SSRG International Journal of Mechanical Engineering
ISSN: 2348 – 8360/doi:10.14445/23488360/IJME-V6I3P103
Volume 6 Issue 3, 14-20, March 2019

Bamboo and Rosewood Fibres-Modified Bitumen Evaluation for Carbon Steel Corrosion Coat-Inhibition in Acidic Chloride Media

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Abstract
An ascertained mild steel rod was used to machine-produced eight annular disk coupons. The coupons were procedurally cleaned to uniform smooth surface finishes in accordance with the ASTM G1 standard procedure and weighted to the nearest 0.001g. Six of the prepared coupons were similarly separately coated in pairs to an average thickness of 1.87mm withunmodified synthetic bitumen from Kaduna refinery in Nigeria and 15%bamboo and 15% rosewood weight-contained modified samples of the bitumenwhich were found to best improve physicochemical propertiesof the bitumen to practicable levels for coating applications. The coated and uncoated coupons were thereupon subjected to accelerated corrosion test by soaking them for 42 days under ambient temperatures in a very aggressive acidic chloride medium prepared by weight-determining and mixing 400,000ppm of analytical grade H_2SO_4 with 500,000ppm of water and then100,000ppm of NaCl in glass containers.The coupons were thereupon removed,procedurally cleaned off of the coatings and any undercoat corrosion products, and reweighed. Corrosion penetration rates of the coupons in the medium were determined from their respective weight losses and results reported in average pair values for the coating types. Collated results indicated a decrease in the corrosion rate of the uncoated steel from 0.298mm/yr to 0.134mm/yr, 0.073mm/yr, and 0.067mm/yr with coatings of the unmodified (control) bitumen, bamboo, and rosewood containedsamples respectively; resulting in protection efficiencies of 55, 75 and 78 % of the steel by the three coatings respectively.

Key Words - *Unsatisfactory bitumen properties, Nigerian bitumen, low exploitation, research and development, modification information, application, and steel corrosion protection.*

I. INTRODUCTION

Corrosion is an ineluctable innate process of material degradation that seriously hampersour Economic and technological progress to an optimal level and needs to be tackled cost-justifiably to reduce its consequences to the barest level. Carbon steel is themost important structural material but haslow corrosion resistancewith corrosion problems thatreputedly accountatop of all corrosion problems in the world. The most flexible, inexpensive, and widely used method of counteracting itscorrosion is by organic coatings. About 90% of all structural steelworks are corrosion-coat-protected by organic coatings, but the choice of the protective coating material is dictated by both economics and service requirements [1-3]. By design standard, optimal methodical corrosion control of any steel type can be based on information from mild steel as the least corrosion-resistant type [1, 2].

Acidic chloride media are great agents of steel corrosion and are commonly encountered in many natural and industrial environments such as tropical coastal areas and in petroleum production and processing. These media are known to aggravatesteel corrosion with the capability to even attack and break down protective barriers on it [2]. Owing to theworldwide availability of bitumen at cheaper rates compared to many other materials and its excellent resistance to industrial pollution, suitably modified bitumen is commonly used in various coating and other forms forcorrosion protection of steelworks and concrete structures in corrosion-predominant industries such aspetroleum or other chemical and water industries [4-6]. Significant advances in corrosion protection of steel and other ferrous materials have reportedly been found in the literature involving modified bitumen. Still, only a number of the diverse possible material modifiers in existence have been researched on and exploited in the applications. Although polymer-modified bitumen has been used extensively for various levels of coating protection of structural steelworks and other applications, the high cost and environmental impact of the polymers have made engineers be in search for cheaper, environmentally friendly and sustainably available alternative modifiers such as plant fibers [4,5, 7].Both natural and synthetic bitumen resources are dependably available in the Nigerian economy, which can be used for the overall development of the country. Still, the resources have essentially remained uncharacterized and unexploited [8, 9].The country cannot develop to industrial status without bidding to keep material corrosion abbey in its domain. This work was a follow on from our previous research contributions towards exploiting the bitumen resources in Nigeria for economically reducing the cost of corrosion in the country [7, 10-15].

Inhibitory effects oflow carbon steel corrosion in acidic chloride media by coatings of unmodified bitumen from three critical bitumensources in Nigeria, including Kaduna refinery, was investigated by Guma *et al*. [10-13]. Their work indicated that using the bitumen coatings above 2.1mm-thickness would provide 100% corrosion protection of the steel in acidic chloride medium. Still, it reaffirmed the need for modifying bitumen from the sources to satisfactory coating properties before their service applications due to the generally known poor engineering service performance of asphalt per se.

This research work aimed to conduct a laboratory study on affordablecoat-inhibition levels of mild steel corrosionin acidicchloridemedia by synthesizedbitumen at Kaduna refinerywith Venezuelan crude that wasmodifiedwith bamboo and rosewood by Guma *et al*. [7]andfoundtoindividually exhibit the best physicochemical properties of the bitumen for coating applications at the bamboo and rosewood contents of 15% by weight in the modifications. The objective was to understandthe extents to which the modified bitumen samples were practicable for corrosion protection of any carbon steel in such critical corrosive media about the unmodified bitumen and to contribute more to the much-needed research output information for proper utilization of Nigeria's vast bitumen resources for beneficially controlling corrosion in her corrosion-predominant sectors.

II. METHODOLOGY

A. Materials

The following materials were utilized for the study

1. A sample of freshly manufactured bitumen with Venezuelan crude at Kaduna refinery.
2. Bamboo.
3. Rosewood.
4. Two-metre long 40mm-diameter mild steel rod.

B. Modification optimality of the refinery bitumen with bamboo and rosewood

A study on the possibility of using bamboo and rosewood as cheap locally available materials in Nigeria for modifying the Kaduna refinery bitumen in the country to better properties for corrosion protectionwas conducted using acquired bitumen samples from the company with the results presented by Guma *et al*. [7]. They individually ground dry bamboo and rosewood fiber materials into powders of 75µm sieve mesh size and sequentially singly additively blended them in different amounts of 0 to 20% by weight with prepared samples of the bitumen. They determined the basic physicochemical properties of the blended samples to know their respective values in relation to the unmodified bitumen sample. Their flash point, fire point, penetration, softening point, viscosity, relative density, and weathering resistance test results in accordance to appropriate ASTM or IS test procedures indicated a marked improvement in the properties with the 10 to 20% bamboo and rosewood contained bitumen samples. They, in particular, found that the 15%-bamboo and 15%-rosewood contained samples produced a lot better of the properties to practicable coating use than the rest. They conducted X-ray fluorescence (XRF) analyses of the two samples to know the distinct chemical compositions that underlay the improvement of their properties and scanning electron micro-structural (SEM) analyses to understand compatibility levels of the additives with the bitumen. Their XRF results showed that the additives altered the percentage compositions and number of 15 chemical species in the unmodified bitumen to 17. Regular smoother microstructures devoid of marked abnormities and indicative of very high compatibilities of the additives with the bitumen were observed by SEM analysis of the samples [7].

1. Production and coat-preparation of coupons for the study

The procured purported mild steel rod was chemical-compositionally analyzed by elemental weight contents at Defence Industries Corporation of Nigeria, Kaduna, to ascertain it.The analysis confirmed that the rod was indeed mild steel material with99.314%Fe, 0.15%C, 0.208%Mg, 0.089%Al, 0.171%Ti, 0.056%Sn, and 0.012%Cu content.After that, the rod was used to produce eightannular disk coupons, each of internal diameter 15mm, outer diameter 20.1mm, and thickness 1.5mm for the study. The productions were achieved by first turning the 40mm-diameter rod to 20.1mm-diameter and drilling it with a 3mm-diameter drill, boring it to 15mm internal diameter, followed by facing and parting off the machine-finish rod into pieces of 1.5mm-thickness using an engine lathe and drilling machine at the Nigerian Defence Academy's Department of Mechanical Engineering workshop. The coupons were procedurally cleaned to uniform smooth surface finishes in accordance with the ASTM G1[16] standard procedure for corrosion tests of metallic materials, and each weight to the nearest 0.001g. Two of the coupons were similarly coated to a micrometer-determined average thickness of 1.87mm with unmodified synthetic bitumen from the Kaduna refinery in Nigeria. Two pairs of the coupons were also similarly coated, each with the15%-bamboo and 15%-rosewood weight-containedmodified samples of the bitumen, which were hitherto found to improve physicochemical properties the bitumen to practicable levels for coating applications [7]. The coatings were achieved by holding each coupon with a thin-lip handling tong andbath-dipping it in each test bituminous sample for 30 seconds, with each samplegas-heated and maintained at the temperature of 150 ± 2^oC in a steel container. By this, the respective material coating was produced on the disk coupons. The attained bath temperature was monitored with a mercury-in-glass thermometer and controlled by regulating the valve opening that the admitted amount of gas burned. The coating process was carried out in accordance with the procedure used by Guma *et al*. [15]. Plate I shows an instance of the bitumen-heating processin the steel container with the gas burner.

Plate I: A gas unit with the steel container for heating the bituminous samples

After bath-dipping-coating the coupons, they were removed from the bath and put in cold water at 5^OC in a plastic container for 12 minutes to set the coatings and make them less sticky for handling. The 15mm-diameter hole on each steel sample was used for handling the coated samples with a small thin-lip tong. With proper handling, the sectional thicknesses of the coating on each coated coupon from the 3mm-diameter disk base were measured at 10 different randomly selected positions on the coating by changes in thickness from 3mm using a hand-held micrometer and averaging results for all the coatingsof the coupons to obtain the working thickness in accordance with the procedure used by Guma *et al*. [15]. By this, the working thickness of the unmodified bitumen sample (control) and two modified examples of the bitumen, each containing 15% bamboo and rosewood additives, was found to be 1.87mm. Plate II shows the cleaned and coated steel samples.

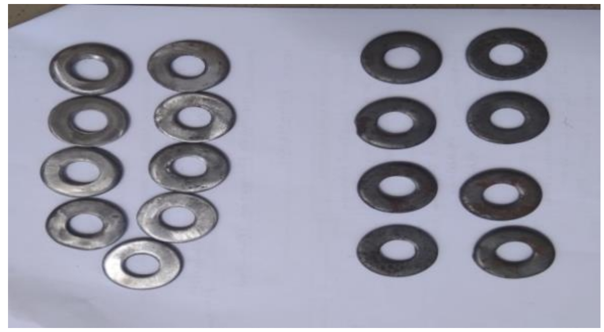

Plate II: Cleaned and coated annular disk coupons for the test.

2. Corrosion test of the coated steel samples

Accelerated corrosion test was used to evaluate the corrosion resistance of the steel sample under each coating protections to simulate practical service corrosion behavior of the steel material in acidic chloride environments. The test was carried out in principle to the ASTM G1 procedure [51] at the Nigerian Defence Academy Mechanical Engineering Department workshop. Each prepared uncoated coupon for the test was initially weighed, and its weight recorded to the nearest 0.001g using the Kerro BL200001 electronic compact balance shown in Plate III.

Plate III: The Kerro BL200001 electronic compact balance

After weighing, each pair of coupon coated type was immerse-placed in an acidic chloride medium made by weight determining and mixing400,000 parts per million (ppm) of analytical grade sulphuric acid (H_2SO_4) with and 500,000 ppm of distilled water and then 100,000 ppm of pure table saltat ambient temperature in three glass containers. Therein the containers, the samples were allowed to undergo any possible levels of corrosion in the laboratory for 7 weeks (42 days) with the glass containers' tops opened to the atmosphere for continuous natural aeration of the medium. Plate IV shows acids in bottles from the Chemistry Department of Nigerian Defence Academy,Kaduna, where the $H_2SO_4$was obtained and used. In contrast, Plate V shows the top view of the glass containers with open ends to the atmosphere with the coated coupons in them and labels indicating the modifier material in the bitumen coating used.

Plate IV: Procured hydrochloric acid in bottles used for preparing the corrosive test medium

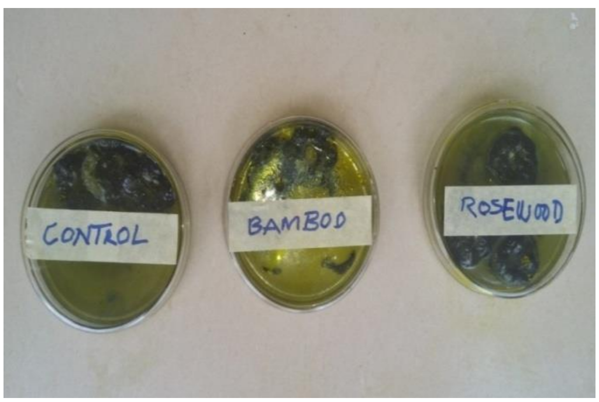

Plate V: Coated samples with identification labels as soak-exposed to the corrosion test medium

At the end of the 42-day exposure duration, the coated samples were removed from the containers with a tong and put in kerosene in a plastic bucket and washed with hands to remove the coatings on them. After removing the coatings, the coupons were further washed in accordance with ASTM G1 standard procedure for cleaning metals for corrosion test using tap water,detergents, bristle brush, clean, soft towel and phosphoric acid followed by sun-drying for 30 minutes to remove any corrosion products, moisture, and other adherents on them without any abrasion of the coupons. After that, each cleaned card was again weighed to the nearest 0.001g using the same Kerro BL200001 electronic compact balance. The weight loss of the steel coupon in milligrams (W) was obtained in each sample case by subtracting its final weight from its respective initial weight. The weight loss in each case was used to determine the corrosion penetration rate (CPR) of the steel material undercoat in mm/yr according to the relation [2]

$$CPR = \frac{87.6W}{DAT} \quad \ldots\ldots\ldots\ldots (1)$$

Where: W = weight loss of the coupon in milligram, D = density of the carbon steel disk samples (7.87 g/cm^3), A = $4.4872cm^2$total exposed surface area of the uncoated steel disk specimen in square centimeters, and T = the 42-day exposure time of the coupons in hours (1008 hours). A was evaluated as

$$\frac{\pi(d_2{}^2-d_1{}^2)}{2} + \pi t(d_2 + d_1) = 448.72mm^2 \quad \ldots\ldots\ldots\ldots (2)$$

Where $d_2 and d_1$ are the outer and inner diameters of the steel disk sample that is 20.12mm and 15mm, respectively, and t = 1.5mm is the uniform thickness of the sample. The results for the respective pair samples were separately averaged and reported as their test CPRs.The test CPR results were used to evaluate the percentage protection efficiencies (PP) of each coating [2],

$$PP = \left(1 - \frac{CPR}{CPR_O}\right) 100\% \quad \ldots\ldots\ldots\ldots (3)$$

CPR is the corrosion rate of the coated steel, and CPR_O is the corrosion rate of the uncoated steel.

III. RESULTS AND DISCUSSIONS

A. Results

The corrosion test results are presented in Figs. 1, 2 and 3

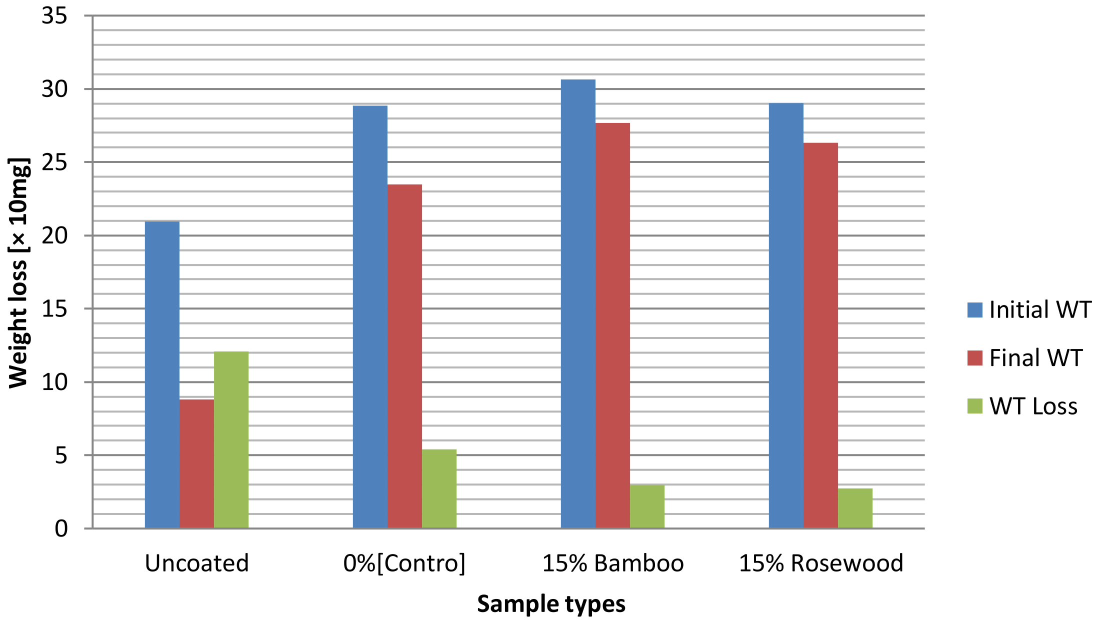

Fig1: Prepared sample typeFig. 1: Initial and final weights and weight loses of the steelsamples coated with the unmodified (control) and modified samples that individually contained 15% bamboo and rosewood

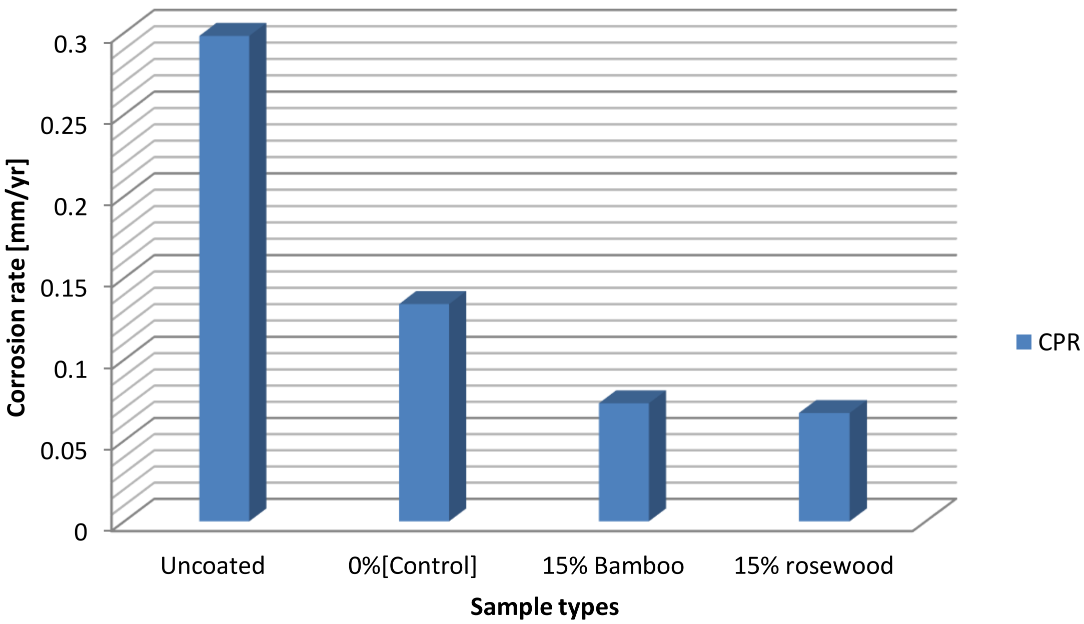

Fig. 2: Corrosion rates of the mild steel samples coated with the fresh refinery bitumen modified to the specified levels with bamboo and rosewood

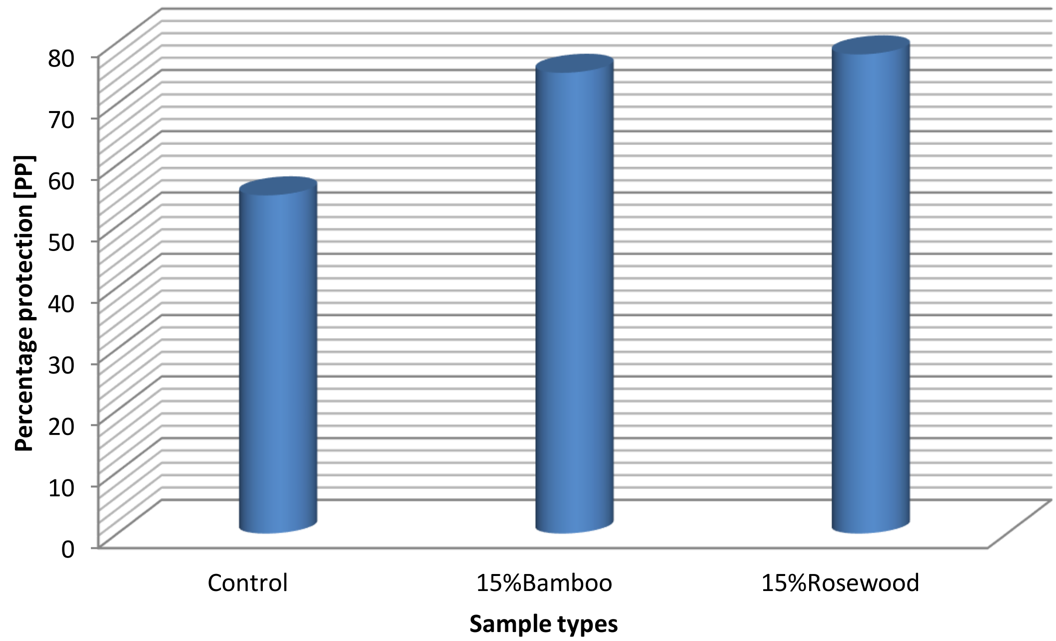

Fig. 3 : Protection efficiency of mild steel [%] by 1.87mm-thick coatings of the unmodified bitumen and modified samples that individually contained 15% by weight bamboo and rosewood

B. Discussion

From Fig. 1, it is observable that the weight loss of the uncoated steel after 42-day exposure in the test acidic chloride medium was greatest followed in descending order by the steel coupon coated with the control bitumen, modified bitumen sample that contained 15% by weight bamboo, and the other sample with 15% by weight rosewood content. The coatings had different effects on corrosion rates of the uncoated steel and when undercoatsthe bituminous materials in a similar order, as can be seen in Fig. 2. Fig. 2 shows that the corrosion rates of the uncoated steel, coated steel with control bitumen, modified bitumen sample with 15% bamboo weight content, and modified bitumen sample with 15% rosewood contents were 0.287mm/yr, 0.192, 0.134, and 0.093 mm/yr respectively; resulting in protection efficiencies of 55, 75 and 78 % of the steel by the three coatings respectively as can be observed from Fig. 3.

IV. CONCLUDING REMARKS

A laboratorystudy of mild steel corrosion inhibition in acidic chloride media by coatings of individually optimally modified Kaduna refinery bitumen with bamboo and rosewood fibers of 75µm sieve mesh size for coating application at15%-bamboo and 15%-rosewood content in the bitumenhas been conducted in relation to the unmodified sample of the asphalt. The objective of the research was to understand whether the bamboo and rosewood modified bitumen can have any reasonable corrosionprotectiveness of the steel relative to the unmodified bitumen.Evaluated results of accelerated acidic-chloride-medium corrosion damage to the steel undercoat by separate coatings of 1.87mm average thickness with the unmodified and modified bitumen samples indicated a decrease in the corrosion rate of the uncoated steel from 0.298mm/yr to 0.134mm/yr, 0.073mm/yr, and 0.067mmyr with coatings of the unmodified, 15%-bamboo and 15%-rosewood contained samples respectively; resulting in protection efficiencies of 55, 75 and 78 % of the steel by the three coatings respectively. This indicated that the modified Kaduna refinery bitumen with rosewood contents of 15% could provide better corrosion protection of the steel than the modified refinery bitumenwith bamboo, and the unmodified refinery bitumen the least protection.The results also indicated that to completely inhibit corrosion of any carbon steel in such corrosive media, coating thicknesses of the bituminous materials well above 1.87mm need to be considered.Field and service tests, as well as practical experience, are recommended forestablishing the economic coating thickness.

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