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Synergistic effect of inhibitors on Corrosion of Reinforced Concrete Structures According to ACI Standards

ABSTRACT

The application of low-cost, low-toxic corrosion inhibitors lowers the rate of corrosion of reinforced concrete in a salt-aqueous medium. The purpose of this work is to compare an innovative, supposedly environmentally benign inhibitor derived from fruit waste (pomegranate peels extract (PPE)) with sodium benzoate, an organic inhibitor. The inhibitors were introduced to the concrete mixture at quantities of two and four percent by weight of cement according to ACI standards. The maximum extraction yield in terms of entire phenolic content was obtained by using an aqueous solvent and the Soxlet technique. The efficiency of corrosion inhibitors in preventing corrosion was investigated using compressive strength and optical microscopy methods. PPE forms an organic layer made up of several components in a variety of salt environments, providing both a chemical antioxidant activity and a mixed-type corrosion inhibitor, most likely due to the polyphenol concentrations.

Keywords: *Green inhibitor, Sodium benzoate, Reinforced concrete, Compressive strength, Optical microscopy.*

1. INTRODUCTION

Reinforcement corrosion is the main cause of early collapse of reinforced concrete structures worldwide, and it attracted a lot of attention at the end of the 1980s and the start of the 1990s. [1]. Steel embedded in concrete is often in a passive state against corrosion due to a thin layer of iron oxide that forms on the steel's surface and remains stable in the extremely alkaline environment of the concrete. There are two primary methods for depassivation, which is the process of removing the protective layer that shields steel from corrosion: using chlorides (seawater, deicing salt, unwashed sea sand, admixtures, etc.) to attack the steel, or carbonating the cover concrete by reacting with carbon dioxide to reduce the alkalinity of the concrete. The reinforced concrete structure may fully degenerate electrochemically once corrosion has commenced. Here on the steel surface are the anodic and cathodic areas. [2–6]. During the carbonation process, carbon dioxide seeps into the concrete and reacts with hydroxides. This results in the production of carbonates and water, which lower pH and harm the passivation layer on the steel. [7–10]. CaO and SiO_2 make up the majority of the oxide combination that is dry Portland cement. Calcium oxide hydrates to produce portlandite [$Ca(OH)_2$] when combined with water. This compound can then react with carbon dioxide to form $CaCO_3$. Concrete that is porous is sealed by $CaCO_3$, which has a larger volume than $Ca(OH)_2$ [11]. This dangerous damage could be caused by a decrease in the reinforcing section, the formation of fractures in the cement covering, or a lack of adhesion between the metallic substance and the concrete. The significant impact of chloride ions in the environment is one significant element limiting the longevity of concrete constructions and complicating the work of civil engineers. As seen in Fig. 1, the chloride ions catalyse the dissolving reaction, causing fast disintegration, chipping, and cracking by removing the protective layer Fe_2O_3. [12].

The methods for preventing corrosion that have been developed include cathodic protection, coat-

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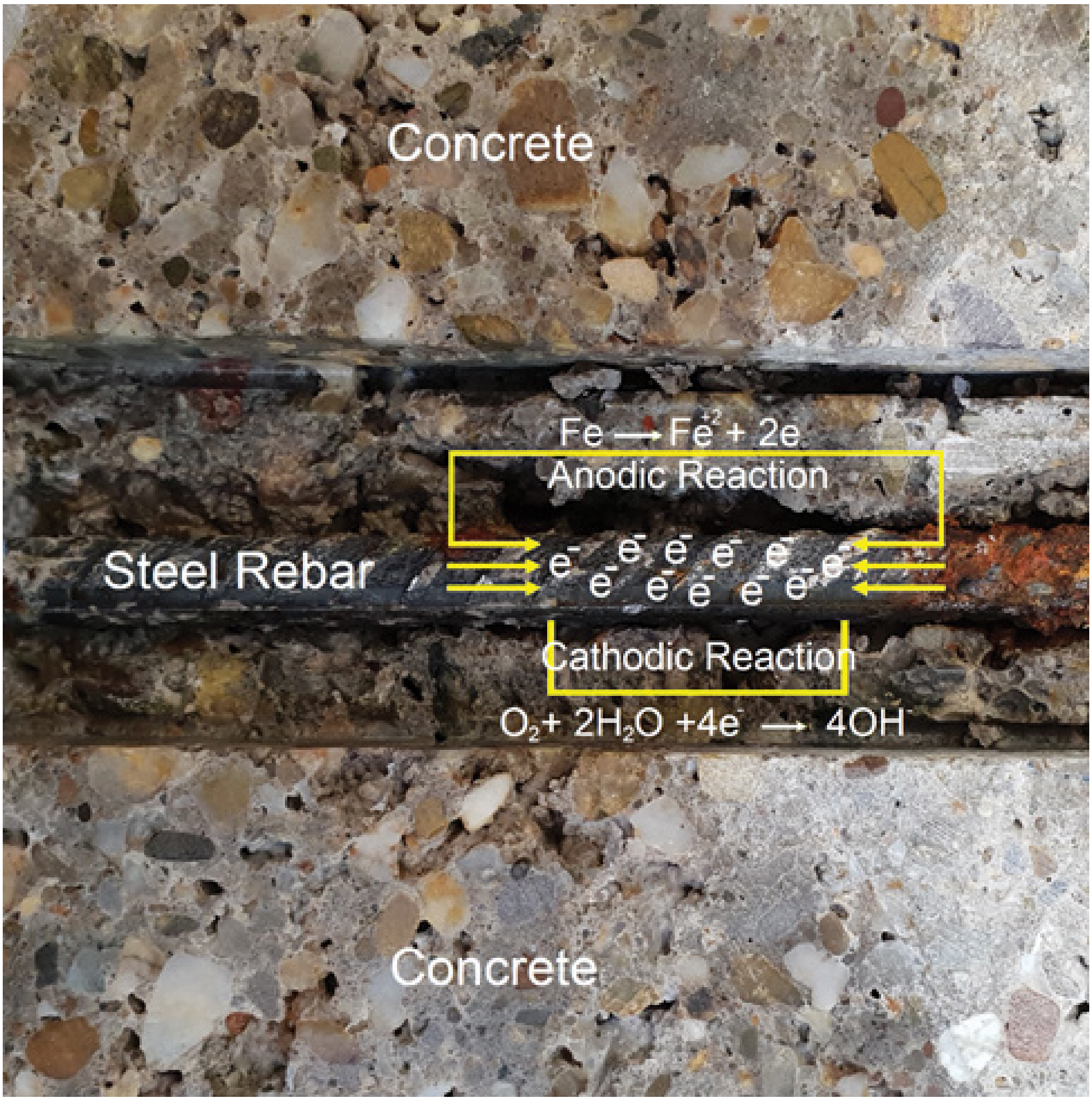

Figure 1 Mechanism of corrosion of reinforced concrete [3].

ings, and corrosion inhibitors. Among all of them, using inhibitors to reinforce steel became standard procedure [7]. Corrosion inhibitors are chemical substances that change the surface state of reinforced steel when added to the concrete mix in small amounts, which slows or stops the rate of corrosion [8]. Using inhibitors was the most effective way to deal with this harmful event. Corrosion inhibitors can be grouped according to the corrosion protection method, environment, layer of protection, type of structure and composition, and physicochemical properties. While total inhibition of corrosion is practically unachievable, inhibitors can be used to limit the rate and abrasiveness of the process. Environmental constraints frequently result in the substitution of less harmful compounds for inorganic inhibitors [9]. The most ecologically friendly method of corrosion inhibitor is green technology, which is based on the usage of plants and biodegradable in nature [10].

The main objective of this research is to report an experimental study that monitors and evaluates corrosion processes in the surface of steel rebar used in reinforced concrete using optical microscopy and compressive strength—a green inhibitor and an organic inhibitor for comparison.

2. EXPERIMENTAL PART

2.1 Materials used

The Portland cement sulphate-resistant cement utilised in this work was produced by the Karbala cement factory, and the cement's physical and chemical test results were in line with the Iraqi IQS No. 5- 2019 [13] for class 42.5 N cement. Coarse aggregate is defined as river gravel that meets the reapproved Iraqi criteria IQS 45–84 and has a grade of 5–19 mm [14]. Sand from a najaf quarry (grading area no. 2) that complies with Iraqi specifications IQS 45-84 [14] is considered fine aggregate and is utilised in all concrete mixtures. In this work, the specimens were made and cured using tap water. Pomegranate peels extract were employed as a green inhibitor in this study. The organic inhibitor utilised in this experiment was sodium benzoate, which has the formula C_6H_5COONa.

Since the research was limited to addressing external chloride attacks, all concrete materials were chosen based on their chloride concentration, staying within permissible limits. The concentration of chloride salt in the aqueous solution to which the specimens were exposed was represented by the exposure conditions, which were 2% or 4%.

All specimens utilised mild steel, whose chemical makeup is given in Table 1. Samples of steel rebar with a diameter of 10 mm in the transverse direction (shear reinforcement) and 16 mm in the longitudinal direction (primary reinforcement protruding 5 cm above specimen surface.

Table 1 Chemical composition of rebar

Element	C	Si	Mn	P	S	N
Weight [%]	0.24	0.65	1.66	0.058	0.058	0.014

2.2 Preparing of Concrete Mixtures

ACI standard technique was used for designing the concrete mix. In order to create concrete with a mean 28-day compressive strength of 35 MPa, ACI 211.1.91 was reapproved in 2002 [15]. This strength was selected to stand in for the typical concrete used in traditional building. The mix had the following proportions: 1:1.62:3.01 for cement, sand, and gravel; the w/c ratio was 0.55. In both combinations, 210 kg/ m3 of water were used. The model symbols and additive proportions for concrete mixtures are displayed in Table 2.

Table 2 The preparation of the concrete mixtures (specimens) for the experiments

Symbol of Mix	Type of Mix	
	% of Adding Pomegranate Peels Extract Inhibitor	% of Adding sodium benzoate Inhibitor
A, A1, A2 Reference	without	without
B ,B1 ,B2	_	2% by weight of cement
C, C1, C2	_	4% by weight of cement
D ,D1 ,D2	2% by weight of cement	_
E, E1, E2	4% by weight of cement	_

2.3 Acceleration of Chloride ion permeation

The purpose of this method to bring chlorides into the concrete to the level of the rebar by diffusion. It A system comprising a glass water container that was constructed to fit the tested reinforced concrete specimens was utilised to expedite the penetration of the chloride ion carried by the soil into the reinforced concrete, utilising „The electrical migration technique" [16]. Concrete specimens were used to partition each container into two sections. As a representation of the salt-laden soil the concrete was exposed to while in use, the first section was partially filled with water containing chloride salt. The specimen was exposed on two sides, and it was raised using a tiny glass base that let saline water come into touch with the targeted portion of the specimen. Distilled water was poured into the second section of the container. Silicone material was put at the points of contact between the glass and the specimens, between the touched glass pieces, or between the concrete pieces themselves to isolate these two sections from one another (see Fig. 2).

2.4 The Tests

2.4.1 Compressive Strength Test

The compressive strength was assessed using the LEL International machine, which is housed in the structural laboratory of the University of Kufa's civil engineering department, in accordance with British Standard [B.S. 1881: part 116: 1989] [17]. The cubes were taken out of the curing water after 28 days and used to measure the compressive strength of the concrete. Three samples on average from each type of concrete mix were used to report the values.

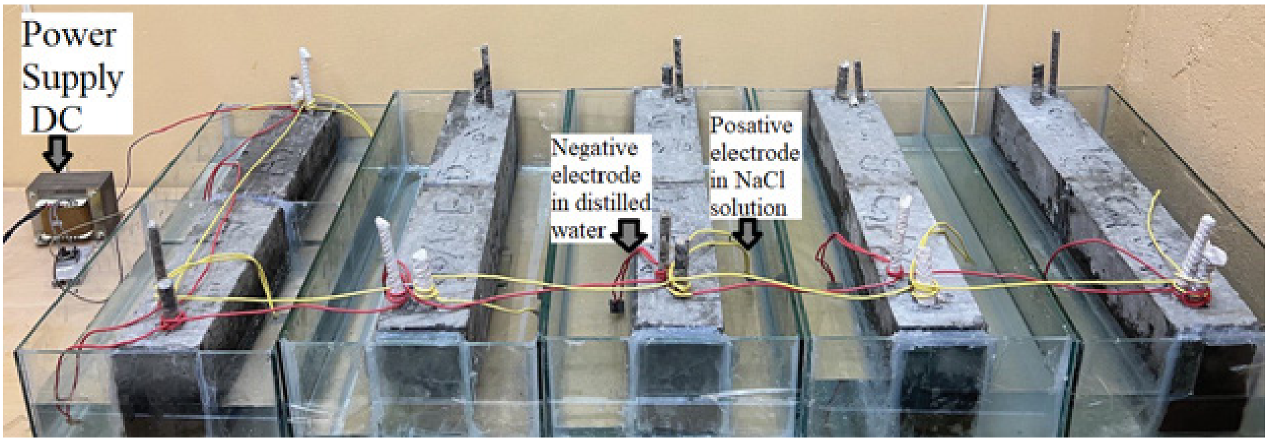

Figure 2 Cell accelerates the penetration of chloride ions

2.4.2 Optical Microscopy

Optical microscopy (OM)was specifically used to detect areas of rust and its spatial distribution on surfaces of reinforcing steel samples. This test was performed at the Nanotechnology Unit at the University of Kufa using an optical microscope device (NMM-800RF, Xiamen Phio, China Origin) equipped with appropriate reflected illumination for observation. Non-transparent surfaces of objects. The camera is connected to computer programs and has the ability to display and show images of the surfaces of objects.

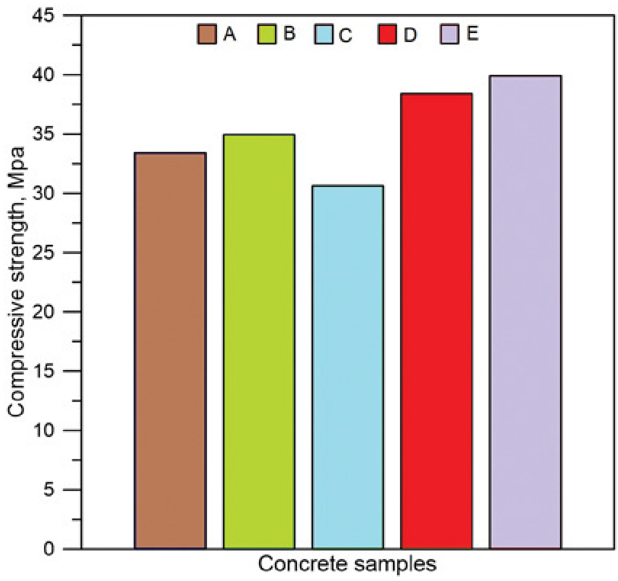

Figure 3 Compressive strength of concrete samples with green inhibitor and organic Inhibitor after immersion in tap water for 28 days.

3. RESULTS AND DISCUSSION

3.1 Compressive Strength Test

The results of the compressive strength test at age 28 days for samples containing 2% and 4% by weight of cement of both organic (sodium benzoate) and green (pomegranate peel extract) inhibitors are shown in Fig. 3.

The addition of sodium benzoate admixture (2% by weight of cement) to concrete does not result in a reduction in compressive strength after 28 days, but the addition of sodium benzoate inhibiter admixture (4% by weight of cement) to concrete does. This admixture may act as a retarder [18], delaying the action of tricalcium aluminate (C3A) and altering the concrete's compressive strength during its early ages.

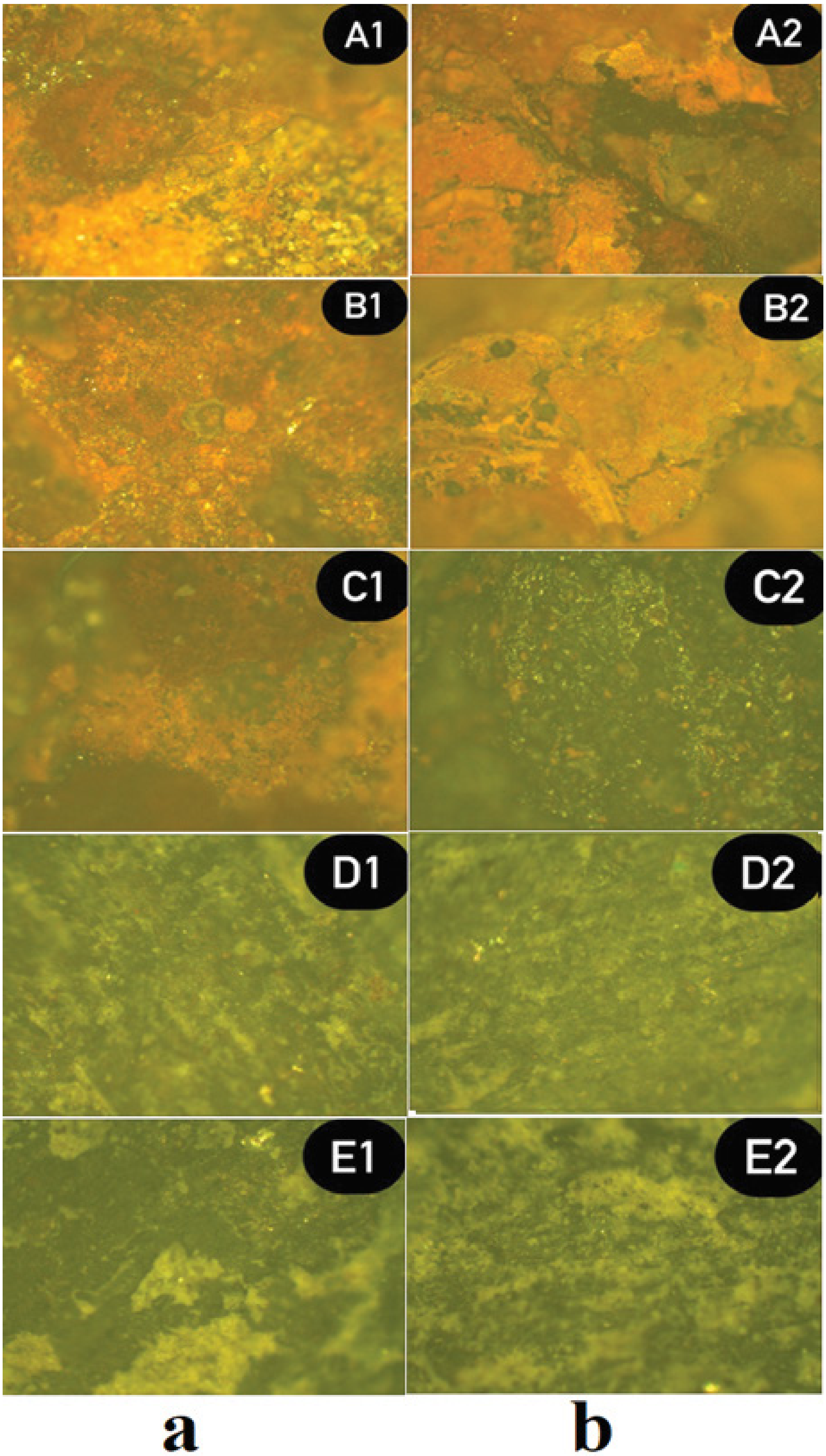

Figure 4 Light optical micrographs of the steel surface with magnification 20X of the concrete columns samples and with and without inhibitors showing the microstructure and the corrosion attack: a) immersed in 2% NaCl solution, b) immersed in 4% NaCl solution.

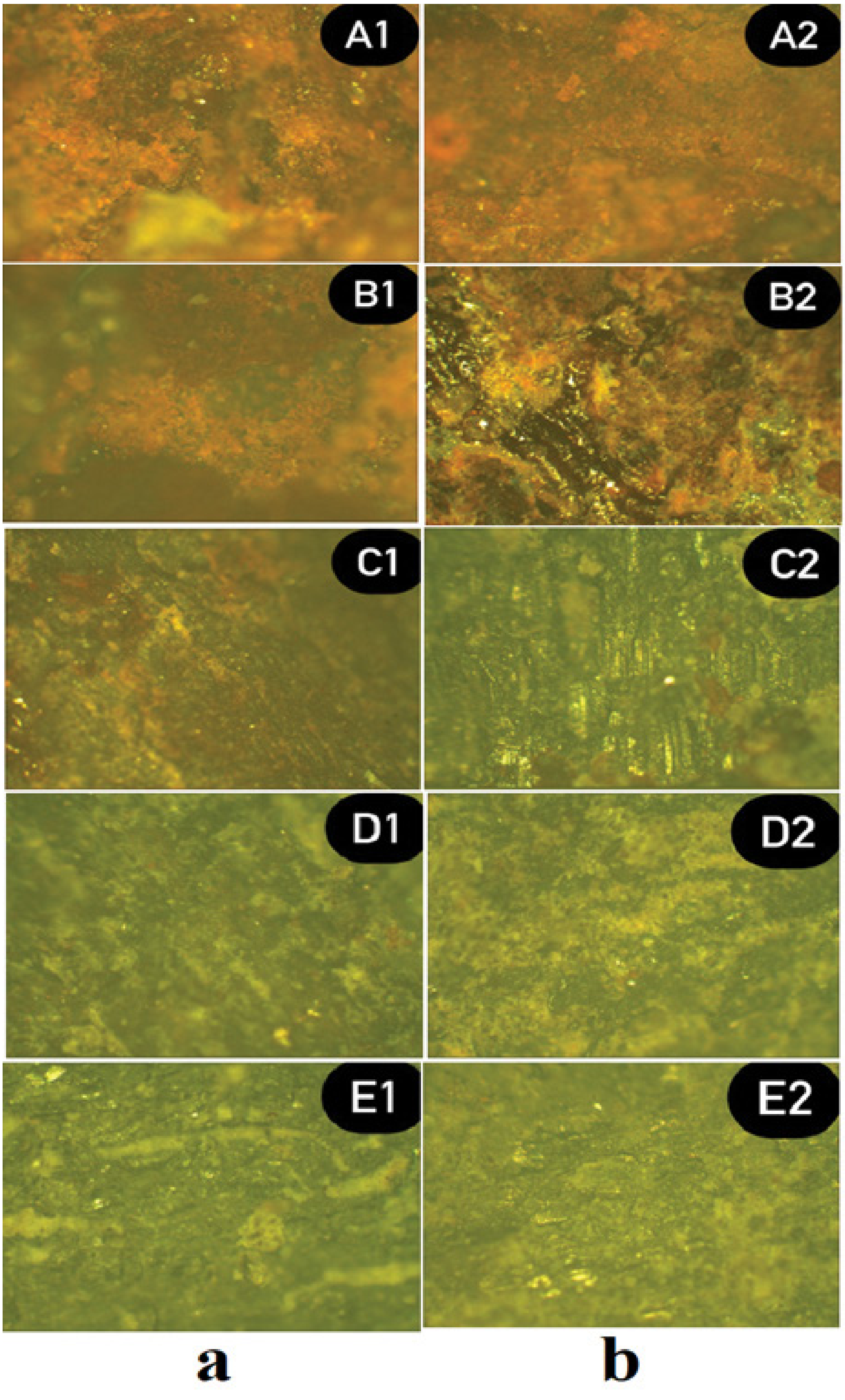

Figure 5 Light optical micrographs of the steel surface with magnification 20X of the concrete beams samples and with and without inhibitors showing the microstructure and the corrosion attack: a) immersed in 2% NaCl solution, b) immersed in 4% NaCl solution.

Following the application of a green inhibitor, pomegranate peel extract added at 2% and 4% by weight of cement increases compressive strength by 3.39% and 4.90%, respectively. Pomegranate peel extract increases the durability of concrete and is responsible for the noted increase in compressive strength. Pomegranate peels, which have a calcium content of 162.1 mg per 100 g, help to build additional calcium gel, which increases the strength of the concrete by producing C-S-H gel. The densification effect was brought about by this gel, which filled the spaces between the cement matrixes [19, 20].

3.2 Optical Microscopy

Optical micrographs of all reinforced concrete samples with or without the presence of inhibitors types are shown in the Figs. 4 and 5. Visual inspection revealed that in most cases of corrosion the corrosion began between the ribs of the reinforcement or directly at the edge of the rib as shown in Fig. 4 (some flash rust spots can also be seen on the surface of beams and columns steel samples).

In Fig. 5, there are also some minor rust areas on the steel surface of the samples.

Inspection of the steel concrete surface at the onset of corrosion typically revealed a single distinct corrosion point, which in some cases was surrounded by much smaller corrosion pits, as shown in Fig. 5. Small corrosion pits have been interpreted as sites where corrosion had begun but were unable to reach stable pit growth (as opposed to a dominant corrosion site), and these pits were typically covered by a crust of corrosion products.

3.3 Conclusion

1- This study investigated a green technique to maintain the environmental cleanliness of organic materials, limit the aggravation of chemical combinations applied to concrete, and promote sustainable engineering. This is accomplished by using pomegranate peel extract, a low-cost, readily available, and non-toxic corrosion inhibitor, in reinforced concrete exposed to chloride attack.

2- A concrete mix that contains 2% or 4% of pomegranate peel by weight will have a higher compressive strength; additionally, the addition of pomegranate peel promotes the creation of calcium gel, which further enhances the concrete's strength development by producing C-S-H gel. Densification is caused by this gel, which filled the spaces between the cement matrixes. The compressive strength of fresh concrete mix is affected when 2% and 4% of sodium benzoate by weight of cement is added. This is because sodium benzoate serves as a retarder after 28 days of immersion.

3- Optical microscopy revealed that the amount of oxides formed as a result of corrosion (iron oxide and chlorides) increased while the concentration of inhibitors (pomegranate peel extract and sodium benzoate) decreased on the surface of the reinforcing steel after it was removed from the concrete blocks. Corrosion products were also found on the surface of the reinforcing steel in samples C2, D1, D2, E1, and E2. Simply looking at the surface reveals that these samples have a less corroded surface or are practically corrosion-free.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

*** Data availability**

Data generated or analyzed during this study are available from the corresponding author upon reasonable request.

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IZVOD

SINERGISTIČKI EFEKAT INHIBITORA NA KOROZIJU ARMIRANOBETONSKIH KONSTRUKCIJA PREMA ACI STANDARDIMA

Primena jeftinih, niskotoksičnih inhibitora korozije smanjuje stopu korozije armiranog betona u medijumu sa slanom vodom. Svrha ovog rada je da se uporedi inovativni, navodno ekološki benigni inhibitor dobijen iz voćnog otpada (ekstrakt kore nara (PPE)) sa natrijum benzoatom, organskim inhibitorom. Inhibitori su uvedeni u betonsku mešavinu u količinama od dva i četiri procenta mase cementa prema ACI standardima. Maksimalni prinos ekstrakcije u pogledu celokupnog sadržaja fenola dobijen je korišćenjem vodenog rastvarača i Soklet tehnikom. Efikasnost inhibitora korozije u sprečavanju korozije je ispitivana primenom metoda čvrstoće na pritisak i optičke mikroskopije. LZO formira organski sloj sastavljen od nekoliko komponenti u različitim okruženjima soli, obezbeđujući i hemijsku antioksidativnu aktivnost i inhibitor korozije mešovitog tipa, najverovatnije zbog koncentracije polifenola.

Ključne reči: *zeleni inhibitor, natrijum benzoat, armirani beton, čvrstoća na pritisak, optička mikroskopija.*

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