# Coconut Coir Dust Extract (CCDE) as green corrosion inhibitor for rebar' steel in concrete environment

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#### **Abstract**

Corrosion of reinforcement steel in concrete is one of the drawbacks of reinforced concrete structures. An attempt is made to use Coconut Coir Dust Extract (CCDE) as a green corrosion inhibitor. The efficacy of the CCDE is examined in simulated concrete pore solutions and in concrete structures. The influence of CCDE on the inhibition of corrosion of steel in concrete has been evaluated by non-electrochemical and electrochemical techniques. The various concentrations of CCDE (0%, 10%, 20%, 30% and 40%) in simulated concrete pore solution (SCPS with 3.5% NaCl) were studied by weight loss, potentiodynamic polarization and electrochemical impedance spectroscopy. The addition of CCDE up to 40% did not affect the mechanical property of concrete. It is observed that CCDE was able to provide more than 95% inhibition efficiency in SCPS with 3.5% NaCl solution. The mechanism of inhibition is due to adsorption and, thereby, film formation on the steel surface. Potentiodynamic polarization studies indicated that CCDE act as a mixed type inhibitor and predominantly cathodic. CCDE is a good candidate greener inhibitor for corrosion of steel in concrete because it increases the compressive strength of concrete and reduces the self-corrosion of steel rebar in chloride environment to the maximum extent.

**Keywords:** concrete, rebar, coconut coir dust extract, green corrosion inhibitor.

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#### 1. Introduction

Globally, corrosion of reinforcement is a serious problem in the construction industry. Many approaches are used to mitigate the corrosion of rebars in concrete, such as coating to rebar, cathodic protection, re-alkalization of the concrete, electrochemical removal of chloride from concrete, and corrosion inhibitors [1, 2]. Among the methods listed, the use of corrosion inhibitors is considered an effective way of mitigating reinforcement corrosion [3–5]. A lot of literature is available on the use of corrosion inhibitors in concrete [6–12]. Reviews on the most commonly used inhibitors in concrete systems and their probable mechanism have been recently published [13–19]. In fact, calcium nitrite-based inhibitors

are widely used as corrosion inhibitors worldwide [6]. In the next generation, the use of organic inhibitors is an alternative way to calcium nitrite-based inhibitor [14]. Organic corrosion inhibitors are able to adsorb and forming a barrier film on the steel surface [15]. Duprat and Dabosi examined the effect of various amino alcohols as corrosion inhibitors for carbon steel in 3.5 % NaCl solution.

Recently, the use of green corrosion inhibitors in the construction industry is coming into existence in order to satisfy our demands [20, 21]. Actually, green corrosion inhibitors are extracted from the plant products such as bark, leaf, seed, fruit, roots, *etc*. Green corrosion inhibitors are biodegradable. They do not contain heavy metals or other toxic compounds [17]. Some research groups have reported the successful use of naturally occurring substances to inhibit the corrosion of metals in acidic and alkaline environments. The coconut coir dust which is a by-product in the coir industry, is used by Saviour A. Umoren *et al.* (2014) [19] and reported that the coconut coir dust extract obtained from a solvent system is inhibiting steel corrosion.

Coconut coir dust extract (CCDE) was used as a green corrosion inhibitor in this study. Palanisamy *et al.* [18] highlighted natural products/biomaterials of plant origin that have been reported as corrosion inhibitors for metals in corrosive media. In the extraction of coir fiber from the coconut husk and in the production of finished materials from the extracted fiber, a large amount of coir dust is produced. Coir dust is rich in lignins, alkaloids, and tannins. It is reported to be composed of cellulose, pentosane, furfural, lignin [19]. Hence, the present study utilizes CCDE as a possible green corrosion inhibitor for steel in concrete. The objectives of the current investigation are as follows:

The inhibitive performance of CCDE is examined in simulated concrete pore solution (SCPS)+3.5% NaCl with varying percentage of CCDE (0%, 10%, 20%, 30% and 40%).

The influence of CCDE on the mechanical and corrosion-resistant properties of concrete with varying percentages of CCDE (0%, 10%, 20%, 30%, and 40%) was studied.

## 2. Materials and Methods

#### 2.1 Materials used

# 2.1.1. Cement and aggregates

Portland Pozzolana cement (PPC) was used throughout this investigation. Manufactured sand (M-sand) was used as fine aggregate with specific gravity 2.73 conforming to zone II of IS 456:2000. A coarse aggregate of maximum size 20 mm with a specific gravity of 2.85 was used. M30 grade of concrete was designed as per Indian Standard. Thermomechanically treated (TMT) rebar of size 16 mm diameter and 12 cm length was used.

# 2.1.2. Preparation of coconut coir dust extract (CCDE)

The coir dust was collected from the coir industry located in Pollachi, Tamilnadu, India. As received, coir dust was immersed in distilled water for 72 hours. During this period, the coir

dust was paddled at regular intervals of time. After 72 hours, CCDE was obtained by filtration. This filtrate was used for casting concrete specimens and further examinations. Structures of some commonly occurring alkaloids and flavonoids is shown in Figure 1.

**Figure 1.** Structures of some common alkaloids and flavonoids present in plants.

**Flavonoids** 

## 2.1.3. Preparation of simulated concrete pore solution (SCPS)

SCPS was prepared using 34 g of KOH and 25 g of NaOH in one litre of saturated Ca(OH)<sub>2</sub> solution [22]. Studies were carried out in SCPS with 3.5% NaCl.

# 2.1.4. Preparation of concrete specimens

Reinforced cylindrical concrete specimens of size 10 cm diameter and 15 cm height were cast. Rebar of size 16 mm diameter and length 12 cm was centrally placed in the specimen. 2 cm length of rebar exposed to the environment is coated with epoxy, and the remaining 10 cm length is embedded in concrete. M30 grade of concrete with a w/c ratio of 0.4 was designed. Specimens were cast with 10%, 20%, 30%, and 40% of CCDE by weight of water in the actual w/c ratio. The specimen details are given in Table 1. The concrete specimens were subjected to a curing period of 28 days in normal water and subjected to alternate wet and dry cycle in 3.5% NaCl solution for another 30 days.

Mix designation	System  Control Specimen			
M30CM00				
M30CM10	10% CCDE			
M30CM20	20% CCDE			
M30CM30	30% CCDE			
M30CM40	40% CCDE			

**Table 1.** Mix designation for concrete with various proportions of CCDE.

# 2.2. Mechanical property: Compressive strength of concrete

A compressive strength test was carried out as per IS-516-1959 in concrete cubes of size  $150 \times 150 \times 150$  mm using a designed mix of M30 with a w/c ratio of 0.40. The cured specimens were tested for compressive strength using the AIMIL Compression testing machine of 2000 kN capacity at a rate of loading of 140 kN/minute. The test was carried out on triplicate specimens, and the average compressive strength values were recorded.

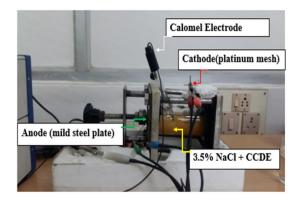
## 2.3. Corrosion rate by weight loss measurement

Triplicate steel rebar specimens were immersed in SCPS with 3.5% NaCl by varying the percentage of CCDE (0 %, 10%, 20%, 30%, and 40 %). The corrosion rate of rebar specimen in mmpy for an exposure period of 90 days was calculated as reported elsewhere [23].

### 2.4. Electrochemical studies

# 2.4.1. Open circuit potential measurements

The potential time behavior of steel in SCPS with 3.5% NaCl and in concrete specimens prepared as specified earlier was periodically monitored using a high impedance voltmeter  $(20 \text{ M}\Omega)$  for an exposure period of 90 days. The experimental setup for performing the electrochemical corrosion tests is shown in Figure 2.



**Figure 2.** Experimental setup for corrosion study.

## 2.4.2. Potentiodynamic polarization studies

Potentiodynamic polarization studies were carried out for steel in SCPS with 3.5% NaCl by varying the percentage of CCDE (0 %, 10%, 20%, 30%, and 40 %). Three electrode glass cell assembly was used for this study. Rebar sample was served as a working electrode, platinum foil of larger area was used as the counter electrode, and saturated calomel electrode (SCE) was served as the reference electrode. The potentiodynamic conditions correspond to  $\pm 250$  mV vs. SCE. The sweep rate was 1 mV/s. Both cathodic and anodic polarization curves were recorded using a Gamry Electrochemical workstation. This instrument itself has provision for calculating the corrosion kinetic parameters such as  $E_{corr.}$ ,  $I_{corr.}$ ,  $\beta_a$ , and  $\beta_c$ . All the experiments were carried out at a room temperature of  $30\pm1^{\circ}C$ .

Potentiodynamic polarization studies were carried out for rebar embedded in concrete with different proportions of CCDE inhibitors. Here rebar embedded in the concrete act as working electrode, platinum foil acted as counter electrode and SCE act as a reference electrode. The other conditions remain the same as stated for solution studies.

## 2.4.3. AC-Impendence spectra

The same three-electrode cell assembly was used here also. Nyquist Plot was recorded in the frequency range from 10 mHz to 100 kHz using a frequency response analyzer. The charge transfer resistance was obtained from the difference between initial and final frequency. The double-layer capacitance values were measured with maximum frequency using the following formula  $C_{\rm dlma} = 1/(2\pi R_{\rm ct})$ . All the experiments were carried out at a room temperature of  $30\pm1^{\circ}{\rm C}$ .

# 2.5. Surface examination by FTIR Spectra

After the exposure period, the concrete specimen is split open, and the steel-concrete interface was subjected to FTIR spectra by using Bruker Optik GmbH, Germany, with the spectral range 400 to 4000 cm<sup>-1</sup>.

#### 3. Results and Discussion

# 3.1. Compressive strength measurements

The compressive strength data for concrete with varying percentages of CCDE is given in Table 2. From the table, it was observed that the average compressive strength of concrete with varying percentages of CCDE was found to be above 30 MPa, which is actually designed strength. The percentage variation in increase of compressive strength compared to control specimen for 10%, 20%, 30% and 40% CCDE are 5.94%, 13.15%, 8.28% and 8.04% respectively. Here it was interesting to note that the addition of inhibitor CCDE does not reduce the compressive strength of concrete; rather, it will slightly increase the compressive strength of concrete. Here it was concluded that the addition of CCDE in the concrete formulation is beneficial with respect to concrete's mechanical properties.

**Table 2.** Compressive strength data for concrete with varying percentage of CCDE.

No.	Mix designation	Snaciman	Weight (kg)		Load (Ton)		Compressive strength (MPa)		Average compressive strength (MPa)
			Day 7	Day 28	Day 7	Day 28	Day 7	Day 28	Day 28
		1	8.84	8.75	52.0	74	22.67	32.26	
1	M30CM00	2	8.70	8.73	53.0	72	23.11	31.39	34.29
		3	8.55	8.76	51.0	90	22.24	39.24	
		1	8.68	8.60	67.0	81	29.21	35.32	
2	M30CM10	2	8.71	8.63	65.0	84	28.34	36.62	36.33
		3	8.89	8.78	59.0	85	25.72	37.06	
		1	8.36	8.84	55.0	81	23.98	35.32	
3	M30CM20	2	8.74	8.99	62.0	89	27.03	38.80	38.88
		3	8.51	8.84	58.0	97	25.29	42.29	
		1	8.59	8.63	60.0	82	26.16	35.75	
4	M30CM30	2	8.62	8.76	60.0	89.5	26.16	39.02	37.13
		3	8.73	8.69	61.0	84	26.60	36.62	
		1	8.68	8.76	66.0	89	28.76	38.80	
5	M30CM40	2	8.55	8.65	51.0	78	22.24	34.00	37.05
		3	8.59	8.76	61.0	88	26.60	38.36	

# 3.2. Weight loss measurement

The corrosion rate of rebar in SCPS with 3.5% NaCl and embedded in concrete by varying the percentage of CCDE (0%, 10%, 20%, 30%, and 40%) is given in Figure 3a and Figure 3b, respectively. The corrosion rate of steel in SCPS+3.5% NaCl without CCDE was 0.0537mmpy. The corrosion rate of steel in SCPS+3.5% NaCl with 10%, 20%, 30%, and 40% CCDE were 0.0395 mmpy, 0.0350 mmpy, 0.0330 mmpy and 0.0500 mmpy, respectively. Comparable corrosion rate with control specimen was observed up to 30% CCDE. Hence, the optimum level of CCDE with the better corrosion-resistant property was achieved at 30% CCDE. The better inhibition of CCDE is due to the formation of a compact barrier film on the steel surface. The inhibitor CCDE able to inhibit the corrosion of steel in SCPS, even in the presence of 3.5% NaCl. This is due to the competitive adsorption of CCDE over the steel surface in the presence of chloride environments. Adsorption of inhibitor molecules leads to some of the attacking anions being rendered

inactive. Further, the adsorption process promotes film formation. Hence the combined effect of adsorption and film formation maintains perfect passivity on the steel surface even in the presence of higher concentrations of aggressive ions.

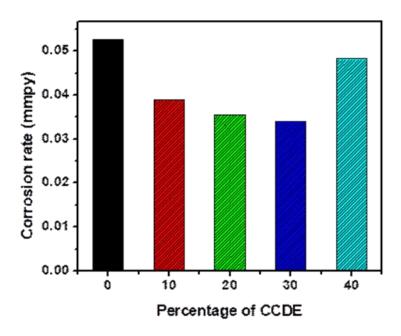
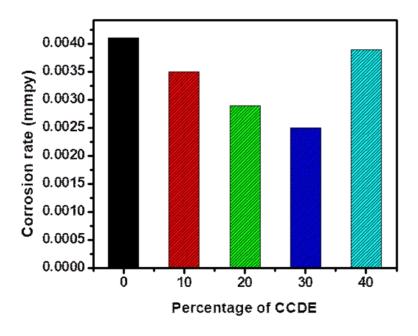


Figure 3a. Corrosion rate of steel in SCPS with varying percentage of CCDE.



**Figure 3b.** Corrosion rate of steel in concrete with varying percentage of CCDE.

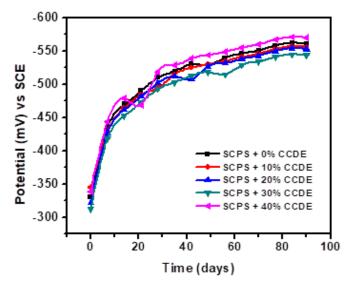
Similarly, the corrosion rate of steel in concrete without CCDE was 0.0042 mmpy. The corrosion rate of steel in concrete with 10%, 20%, 30% and 40% CCDE was 0.0035 mmpy, 0.0029 mmpy, 0.0025 mmpy and 0.0040 mmpy, respectively. Comparable corrosion rate

with control specimen was observed up to 30% CCDE. CCDE contains organic molecules like lignin, tannins, *etc.*, which contains an abundance of pi electrons and lone pair of electrons in N and O atom able to donate and sharing with vacant d orbital of Fe, which provides better inhibition even in the higher concentration of chloride ions.

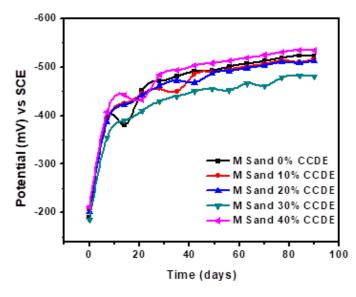
#### 3.3. Electrochemical studies in SCPS and concrete

## 3.3.1. Open circuit potential

The potential-time behavior of rebar in SCPS+3.5% NaCl and embedded in concrete with various concentration of CCDE (0%, 10%, 20%, 30% and 40%) is shown in Figure 4a and Figure 4b respectively.



**Figure 4a.** Potential-time behavior of steel in SCPS with varying percentage of CCDE.



**Figure 4b.** Potential-time behavior of steel embedded in concrete with varying percentage of CCDE.

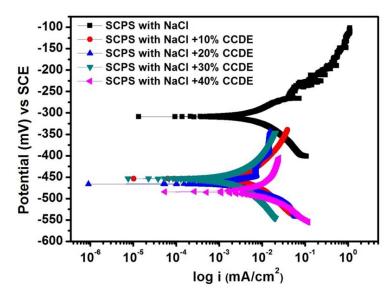
Figure 4a shows the potential-time behavior of steel in SCPS+3.5% NaCl with varying percentages of CCDE (0%, 10%, 20%, 30%, and 40%) for the exposure period of 90 days. It was observed from Figure 4a that the OCP of steel is cathodically shifted throughout the exposure period. Initially, the OCP of steel was –561 mV, –556 mV, –553 mV, –544 mV and –570 mV in SCPS+3.5% NaCl, SCPS+3.5% NaCl with 10%, 20% 30% and 40% of CCDE, respectively. The OCP of steel in SCPS+3.5% NaCl with 30% of CCDE was –544 mV. It indicates that the CCDE up to 30% is to minimize the corrosion of steel in chloride-contaminated SCPS compared to SCPS+3.5% NaCl with 40% CCDE.

Figure 4b shows the potential-time behavior of steel in embedded concrete with various percentages of CCDE (0%, 10%, 20%, 30%, and 40%) and which is exposed to 3.5% NaCl solution over a period of 90 days. In this process, alternate wet and dry cycles were performed to accelerate the corrosion process. One cycle consists of 3 days of wetting in chloride solution and 3 days drying in an open atmosphere at room temperature. It was observed from Figure 4b that passivity of steel was maintained up to 30% of CCDE throughout the exposure period. CCDE is admixed into concrete during the casting process; hence the organic inhibitor molecules are directed towards the steel surface from day one onwards. However, chloride ions in concrete tend to become complex and exist in three forms, namely physically adsorbed chlorides, complex chlorides, and free chlorides. Only free chlorides are move towards steel and accelerate the corrosion process. In our studies, CCDE able to form a compact barrier film on the steel surface before chloride ions move towards to steel. Hence a perfect passivity is formed between CCDE and steel interfacial region.

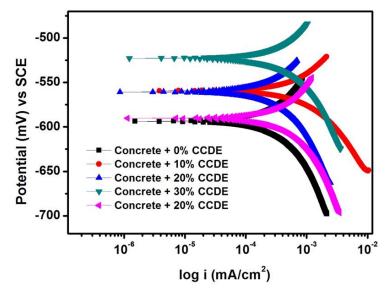
## 3.3.2. Potentiodynamic polarization

The potentiodynamic polarization of rebar in SCPS and embedded in concrete with various concentrations of CCDE is shown in Figure 5a and Figure 5b, respectively. From Figure 5a, it was observed that the corrosion current density values are reduced up to 30% CCDE. The reduction in the corrosion rate for various systems follows the order:

The coconut coir dust extracts act as a mixed-type inhibitor with predominantly cathodic type. From Figure 5b, the corrosion rate of rebar embedded in concrete follows the same order as already observed in solution studies.



**Figure 5a.** Polarization curves for rebars exposed to SCPS with varying percentage of CCDE.

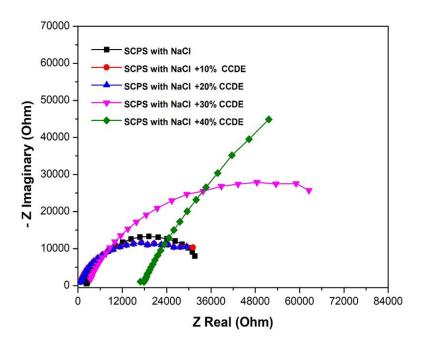


**Figure 5b.** Polarisation curves for rebar embedded in concrete with varying percentage of CCDE.

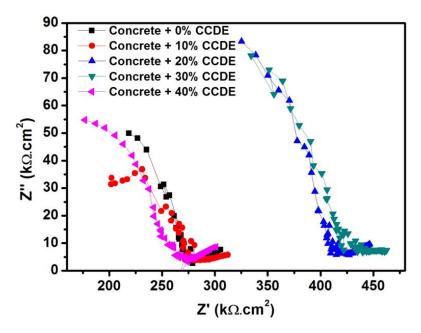
# 3.3.4 AC-Impedance spectra

The Nyquist plots for rebar in SCPS with various concentrations of CCDE are shown in Figure 5a. The EIS technique provides a means of characterizing electrode processes and complex interfaces. It is ideal for studying the system response to applying a periodic small amplitude AC signal. Figure 6a shows the Nyquist diagrams of steel in concrete pore solution without and with selected concentrations of coconut coir dust extract. It is clear from Figure 6 that the charge transfer resistance values increase up to 30% CCDE. On the other hand, the double-layer capacitance values decrease up to 30% CCDE. Here again, it

was proved that the inhibitor CCDE performed better up to 30%. Bode (Figure 6c) and phase (Figure 6d) impedance plot shown in indicate that the difference of impedance at high frequency and low frequency is higher for 30% CCDE than 10%, 20%, and 40% CCDE.



**Figure 6a.** Nyquist plots for rebar exposed to SCPS with varying percentage of CCDE.



**Figure 6b.** Nyquist plots for rebar embedded in concrete with varying percentage of CCDE.

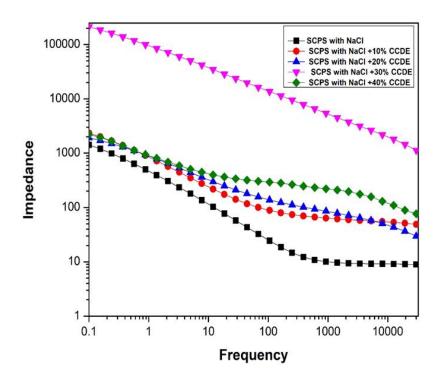
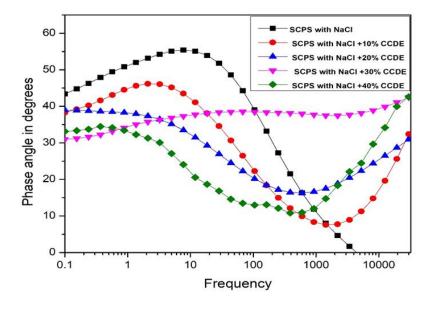


Figure 6c. Bode impedance plot.



**Figure 6d.** Bode phase plot.

## 3.4 FTIR spectra

Figure 7(a, b) shows the FTIR spectra of steel-concrete interface for concrete with 30% CCDE and the dry recorded spectrum of CCDE. The peak at 3434.38 cm<sup>-1</sup> (associated hydroxyl) was overlapped by the strong stretching mode of N–H. The 1634.17 cm<sup>-1</sup> band is corresponding to the N–H bend. The peak at 1262.22 cm<sup>-1</sup>can is assigned to the stretching mode of C–N group. The band at 1453.93 cm<sup>-1</sup> is attributed to C–C in the ring (for aromatic). These results show the presence of coconut extract contains a mixture of compounds, *i.e.*, alkaloids and flavonoids. It can also appear on the steel-concrete interface and inhibit the corrosion of steel. A comparison of the FTIR spectra shown in Figure 7a and Figure 7b supports the adsorption of the corrosion inhibitor on the metallic substrate.

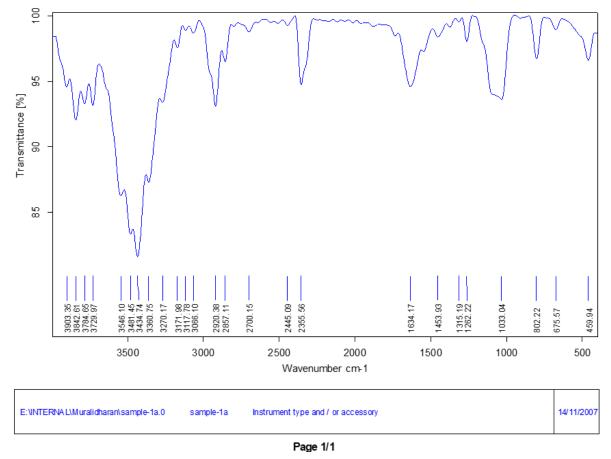


Figure 7a. FTIR spectrum for steel concrete interface of 30% CCDE admixed concrete.

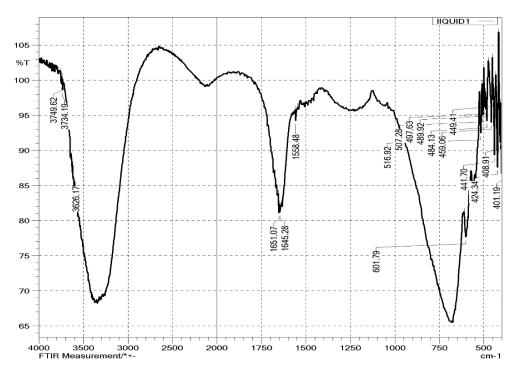


Figure 7b. Dry Record Spectrum of CCDE extract.

#### 4. Conclusion

The following conclusions can be drawn from the present investigation.

- Coconut Coir Dust Extract has been used for the first time as a corrosion inhibitor for rebar in concrete.
- Weight loss measurement revealed that CCDE able to provide more than 95% inhibition efficiency even in 3.5 % NaCl solution.
- The addition of CCDE up to 40% does not affect the mechanical property of concrete.
- 30% of CCDE admixed in concrete showed better corrosion resistance properties.
- Potentiodynamic polarization studies indicated that the inhibitor CCDE act as a mixed type and predominantly cathodic.
- EIS studies showed that 30% CCDE in SCPS and also in concrete showed better corrosion resistance.
- FTIR spectra confirmed the adsorption of organic molecules on the steel surface and thereby provided the inhibition.
- CCDE is a good candidate greener inhibitor for corrosion of steel in concrete because CCDE not only increases the compressive strength but also reduce the self corrosion of steel to the maximum extent.

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