produces more than one-fourth of the total coconut oil production of the world, it is also the major reason for the increase in land pollution due to the accumulation of solid waste in the form of coconut shells. The annual coconut shell production is approximately 3180 thousand tonnes representing more than 60% volume of the domestic waste[9]. To resolve the issue of agricultural waste materials disposal in India, many researchers have studied the utilisation of coconut shells or CSA as a promising material for the replacement of cement or aggregates in the construction industry. Previous studies by Utsev and Taku[10], Nagarajan *et al.*[11] and Bheel *et al.*[12] suggested that 10-15 % replacement of ordinary Portland cement with CSA can be done for the production of heavy-weight as well as light-weight concrete despite of reduction in compressive strength of concrete. Garba *et al.*[13] studied the use of CSA as an admixture and found that CSA can be effectively used as a retarder along with improvement of compressive and tensile strength of concrete with optimum doses of 2% by weight of cement. The researchers also studied the application of CSA in combination with other cement replacement materials like stone dust[14], Eggshell powder[15,16], etc., and found enhancement in compressive strength development with 10% CSA as a substitute for cement. Some researchers also studied the effective use of coconut shells as an aggregate in concrete[9,17,18]. To the knowledge of the authors, no research has been conducted in the literature on the use of CSA as a corrosion-controlling agent[19-23]. Hence, the major purpose of current experimental work is to explore the efficacy of CSA as a corrosion-controlling agent in concrete. In the experimental investigation, CSA was added to concrete in the dosage of 0%, 5%, 10%, 15% and 20% at the time of casting of specimens. The RC specimens were then exposed to an accelerated

corrosion procedure and the progress of corrosion was further monitored by electrochemical measurements. Previous studies[24,25] have shown that the thickness of plates plays a crucial role in determining the strength and deformation characteristics of curved plates. Kurhade *et al.*[26-29] examined the application of nanofluids across various fields, emphasising their role in enhancing the understanding of fluid strength behaviour. Yadav *et al.*,[30-33] concentrated on the significance of welding in the design and analysis of electric bikes, addressing aspects such as Body-in-White (BIW) fixtures, leaf springs (both composite and metal) and chassis components in Light Commercial Vehicles (LCVs). Khot *et al.*,[34-36] focused on laser welding, specifically aiming to optimise process parameters for improved strength outcomes. Lastly, Kurhade *et al.*,[37-41] investigated heat transfer performance under different conditions, including the use of Corrugated Twisted Tape, recycled aluminium cans, electronic cooling technologies, biodiesel blends and wind tunnels.

In India, measurement of half-cell potentials is the most common technique used for corrosion assessment of RC structures in combination with other qualitative non-destructive techniques, whereas, for quantification of corrosion, determination of corrosion rate is achieved using techniques like Tafel extrapolation, linear polarisation resistance, or Alternating Current (AC) impedance spectroscopy. The application of these quantitative techniques is limited to laboratory-based research only as the current/potential scans of reinforcing steel embedded in real structural members may accelerate the corrosion process during measurements. Based on these facts, in the present work, the corrosion activity in all the RC specimens was monitored using commonly adopted quantitative as well as qualitative electrochemical techniques namely - the Tafel extrapolation technique and half-cell potential technique respectively.

2.0 Experimental Program

2.1 Material and Specimen Specifications

RC cylinders with dimensions 6cm x 10cm were cast with steel rebar of 12 mm diameter placed centrally in the concrete. To avoid the corrosion initiation at the steel-concrete interface the part of rebar extending out from the concrete was coated with epoxy coating. CSA was added into fresh concrete with dosages of 0%, 5%, 10%, 15% and 20%, and three replicates of specimens were cast in every set. To check the mechanical properties of concrete added with CSA, three concrete cubes of standard dimension – 15 x 15 x 15cm were cast and tested as per IS 516:1959 19 for obtaining 28 days of concrete compressive strength. M35 grade of concrete was prepared for the casting of all cylindrical specimens. For the preparation of concrete mixes, OPC 53 grade cement was used with the physical and chemical properties as presented in Table 1. 10mm nominal size crushed stone and zone II natural river sand as per IS 383:197020 were used as coarse aggregates and fine aggregates respectively. The concrete mix proportion, as per the specifications of IS 10262:2009 was obtained as 1:1.2:1.83 with 0.4 water to cement ratio. A single reinforcing bar of TMT 500 grade with a 12mm diameter and 105mm length was placed at the centre of the cylindrical specimen. Before casting the cylindrical specimen, the weight of every rebar was measured with an accuracy of 0.01gm.

While preparing the concrete mix, CSA supplied from Kerala, India with chemical composition and properties shown in Table 2 was added as an admixture. Five dosages of CSA 0 %, 5 %, 10 %, 15 % and 20 % by weight of cement were mixed in the concrete.

Table 1. Cement properties

Chemical Properties	
C_3S	51.58%
C_2S	17.77%
C_3A	8.01%
C_4AF	12.77%
Physical Properties	
Initial Setting Time	30min
Final Setting Gime	620min
Specific gravity	3.15
Fineness	500m^2/kg

Table 3 presents the test matrix used in the experimental work. The RC specimens were cast using a special moulding system and were immersed in a

Table 2. Properties of CSA

Chemical Properties	
SiO_2	6.33%
Al_2O_3	28.06%
Fe_2O_3	17.44%
CaO	0.9%
MgO	0.08%
MnO	0.29%
Na_2O	0.36%
K_2O	0.91%
P_2O_5	0.02%
SO_4	0.028%
Physical Properties	
Specific Gravity	1.34
Fineness	597 m^2/kg

water tank for curing at room temperature for 28 days. Thereafter, the RC specimens were submerged in 5% NaCl solution for one day and then subjected to constant potential (4V) from the 30th day for activation of the corrosion process.

Table 3. Test matrix

Sr. No.	Description	Notations	CSA Dosage
1	Control specimens with three replicates	CS-1	0%
		CS-2	
		CS-3	
2	Specimens with 5 % CSA with three replicates	SP5-1	5%
		SP5-2	
		SP5-3	
3	Specimens with 10 % CSA with three replicates	SP10-1	10%
		SP10-2	
		SP10-3	
4	Specimens with 15 % CSA with three replicates	SP15-1	15%
		SP15-2	
		SP15-3	
5	Specimens with 20 % CSA with three replicates	SP20-1	20%
		SP20-2	
		SP20-3	

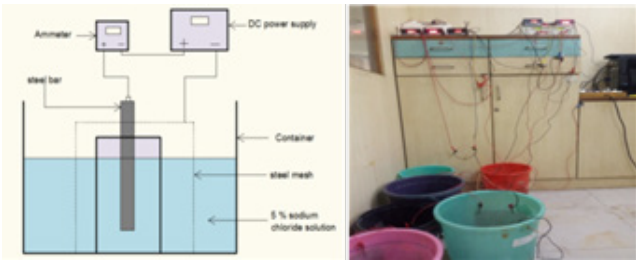


Figure 1. Accelerated corrosion set-up.

2.2 Corrosion Set-Up and Testing Procedure

To investigate the performance of CSA as a corrosion-controlling agent in concrete, it was needed to induce corrosion into the rebars. In the present study, the impressed current technique was used to activate the corrosion in rebars. This method was adopted considering the time constraint of experimental work as well as the suitability of the method for inducing corrosion as per previous studies of 2022-23. In this technique, the current was applied to the reinforcing steel bar of the RC specimen submerged in a 5% sodium chloride solution. Figure 1 presents the schematic diagram of the accelerated corrosion set-up used in the current study. A wide strip of stainless-steel mesh was placed along the side of the specimens as a cathode. The external Direct Current (DC) power supplier (capacity - 200mA DC and 30V) was connected to a reinforcing steel bar as well as a stainless-steel strip to apply a constant voltage of 4V between them as shown in Figure 1. The accelerated corrosion process was paused during the electrochemical measurements and stopped when a distinct crack appeared in the concrete specimen.

The corrosion activity in all the RC cylindrical specimens was monitored regularly using commonly adopted electrochemical techniques namely - the Tafel extrapolation technique and half-cell potential technique till the end of the testing. The first electrochemical measurements were recorded immediately after the completion of the curing period, thereafter the measurements were recorded periodically whenever the colour of the Sodium Chloride (NaCl) solution changed to a light brown colour which indicated the oozing of corrosion products.

The power supply was interrupted for half an hour before the electrochemical measurements. Saturated Calomel Electrode (SCE) was used for recording half-cell

potential values whereas Potentiate (Crest Technology) was used for obtaining Tafel plots. The potentiation scanning was carried out with a 0.5mV/s scan rate and a -1.0V to +1.0V potential range.

3.0 Results and Discussions

The integration of machine learning algorithms into tool wear Through the current experimental work, the performance of RC specimens with various dosages of CSA for corrosion inhibition was evaluated considering different parameters viz. compressive strength of concrete, variation of half-cell potential values with time, corrosion rate values, condition of test specimens as well as mass loss values of steel rebars after corrosion exposure as described below.

3.1 Concrete Compressive Strength

Table 4 indicates the compressive strength values of cubes at 28 days of curing for all concrete mixes. Table 4 indicates that the average compressive strength values of cubes with a 5% dosage of CSA are greater as compared to all other specimens followed by cubes with a 10% CSA dosage. Thus, the addition of 5% CSA in concrete resulted in a significant increase in the compressive strength of concrete (approximately 28%) whereas the dosage up to 10% improved the compressive strength marginally. The increase in CSA dosage beyond 10% by weight of cement has not shown improvement in concrete compressive strength.

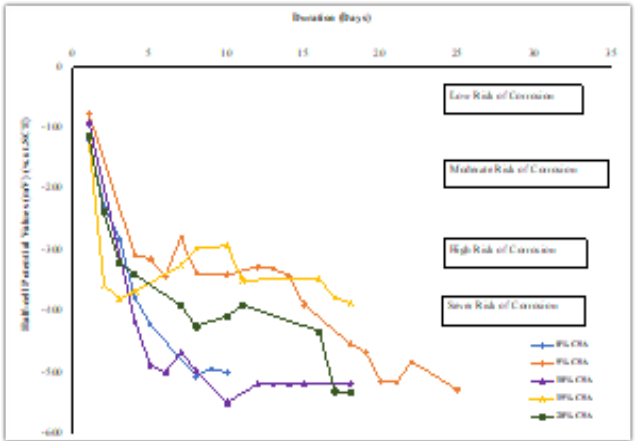


Figure 2. Variation of average half-cell potential values with time.

Table 4. Compressive strength values of concrete with and without CSA

Test Specimen	Compressive Strength (MPa)	Average Compressive Strength (MPa)
CS-1	33.51	35.77
CS-2	39.20	
CS-3	34.60	
SP5-1	48.12	45.70
SP5-2	45.67	
SP5-3	43.60	
SP10-1	37.67	38.77
SP10-2	38.08	
SP10-3	40.56	
SP15-1	32.43	34.00
SP15-2	36.93	
SP15-3	32.65	
SP20-1	31.53	31.58
SP20-2	29.82	
SP20-3	33.40	

3.2 Half-Cell Potential Values

Half-Cell Potential (HCP) values of all the RC cylindrical specimens subjected to accelerated corrosion were recorded periodically when the colour of the NaCl solution changed to a light brown colour which indicated the oozing of corrosion products. The measurements were recorded till a distinct crack appeared on the surface of RC cylindrical specimens. Figure 2 presents the variation of average HCP values (average of three replicates) concerning the testing time of all the RC cylindrical specimens with various CSA dosages.

From the figure, it can be observed that initially, before starting the accelerated corrosion process, the HCP values for all the specimens were less negative than -126mV indicating a low risk of corrosion. With the progression of corrosion, the HCP values started decreasing (HCP (w. r. t. SCE) < - 276mV) till the emergence of a crack on the concrete surface. For the specimen with 0% CSA dosage, the HCP values decreased rapidly to the value more negative than - 426mV on the 6th day of current exposure

indicating a severe risk of corrosion. The values further decreased and specimens developed a distinct crack on the 10th day of current exposure. On the other hand, the HCP values for specimens with 5% CSA dosage indicated a slow rise in corrosion activity. On the 6th day of current exposure, the HCP value of these specimens recorded was -343 mV indicating a high risk of corrosion. With the progression of corrosion, the HCP values decreased and became more negative than - 426mV on the 18th day and the specimens developed a distinct crack on the 25th day of corrosion exposure. Thus, the addition of 5% CSA has slowed down the corrosion activity in RC specimens. The other RC specimens with 10%, 15% and 20% CSA dosage also indicated more or less similar results with the exception that these specimens developed a distinct crack on the surface on the 18th day of testing whereas the same was observed on the 25th day for specimens with 5% CSA dosage.

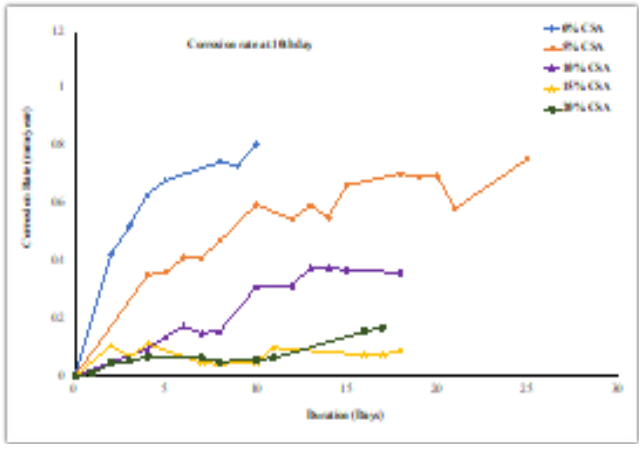


Figure 3. Variation of corrosion rate values with time.

3.3 Corrosion Rate Based on Tafel Extrapolation Technique

After recording the HCP values, all the specimens were scanned using Potentiostat and Tafel plots were plotted. The corrosion current densities were calculated from Tafel plots and corrosion rates were further calculated using Faraday's law. Figure 3 presents the variation of average corrosion rate for all the specimens with time. As the specimen without CSA dosage developed a crack much earlier, on the 10th day of corrosion exposure, the corrosion rate values of the 10th day for all remaining specimens were considered for comparison purposes. From the figure, it can be seen that after the completion of the corrosion exposure period, the corrosion rate value of specimens with 0% CSA dosage is highest (0.8 mm/year) followed by specimens with 5% and 10% CSA dosage (0.6 mm/year and 0.5 mm/year respectively) whereas the specimens with 15% and 20 % CSA dosage recorded the least corrosion rate of 0.1 mm/year. Thus, a decreasing trend in corrosion rate values was observed for specimens with the addition of CSA dosage as compared to the specimens without CSA.

3.4 Visual Observations and Rebar Mass Loss

To verify the results obtained through HCP measurements and corrosion rate calculations, the condition of all the specimens during corrosion progression was recorded through visual observations. After completion of testing, the steel rebars from all the specimens were extracted, corrosion products were removed from the surface of the rebars and the weight of the bars was recorded to find the

Table 5. Details of visual observation and mass loss

CSA dosage (Percentage)	The average duration for the development of hair-line crack (Days)	The average duration for the development of distinct cracks (Days)	Average Mass loss (g)
0	9	10	2
5	22	25	1.2
10	16	18	1.8
15	17	18	1.86
20	13	15	1.9

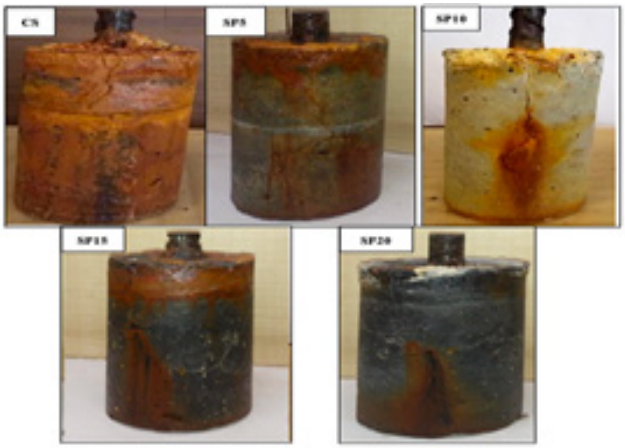


Figure 3. Condition of specimens with various CSA dosages at the end of corrosion exposure.

mass loss. Table 5 shows the recorded visual observations and measured average mass loss values for all specimens. From Table 5 it is evident that the corrosion activity in specimens with CSA dosage is slow as compared to the specimens without CSA.

Figure 4 shows the condition of some of the representative specimens with various CSA dosages at the end of the testing. It is observed from Figure 4 that the specimen with 5% CSA dosage has shown a lesser amount of oozing of corrosion products as well as lesser deterioration of concrete surface in terms of cracking as compared to all other test specimens.

Thus, from the visual observations and mass loss measurements, it is found that the specimens with 5% CSA dosage showed the least mass loss values followed by specimens with CSA dosage of 10%, 15% and 20% respectively. The development of cracks on the concrete surface due to corrosion was also found to be delayed in the specimens with 5% CSA dosage as compared to the other specimens.

4.0 Conclusion

This paper evaluates the performance of CSA as a corrosion-controlling agent. Based on the experimental investigation following outcomes can be summarised:

- Use of CSA as an admixture with a dosage of 5% by weight of cement enhances the compressive strength of the concrete. However, further increase in CSA dosage does not show improvement in the compressive strength of concrete.
- Variation of HCP with time for RC specimens having 5% CSA dosage indicates hindered corrosion activity.
- A decreasing trend in corrosion rate values was observed for specimens with the addition of CSA dosage as compared to the specimens without CSA.
- The addition of 5% CSA by weight of cement in concrete exhibited delayed cracking of concrete cover and the least loss in mass of steel rebar due to corrosion.

Thus, the experimental investigation concluded that CSA, which is considered to be a waste agricultural material, can be effectively used in concrete as a corrosion restraining agent as well as a concrete compressive strength-improving admixture with a dosage of 5% by weight of cement. The use of coconut shell ash as an additive in concrete can be considered an eco-friendly solution as it helps in resolving the issue of disposal of agricultural waste material along with controlling the corrosion activity in concrete. Further studies for improvement of chemical properties of CSA suitable to act as mineral admixture and corrosion inhibitor in concrete are required.

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