

Original Research

Exploring the Use of Plant Extracts from Leaves, Bark, and Roots of *Boswellia dalzielii* as Corrosion Inhibitors on Low-Carbon Steel Embedded in Concrete as Reinforcement When Subjected to Chloride and Acidic Environment

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Abstract

This study explores the use of plant extract to reduce corrosion on low-carbon steel reinforcement embedded in concrete. It is globally known that structures exposed to corrosive environments can collapse due to deterioration of the steel rods embedded in the concrete. The corrosion-inhibition potential of leaves, bark, and root extracts of *Boswellia dalzielii* (BD) on concrete reinforcement was investigated using a half-cell potentiometer and scanning electron microscopy (SEM) analysis. The half-cell potential readings are generally negative, and the higher the magnitude of the negative value, the higher the probability of corrosion occurrence. Measurement of corrosion potential with a half-cell potentiometer is highly effective in determining the inhibition potential of green inhibitors in concrete reinforcements. For the concrete prisms treated with BD plants in an acid medium, the samples containing leaves, bark, and root extracts have potential readings



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ranging from -150 mV to -200 mV, -300 mV to -350 mV, and -350 mV to -400 mV, respectively. On the other hand, the samples treated with leaves, bark, and root extracts in chloride medium have potential readings ranging from -50 mV to -150 mV, -50 mV to -100 mV, and -250 mV to -300 mV, respectively. Scanning electron microscopy (SEM) results show that all protected samples had low corrosion, whereas the unprotected or control samples showed severe corrosion attack. In general, all samples treated with plant extracts showed reduced corrosion risk compared to the control samples.

Keywords

Corrosion; reinforcement; inhibitors; concrete; *Boswellia dalzielii* (BD)

1. Introduction

The use of steel reinforcement in concrete has become a common practice in the construction of structures and infrastructure because of its excellent properties compared with other construction materials in terms of strength, fire resistance, and durability [1]. Reinforced concrete represents a very successful combination of materials, not only from a mechanical point of view but also from a chemical perspective, because the hydrated cement can provide excellent protection against corrosion. This chemical compatibility allows for the composite behavior of reinforced concrete and is the basis of its high durability. The composite action occurring in the steel–concrete bond may be unlimited over time while steel remains passive. The study of the conditions leading to reinforcement corrosion is of high importance because corrosion may significantly affect the load-bearing capacity of reinforced concrete [2]. Corrosion damage to reinforcing steel is an electrochemical process with anodic and cathodic half-cell reactions [3]. In the absence of corrosive species, the anodic dissolution reaction of iron is balanced by the cathodic oxygen reduction reaction.

The corrosion behavior of reinforcement in concrete has been investigated for organic and inorganic inhibitors. The organic inhibitors were extracted from *Azadirachta Indica* (neem) and *Ruta Graveolens* plants, and the inorganic inhibitors used were sodium nitrate and ethylenediaminetetraacetic disodium dehydrates. The inhibitors were added during concrete mixing, and the reinforced concrete specimens were immersed in hydrochloric acid (HCl), sodium chloride (NaCl), and magnesium sulfate (MgSO₄) solutions to induce corrosion. The corrosion resistance of the reinforcement was evaluated using weight-loss measurements and a half-cell potentiostat. The results of the inhibitors studied showed that *Azadirachta indica* has superior corrosion inhibition efficiency compared with the other inhibitors in acid and chloride solutions. Ethylenediaminetetraacetic disodium dehydrate exhibited good corrosion inhibition efficiency in the sulfate solution. It was also observed that the efficiency of inhibitors depends on the exposure environment [4].

This research will explore the use of extracts from the leaves, bark, and roots of *Boswellia dalzielii* as corrosion inhibitors for steel rods embedded in concrete as reinforcement when subjected to chloride and acidic-environments. *Boswellia dalzielii* exhibits strong antioxidant and metal chelating properties, which are important characteristics for corrosion inhibition because

they can suppress electrochemical oxidation [5]. This plant is also available in West Africa, particularly Nigeria. For that reason, it is a cost-effective and sustainable source of green corrosion inhibitors.

2. Materials and Methods

2.1 Materials

Steel rods, Measuring cylinder, Filter paper, Separating funnel, 500 ml Beakers, Digital multimeter (Model: DT 9205A), Cement (Portland cement), Sand, Aggregate, Water and Organic inhibitors (*Boswellia dalzielii*).

2.2 Chemicals

Methanol, sulphuric acid, calcium chloride, and copper sulfate (CuSO_4).

2.3 Methods

2.3.1 Sampling

Three different parts; leaves, bark, and root of *Boswellia dalzielii*, were collected from various locations in the Zaria local government to ensure sample representativeness. The samples were separated by plant part and sent to the laboratory for pretreatment.

2.3.2 Pretreatment of the Samples

The samples were washed and dried, then ground into a fine powder using a mortar and pestle.

2.3.3 Preparation of the Standard Solutions

(CaCl_2 1.0 M). One molar solution of CaCl_2 was prepared by measuring 111.00 g of calcium chloride using a weighing balance. The measured CaCl_2 was carefully poured into a 1 L volumetric flask, a small amount of distilled water was added, and the flask was swirled until the calcium chloride was completely dissolved. The flask was filled to the mark [6].

(H_2SO_4 1.0 M). One molar H_2SO_4 was prepared by measuring 55.55 ml of concentrated H_2SO_4 and pouring it into a volumetric flask containing 500 cm^3 distilled water. The flask was filled with distilled water up to the mark.

(CuSO_4 1.0 M). One molar solution of CuSO_4 was prepared by measuring 159.60 g of copper sulfate. The measured CuSO_4 was carefully poured into a 1 L volumetric flask, and a small amount of distilled water was added and swirled until the copper sulfate dissolved to the mark. This solution was used as a copper-copper reference electrode in the half-cell container [7].

2.3.4 Extraction of Plant Samples

One hundred grams of the powdered leaves were measured and dissolved in 1000 mL of methanol at room temperature for 24 h, and they were filtered using filter paper. The extracts

were recovered by filtration and stored at 40°C in a rotary vacuum evaporator. The same process was performed for the pre-treated (powdered) bark and root samples [8]. 15 g of each organic extract was used as an inhibitor in each concrete prism, based on the composition ratio of cement, sand, and aggregates [9].

2.3.5 Preparation of Reinforced Concrete Prisms

Reinforced concrete prisms of size 200 × 70 × 70 mm were prepared using cement, sand, and aggregates in a ratio of 1:2:3. A reinforcement bar of diameter 8 mm and length 200 mm was embedded while casing at a distance of 40 mm from the prism and allowed to dry before testing began. In addition, based on the concrete prism composition, 15 g of each inhibitor was added during mixing. Seven concrete prisms were prepared, six of which contained 15 g of the inhibitor each from the root, leaves, and bark of plant A (i.e., *Boswellia dalzielia*), and were immersed in acid and chloride solutions separately, while the remaining solution served as a control [10].

2.4 Characterization

2.4.1 Scanning Electron Microscopy Analysis

Surface analysis of the reinforcing bars by scanning electrode microscopy was carried out on Phenom X MVE 0987612. The surface morphology of unprotected (i.e. control samples) and protected (i.e. treated samples) reinforcement bars was analyzed after removal from the concrete prism using a crushing machine. Scanning was performed at magnifications of 350, 500, and 1000 to obtain clearer images, and the instrument was operated at 15 kV.

2.4.2 Potential Difference Measurement

The corrosion potential of the reinforced prisms was measured using a half-cell potentiometer at an interval of 2 weeks up to 12 weeks [11]. The electrical potential of a point on the surface of the steel reinforcing bar was measured by comparing its potential with that of the copper–copper sulfate reference electrode on the surface [12]. Practically, this was achieved by connecting a wire from one terminal of a voltmeter to the reinforcement and another wire to the copper sulfate reference electrode [13].

3. Results and Discussion

3.1 Surface Analysis

The results of surface analysis were obtained by scanning electron microscopy, and the images are presented below:

Surface analysis of the reinforcing bars by scanning electrode microscopy was carried out on Phenom X MVE 0987612. The surface morphology of unprotected and protected reinforcement bars was analyzed at a magnification of 350 and operated at a voltage of 15 KV. Scanning electron microscopy revealed that the plant extract adsorbed on the surface of the steel reinforcing bars increased their smoothness, thereby reducing corrosion attack [Figures 1(C), (D)]. Scanning electron microscopy images of unprotected or control reinforcing bars in acid and chloride show

severe corrosion attack in Figures 1(A), (B) which is due to the absence of inhibition species according to the findings of [14]. The SEM images also demonstrate that the plant extract possesses significant corrosion-inhibition capability for steel reinforcement in aggressive acid and chloride environments. The uninhibited samples exhibited severe surface degradation with pronounced pitting and corrosion product formation, whereas the inhibited samples showed comparatively smoother morphologies with evidence of protective film formation.

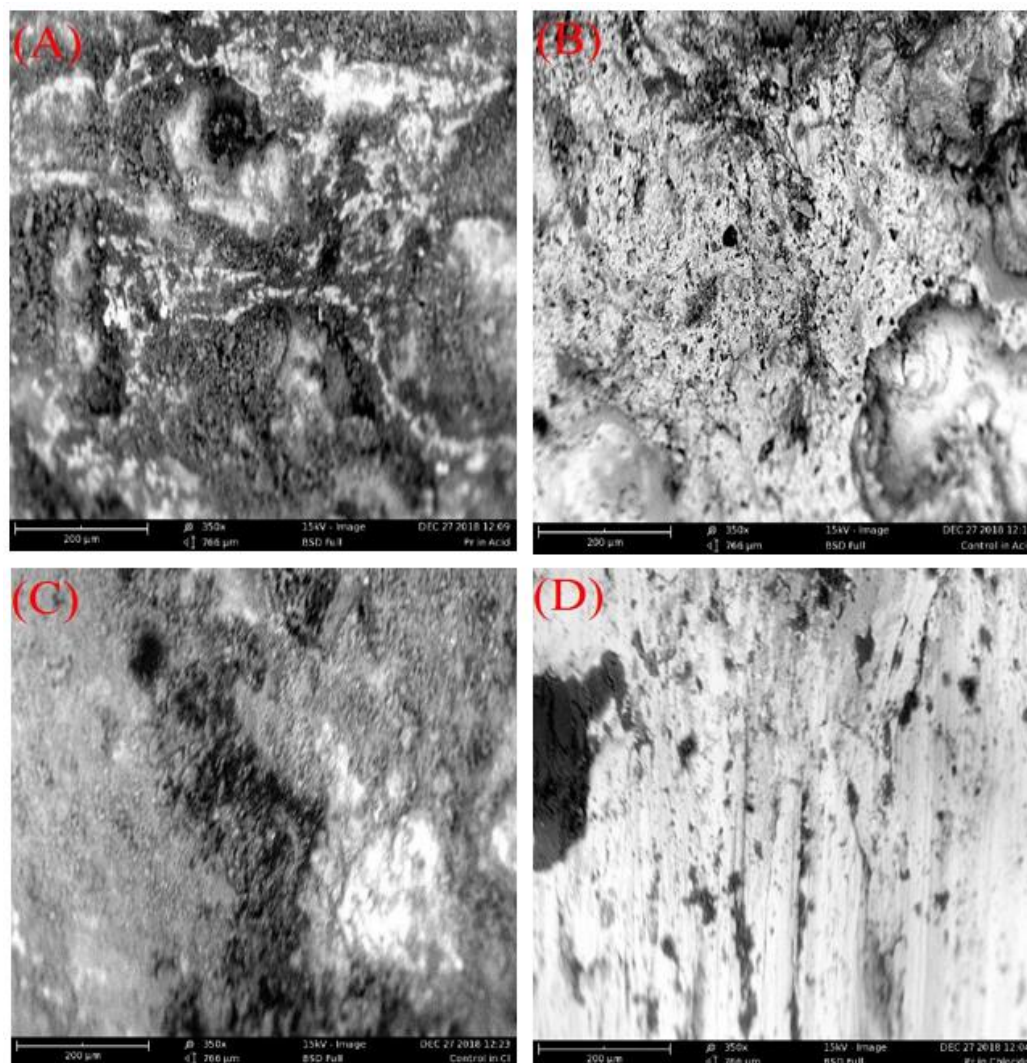


Figure 1 SEM images of (A) unprotected reinforcement treated with acid solution, (B) unprotected reinforcement treated with chloride solution, (C) protected reinforcement treated with acid solution, and (D) protected reinforcement treated with chloride solution, scanned at 350x.

3.2 Potential Difference

The half-cell potential measurements were averaged over three readings for each measurement, and the resulting values were plotted as a function of time in Figure 2 and Figure 3.

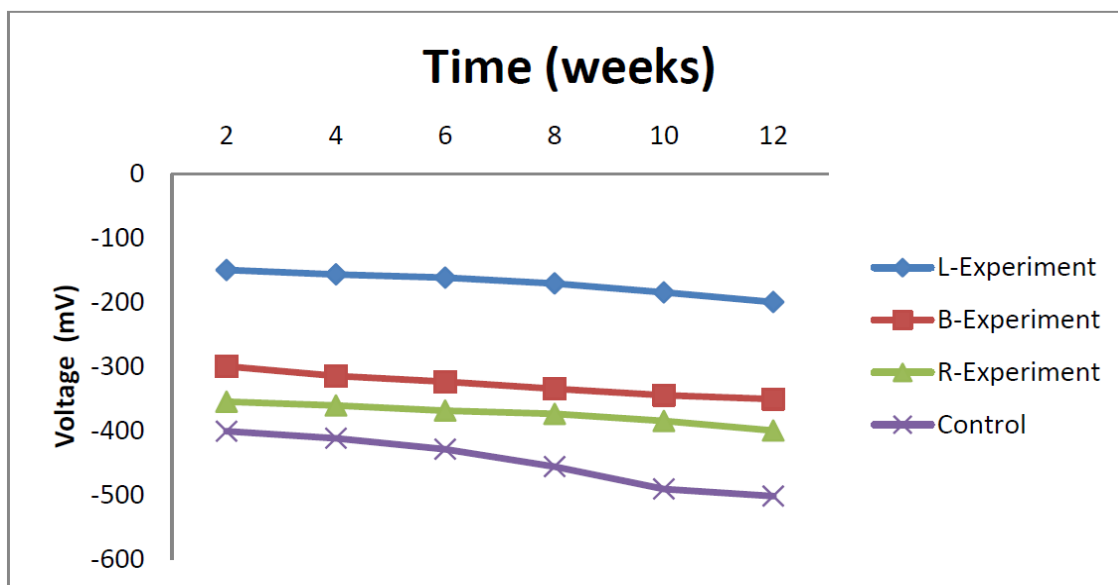


Figure 2 Potential difference vs. Time in (weeks) for concrete treated with leaves, bark, and roots of BD plants in acid solution.

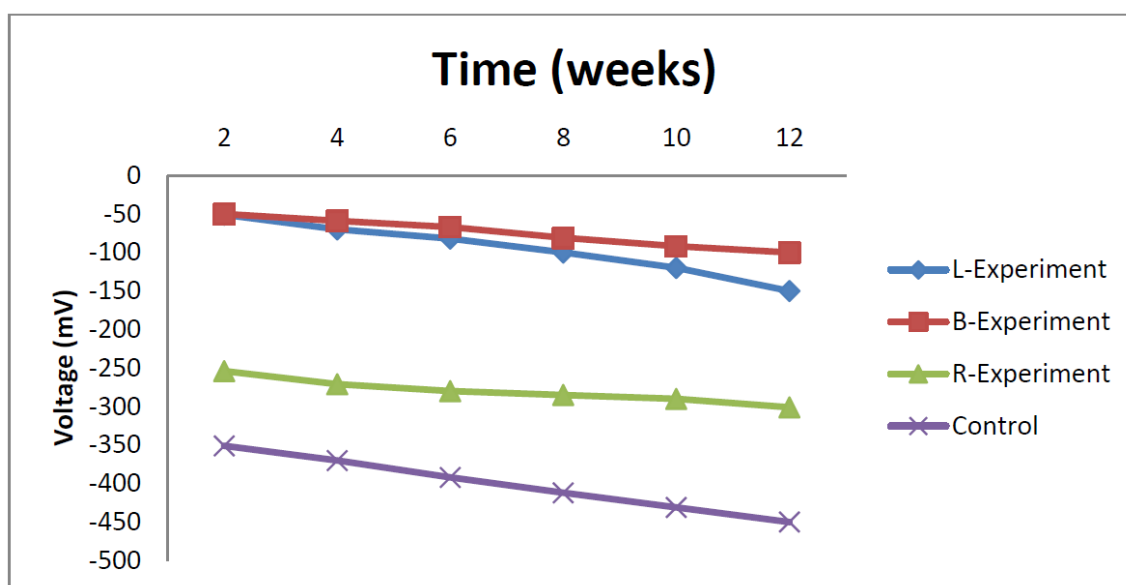


Figure 3 Potential difference vs. Time in (weeks) for concrete treated with leaves, bark, and roots of BD plants in chloride solution.

The inhibition impact is assessed by the magnitude of the negative value of the measured potential difference [15]. The greater the magnitude of the negative values, the greater the probability of corrosion. Electrode potential values greater than -200 mV are considered low (10% risk of corrosion), which is safe according to corrosion/civil engineers, whereas values less than -350 mV but greater than -450 mV are considered to be high risk (90% risk of corrosion), which is unsafe, and values less than -500 mV are considered to be severe corrosion, which is dangerous [16]. The potential difference values obtained were within less than -200 mV for the past 12 weeks, which showed the efficiency of the BD leaf extract in acid medium, whereas the values for BD bark and BD root extracts were above -300 mV (Figure 2), which is 90% risk and are not considered to

be effective inhibitors. The efficiency pattern of the extract from BD leaves, bark, and root in acid shows the following pattern: leaves > bark > root extracts. This probably shows that among the components of leaves, certain compounds are more effective in corrosion inhibition and are not found in bark and root extracts [17].

The measured potential difference for the samples treated with leaf and bark extracts exceeds 200 mV, indicating a 10% corrosion risk and is considered safe by corrosion engineers [18]. For the sample treated with root extract, the magnitude of the measured potential obtained is less than 250 mV and greater than -350 mV (Figure 3) and is considered an intermediate risk of corrosion, i.e., moderately safe according to corrosion engineers [3]. The efficiency pattern of the extract from BD leaves, bark, and root extracts in chloride shows the following pattern: bark > leaves > roots.

4. Conclusion

Based on the results of the experimental investigation into the effect of green inhibitors on concrete reinforcement in acid and chloride media, it can be concluded that SEM and electrochemical potential measurements consistently demonstrate that the plant extract possesses significant corrosion-inhibition capability for steel reinforcement in aggressive acid and chloride environments. The uninhibited samples exhibited severe surface degradation with pronounced pitting and corrosion product formation, whereas the inhibited samples showed comparatively smoother morphologies with evidence of protective film formation. The potential differences over time further confirmed improved electrochemical stability in the presence of the inhibitor, with the sample containing leaf extracts showing the highest protection efficiency, followed by bark and root samples. The inhibition mechanism is attributed to the adsorption of bioactive compounds onto the steel surface, forming a barrier that suppresses corrosion reactions. Overall, the plant extract can be considered an effective, environmentally friendly corrosion inhibitor for reinforced steel in corrosive media.

Author Contributions

Abdulrazak Akilu: Conducted the laboratory analysis and manuscripts write-up. Muhammad Sani Abdullahi: Interpreted the experimental results. Auwal Jaji Aliyu: Conducted the data analysis and review the manuscripts.

Competing Interests

The authors have declared that no competing interests exist.

References

1. Ann KY, Jung HS, Kim HS, Kim SS, Moon HY. Effect of calcium nitrite-based corrosion inhibitor in preventing corrosion of embedded steel in concrete. *Cem Concr Res*. 2006; 36: 530-535.
2. Andrade C, Keddah M, Nóvoa XR, Pérez MC, Rangel CM, Takenouti H. Electrochemical behaviour of steel rebars in concrete: Influence of environmental factors and cement chemistry. *Electrochim Acta*. 2001; 46: 3905-3912.

3. Kamal C, Sethuraman MG. Caulerpin—A bis-indole alkaloid as a green inhibitor for the corrosion of mild steel in 1 M HCl solution from the marine alga *Caulerpa racemosa*. Ind Eng Chem Res. 2012; 51: 10399-10407.
4. Akshatha GM, Kumar BG, Pushpa H. Effect of corrosion inhibitors in reinforced concrete. Int J Innov Res Sci Eng Technol. 2015; 4: 6794-6801.
5. Zhou X, Yang H, Wang F. Investigation on the inhibition behavior of a pentaerythritol glycoside for carbon steel in 3.5% NaCl saturated Ca(OH)₂ solution. Corros Sci. 2012; 54: 193-200.
6. Mahdi A, Rahem S, Nehab M. Study the corrosion inhibition of urea fertilizer—Sn⁺² formulation on reinforced steel in simulated concrete pore solution containing sodium chloride comparing with urea fertilizer—Zn⁺² system. Int J Adv Res Eng Technol. 2015; 6: 33-42.
7. Kondratova IL, Montes P, Bremner TW. Natural marine exposure results for reinforced concrete slabs with corrosion inhibitors. Cem Concr Compos. 2003; 25: 483-490.
8. Loto CA, Loto RT, Popoola AP. Effect of neem leaf (*Azadirachita indica*) extract on the corrosion inhibition of mild steel in dilute acids. Int J Phys Sci. 2011; 6: 2249-2257.
9. Elsener B, Andrade C, Gulikers J, Polder R, Raupach M. Half-cell potential measurements—Potential mapping on reinforced concrete structures. Mater Struct. 2003; 36: 461-471.
10. Jiang L, Xu J, Zhu Y, Mo L. Influence of chloride salt type on threshold level of reinforcement corrosion in simulated concrete pore solutions. Constr Build Mater. 2012; 30: 516-521.
11. Morris W, Vico A, Vazquez M, De Sanchez SR. Corrosion of reinforcing steel evaluated by means of concrete resistivity measurements. Corros Sci. 2002; 44: 81-99.
12. Duranceau SJ, Johnson WJ, Pfeiffer-Wilder RJ. A study examining the effect of stray current on the integrity of continuous and discontinuous reinforcing bars. Exp Tech. 2011; 35: 53-58.
13. Gaius ED, Hamzah E, Ismail M. Effect of inhibitors on the corrosion behaviour of carbon steel reinforced in concrete. J Mek. 2013; 36: 42-49.
14. Nossoni G, Calabrese-Barton S, Harichandran RS. Chloride-induced corrosion of reinforcing steel in concrete: Electrochemical modeling of initial and limiting corrosion rates. Proceedings of the CORROSION 2011; 2011 March 13-17; Houston, TX, USA. Houston, TX: Association for Materials Protection and Performance.
15. Ahlström J. Corrosion of steel in concrete at various moisture and chloride levels. Lund, Sweden: Division of Building Materials, LTH, Lund University; 2014.
16. Abd El Haleem SM, Abd El Wanees S, Abd El Aal EE, Diab A. Environmental factors affecting the corrosion behavior of reinforcing steel II. Role of some anions in the initiation and inhibition of pitting corrosion of steel in Ca(OH)₂ solutions. Corros Sci. 2010; 52: 292-302.
17. Eyu DG, Esah H, Chukwuekezie C, Idris J, Mohammad I. Effect of green inhibitor on the corrosion behaviour of reinforced carbon steel in concrete. ARPN J Eng Appl Sci. 2013; 8: 326-332.
18. Devi M, Kannan K. Analysis of strength and corrosion resistance behavior of inhibitors in concrete containing quarry dust as fine aggregate. ARPN J Eng Appl Sci. 2011; 6: 124-135.