Journal of Cleaner Production 67 (2014) 139–146

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Green *Bambusa Arundinacea* leaves extract as a sustainable corrosion inhibitor in steel reinforced concrete

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A R T I C L E I N F O

Article history:
Received 24 January 2013
Received in revised form
8 December 2013
Accepted 12 December 2013
Available online 21 December 2013

Keywords:
Green corrosion inhibitor
Sustainability
Morphology
Corrosion
Steel reinforcement

A B S T R A C T

The experimental studies carried out on water permeability resistance and microstructure of reinforced concrete treated with *Bambusa arundinacea* as green corrosion inhibitor, are reported in this article. The effectiveness of *Bambusa arundinacea* as green corrosion inhibitor was compared with that of calcium nitrite and ethanolamine inhibitors. Concrete mix was designed for a compressive strength of 30 MPa with a 0.45 water-to-cement ratio (W/C) which was chloride contaminated. Inhibitors addition was 2% by weight of cement. The specimens were subjected to various tests, namely; compressive strength test, durability (permeability using initial surface absorption test (ISAT) and field emission scanning electron microscopy (FESEM)) for 360 days exposure. Water absorption values of steel reinforced concrete in the presence of *Bambusa arundinacea* inhibitor were generally less than 0.25, 0.17, 0.1 and 0.07 mL/m^2 s after 10 min, 30 min, 1 h and 2 h, i.e., as required by ISAT standard for low permeability concrete. This might possibly be due to the presence of residual alkalinity of potassium hydroxide (KOH) in the concrete. KOH is adequate for passivation and reduction of permeability, which serves as a chemical water barrier or hydrophobic agent that stabilizes calcium silicate hydrates.

1. Introduction

There is a growing demand for biodegradable and less toxic corrosion inhibitors to combat corrosion of steel reinforcement in concrete especially in a saline environment (Abdulrahman and Ismail, 2012). Most of the conventional inhibitors that were developed to combat this endemic problem are highly toxic to human beings and has the potential to degrade the environment. For instance, they can cause temporary or permanent damage to human organs, such as kidney or liver (Raja and Sethuraman, 2008). Inhibitors' toxicity, according to Abdulrahman and Ismail (2012), is measured as LD_{50} and LC_{50}. The former is a chemical which is considered lethal for 50% of animals in 24 h exposure time. The latter also has lethal properties in air or water and is known to kill 50% of test population. Inhibitor biodegradation, or biological oxygen demand (BOD), should, at least, be 60%. The BOD is a measure of inhibitor persistence duration in the environment.

Recent studies on green inhibitors have shown that they are more effective and highly environmentally benign compared to organic and inorganic inhibitors used in chemical and petrochemical industries. Among the numerous organic compounds that have been tested and applied industrially as corrosion inhibitors, the non-toxic ones are now far more strategic (Boonsong et al., 2012; Abdulrahman et al., 2011a).

The known hazardous effects of most synthetic organic inhibitors and restrictive environmental regulations have compelled and motivated researchers to focus on the need to develop cheap, non-toxic and environmentally benign natural products as corrosion inhibitors. These natural organic compounds are either synthesized or extracted from aromatic herbs, spices and medicinal plants. Plant extracts are viewed as an incredibly rich source of naturally synthesized chemical compounds, which can be extracted by simple, inexpensive procedure. Moreover, they are also biodegradable in nature. The use of these natural products such as extracted compounds from leaves or seeds as corrosion inhibitors has been widely reported by number of authors (Ismail et al., 2011; Abdulrahman et al., 2011b; Ten et al., 2012; Chen et al., 2013; Behpour and Mohammadi, 2012; Negm et al., 2012).

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http://dx.doi.org/10.1016/j.jclepro.2013.12.033

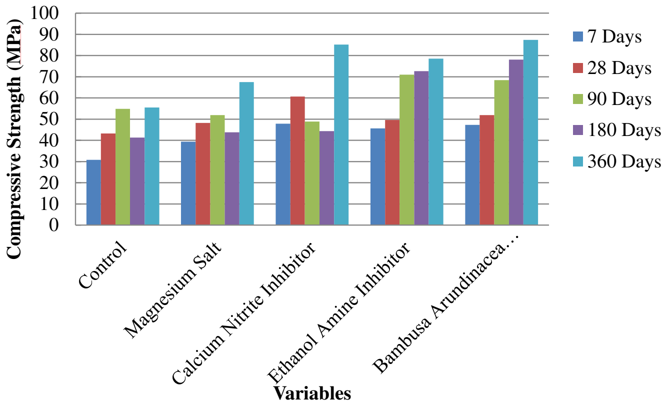

Fig. 1. Compressive strength results.

It is, therefore, imperative to deploy corrosion inhibitor in concrete structure exposed to harsh environments which is eco-friendly. Consequently, exploitation of *Bambusa arundinacea* green inhibitor, an innovative product with new research direction, is necessary in order to ascertain the compatibility and suitability to steel reinforced concrete. It is a step in the right direction to minimize the risk posed by organic and inorganic inhibitors to environment and sustainability.

2. Experimental

2.1. Materials

Ordinary Portland Cement (OPC) was used in this research. The chloride was added into the concrete as magnesium chloride ($MgCl_2$) of analytical grade reagent. The $MgCl_2$ concentration used was 1.5% by mass of cement, while the corresponding chloride concentration was 0.94%. Coarse aggregates (quartzite origin) of sizes 20 mm and 10 mm were used in the ratio of 1.78:1 to satisfy the overall aggregate grading requirements, in accordance with ASTM C192 and Pradhan and Bhattacharjee (2009).

Land quarried sand satisfying BS 882:1992 was used as fine aggregate. The sand has a fineness modulus of 2.5. Tap water was used for the preparation of specimens. All the concrete mixes were designed for similar workability with slump of 30–60 mm. The water content was kept constant at 230 kg/m^3 for the desired slump in all the mixes to have similar workability. The fresh density of concrete was then obtained as per guidelines specified by British method of mix selection (DOE) to be 2380 kg/m^3.

2.2. Hardened concrete tests

Concrete cubes of size 100 × 100 × 100 mm were prepared using cement, sand and coarse aggregates in ratio of 1:1.2:2, at W/C of 0.45. Inhibitor admixtures, namely calcium nitrite, ethanolamine and green *B. arundinacea* in the amount of 2% by mass of cement were added. The concrete cubes were demoulded after 24 h of casting and subjected to water curing for 7, 28, 90, 180 and 360 d. They were then tested for compressive strength using MS EN 12390-8:2012, ASTM C109 and method used by Mefteh et al. (2013). The water absorption test by ISAT was used to determine the concrete permeability using BS 188-208: 1996 and MS EN 12390-3:2012 procedures.

2.3. Metals analyzer by inductively coupled plasma-mass spectrometry (ICPMS)

All reagents used were of analytical grade purity, and high quality water was obtained using a Milli-Q system (Millipore, Bedford, MA, USA). Approximately 2 g of *Bambusa arundinacea* was accurately weighed and transferred to a Teflon container containing 5 mL of 65% nitric acid (HNO_3) (Merck, Darmstadt, Germany) and 1 mL of 30% hydrogen peroxide (H_2O_2) (Merck, Darmstadt, Germany) were then added. After initial digestion process, deionized water was added to adjust the final volume to 25 mL. All specimens were diluted and filtered before analysis, using 0.45 μm filters (Hydropinilic PVDF Millipore Millex-HV). Standard metal solutions were prepared daily from 1000 mg/L stock (Merck, Darmstadt, Germany) in 2% HNO_3 Suprapur grade (Merck). To avoid specimens contamination, all PTFE materials (Teflon vessels, pipettes, micropipette tips, and auto sampler cups) were first immersed in freshly prepared 15% v/v pro analysis HNO_3 (Merck) for 24 h. The PTFE materials were then rinsed thoroughly with doubled distilled deionized water and finally dried in a dust free area before analyzing.

2.4. Preparation of plant extracts

Fresh leaves of *Bambusa arundinacea* (Indian Bamboo) were washed under running water, shade-dried and ground into powder. The extraction was carried out using Soxhlet extraction process. 3 g of pulverized specimens were placed in a porous container and

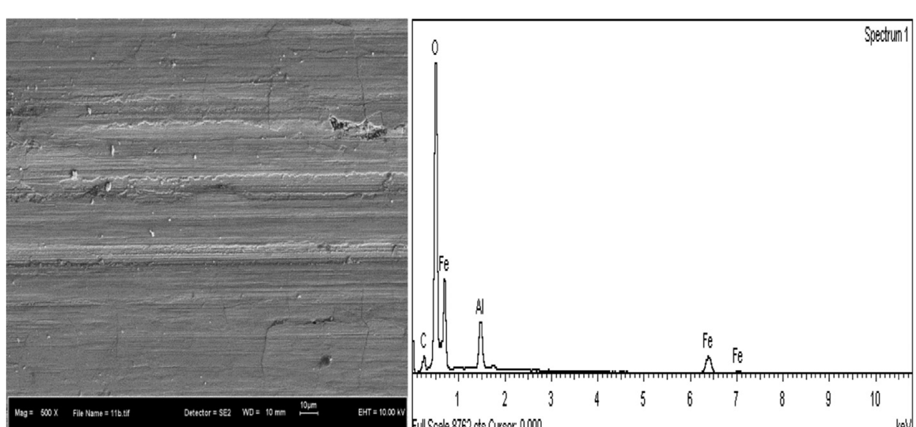

Fig. 2. FESEM/EDX of as-received steel specimens.