Sodium Benzoate and Bitumen Coatings as Inhibitors of Corrosion Deterioration of Mechanical Properties of Low Carbon Steel

Guma, T. N.
Department of Mechanical Engineering, Nigerian Defence Academy, Kaduna, Nigeria
E-mail: *gumathomas@yahoo.com*

Madakson, P. B.
Yawas, D. S.
Aku, S. Y.
Department of Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria

ABSTRACT

Corrosion of carbon steel is an enormous problem of practical importance and there have been searches for optimal ways of preventing it in all quarters. A previous study has shown that Nigeria has abundant good-quality bitumen resources for sustained exploitation. Bitumen are common and economical coat-inhibitors of steel corrosion. In that study, the inhibition performances by various coating thicknesses from 0.81 to 1.46mm of bitumens obtained from the resources on resistance to the corrosion deterioration were evaluated through laboratory tests. The study intended to appreciate better, the capability levels of protective performance by the bitumen coatings. The performances by different quantities of sodium benzoate from 50 to 250ppm which are each per se treated to a similar corrosive test medium and under the same test procedures are evaluated on the other hand. Comparative assessment of all results, shows that 250ppm of the benzoate treatment shows the highest resistance to corrosion while 0.81mm coating thicknesses in inhibiting the corrosion has the least resistance.

Keywords: *Steel corrosion, inhibition, bitumen coatings, sodium benzoate, NaCl-borne aqueous*

INTRODUCTION

The cost of metallic corrosion to the total economy must be measured in hundreds of millions of dollars (or euros) per year. Low Carbon steel is the cheapest, most readily available and widely used engineering material; and accounts to about 90% of all steel in usage. It is however, the most susceptible type of steel to corrosion failures or associated with corrosion problems and costly to protect. Despite the low corrosion resistance of carbon steel its applications are encompassing. About 80% of refinery equipment and transmission pipelines are made of carbon steel, essentially of the low carbon type. Because low carbon steel represents the largest single class of alloys in use both in terms of tonnage and total cost, it is easy to understand that its corrosion is a problem of enormous practical importance (Callister, 2004; Alwan, 2010; Guma, 2010, 2011a-b, 2012). A standard corrosion inhibitor for steel is any established chemical or substance that when added in small concentration to an environment can restrain its rusting. In principle it provides an insoluble precipitate at anodic or cathodic regions in the event of a galvanic corrosion cell being set up (Hassan, Abdul-Kadar and Abdul-Jabber, 2011). It is an economical method of protecting steel used in certain environments such as boilers and pipe work of central heating systems, recirculating systems such as internal combustion engines, cooling systems of road vehicles and railway locomotive; steam condensate lines; the oil industry at every stage of production from initial extraction to refining and storage prior to use, storage tanks, domestic and industrial water supplies, store rooms, and packages. Any inhibitor performance depends on the nature of the metal surface, nature and composition of the liquid, the liquid temperature, its concentration in the liquid, mechanical effects, aeration, movement of the liquid, presence of crevices; dead ends; etc., effects of microorganisms, scale formation, toxicity disposal and effluent problems (Shreir, 1979b; Illston *et al,* 1979).

Although the most important steel-corrosive natural environments include acidic soils, heavy clays and highly saline soils of high electrical conductivity, river and harbour mud, organic deposits such as peat and silts; of noteworthy the material rusts at almost incredible rates on surf beaches in the tropics where it is exposed to a continuous spray of moisture and sea salts, particularly sodium chloride; on the surf beaches. Sodium chloride is plentiful in sea water, brackish water and many chemical processes waters (Shrier, 1979a; Alwan, 2010). Various inhibitors are reported in the literature that can help in protection against metal corrosion in aqueous environments. Among them are toluylalanine, cyclohexyl amine, dicyclohexylamine nitrite, methycyclohexylamine, phenythiourea, sodium benzoate, sebacic acid, calcium silicate, sodium phosphate and sodium nitrite (Kahraman, 2002). Sodium benzoate ($NaC_6H_5CO_2$) is the sodium salt of benzoic acid and exists in this form when dissolved in water. It is produced by reacting sodium hydroxide with benzoic acid. It has found considerable application as a corrosion inhibitor in low concentrations. Its corrosion inhibition has been reported for steel, zinc, copper, copper alloys, soldered joints, aluminum and aluminum alloys.

As a liquid phase inhibitor, low concentrations of sodium benzoate have been reportedly been used for corrosion control at a pH as low as 5.5, but the most effective inhibition appears to be in the pH range of 6 to 12. The effectiveness of the corrosion inhibition has been reported to be positively affected by small concentrations of sodium nitrite and negatively affected by concentrations as low as 0.1% of sodium chloride and/or sodium sulfate. A critical minimum pH for inhibition with respect to the sodium benzoate concentration has also been indicated. It has been suggested that sodium benzoate reduces fouling by reducing the tendency of rust and scale to dislodge from corroded surfaces. Sodium benzoate does not cause foaming or frothing when used as a corrosion inhibitor in these applications, and it presents no toxicity problems when used as a corrosion inhibitor which could be an asset in applications sensitive to odour and toxicity (INTERNET, 2011). The most important method of corrosion protection is however by paint or organic coatings. It is estimated that about 90% of all steelworks are corrosion-protected by paints or organic coatings. The coatings provide the protection by acting essentially as mechanical inhibitive barriers between the substrate steel and the different environmental corrosive agents such as moisture, air, chlorides, sulphates, etc.; and control of the micro-environment on the steel surface. When a steelwork is given a protective coating treatment, it may still corrode under coat but at a much lower rate compared to the bare steel under the same conditions of exposure; depending on the properness of the coating with respect to, coating adhesion and thickness, quality of the coating material, exposure time, environmental factors, etc. If maintenance of the coating is negligibly not provided over a sufficiently long time, the designed and installed steel structure will eventually fail due to corrosion because of deterioration of the coating itself with some attendant increment in its porosity and percolation of the corrosive agents and aggravation of corrosion. The effectiveness of a coating treatment for steel for a particular coating thickness, time, and particular conditions of environmental exposure depends on the degree of porosity of the coating material to corrosive agents and can also be assessed by the state of deterioration of mechanical properties of the insitu steel (Shreir, 1979b; Barton, 1976; Enetanya, 2004). Bitumen is an organic material of great importance in today's technological world which exists naturally or is produced with petroleum from different sources, and can have wide variation in grade or qualities and corresponding levels of service performances. It has been used in the forms of bituminous tapes and wrappings, bituminous paints, admixtures in concrete encasements, direct coatings or coating supplements to other protective methods, etc.; for protecting steel used in transmission pipelines, and other aspects of plants in the petroleum or other chemical and water industries from corrosion based on its excellent resistance to industrial pollution.

Nigeria has abundant reserves of natural bitumen resources to the tune of over 14.86 billion barrels located in Ondo, Lagos, Edo, Oyo and Enugu States; and potentials for sustained production of bitumens from suitable crudes at her Kaduna Refining and Petrochemical Company (KRPC). Ondo State is however the most important source area. Rich bitumen deposits are found in the State around the region of Agbabu, Foriku, Okitipupa, Aiyibi, and Idiobilayo (Oshinowo et al, 1982; INTERNET, 2012; Guma et al, 2010, 2012). This made Guma et al (2010; 2011a-b; 2012) to undertake a study on suitability levels of using some bitumens sourced from Ondo State and KRPC as common and economical coat-inhibitors of low carbon steel corrosion in the country through test-evaluation and analysis of resistance to corrosion deterioration of the basic mechanical properties of the steel by different coating thicknesses of bitumens obtained from some critical sources in the country. In the study; two natural bitumen samples with identification names Ondo S-A, Ondo S-B were collected from rich bitumen deposits on the ground surface in a waterlogged area and underground at Agbabu village in Ondo State respectively, and a sample of KRPC-manufactured bitumen with a blend Nigerian and Basra crudes from Iran with identification name KPB were used. 39 ASTM tensile specimens from similar low carbon steel rods were produced and prepared for the tensile test. Nine were not coated with any bitumen sample and used for control, while each set of 10 from the rest was coated similarly in five pairs of respectively different coating thicknesses with each bitumen sample. Three of the uncoated and one from each of the 15 coated pairs with regard to identity of the bitumen sample used were corroded continuously for 50 days in a design-prepared aggressive corrosive admixture of 30% NaCl, 5% concentrated H_2SO_4, and 65% water, that was under continuous aeration and circulation to simulate corrosive factors of one of the worst natural corrosive environments-the tropical surf beach. This was similarly repeated in each case with 39 ASTM impact specimens, 39 suitably specified hardness specimens, and 39 five-set ASTM fatigue specimens of the same steel rods. In all cases, each corroded or control specimen was test-evaluated of its relevant mechanical property using the relevant facility. The fatigue specimens in each five-set were each tested of its fatigue endurance at one of the 250, 275, 300, 325, and 350N/mm^2 cyclic stress loads. The coat-inhibition efficiency with each coating thickness of each as obtained bitumen sample from Nigerian resources on corrosion deterioration of each basic mechanical property of the steel was then determined appropriately from the test results. The prime objectives in this study are:

i. To compare the results shown in Appendix A with those using different treatment concentrations of sodium benzoate inhibitor on the other hand in the same test corrosive medium and similar steel specimens under the same exposure time and the relevant property tests and determination of inhibition performance.

ii. To contribute to applicable information for better understanding of corrosion protection of steelworks in a very high NaCl-borne aqueous and acidic environment that is under continuous aeration and circulation; with the inhibitors.

MATERIALS AND METHOD

Materials and Facilities: The materials and facilities used for the tests were; low carbon steel, pure benzoic acid and sodium hydroxide, sodium chloride, sulphuric acid, water, a very accurate digital weighing scale; a pH meter, a Hounsfied tensometer, a Hounsfield balanced impact strength testing machine, a dynamic fatigue testing machine, Knoop microhardness testing facility.

Specimen Preparation and Corrosion: The remaining same procured low carbon steel rods used by Guma et al (2010, 2011a-b, 2012) were used for the tests. The overall as-analyzed average consistent chemical compositions by elemental weight of the rods and their microstructures which showed that they were all the same and consistent low carbon steel material has been given by Guma et al (2010, 2011a-b, 2012). The rods used were appropriately machine-produce five pairs of; ASTM tensile, five-set ASTM fatigue, ASTM impact fracture specimens; and 10 others each of 10mm in diameter and 5mm in thickness for the hardness test. Each produced specimen and type was similarly surface-prepared to the same consistent average surface finish of 30 microns in accordance to Guma et al (2010, 2011a-b, 2012). The corrosive admixture of 30% NaCl + 5% con. H_2SO_4 + 65% air of 100% relative humidity at 38°C under continuous aeration; as used by Guma et al (2010, 2011a, b) was reproduced for the test. Using a very accurate electronic digital weighing scale, 461.5385g of NaCl and 76.923g of concentrated H_2SO_4 were determined and mixed thoroughly in $1000cm^3$ of water to get the percentage compositions. The pH of the admixture was determined with the pH meter to be 11.2. The prepared corrosive medium was then divided into five equal portions and each portion poured into a separate plastic 1000ml container. Stoichiometric masses of 40g of the procured sodium hydroxide and 122g of the benzoic acid were determined in the laboratory with the digital scale and added together in a 250ml glass container and gently stirred with a plastic spoon for thorough mixing to get their reaction product as 162g of sodium benzoate

$$\begin{array}{llll} \mathrm{NaoH}+ & C_7H_5O_2 & \longrightarrow & C_7H_5O_2Na + H_2O \\ 40g & 122g & & 162g \end{array}$$

With the same digital scale 0.01539, 0.03078, 0.04617, 0.06156, 0.07695 grammes of the produced benzoate were determined. Each mass was then added separately to one of the prepared corrosive medium in the glass container to get respectively 50, 100, 150, 200 and 250ppm of the sodium benzoate treatment concentration of the medium. Each container of the treated media was then labeled with the treatment concentration value on it for identification, using a piece of paper with the concentration quantity written on the paper and gummed to it. A pair of impact fracture, tensile, hardness, and five-set fatigue specimens as an overall set was immersed similarly in the treated medium in each container. To circulate the inhibitor and also to avoid stagnation of corrosion but make it continuous during the test period, air from a compressor at an arbitrary pressure of 0.015 in excess of one atmosphere was released and allowed to flow continuously through similar thin plastic hoses into and at the depth of each medium in the containers. This made each medium to circulate continuously in an up and down fashion over the specimens. In this way the specimens were allowed in exposure for 50 days to undergo any possible level of corrosion at a prevailing average room temperature of more or less 38°C of the treated medium. This was achieved using the Armfied corrosion studies kit facilities (Guma et al, 2010; 2011a-b; 2012). At the end of the 50 days, the specimens were all removed using crucible tongs, and each clean with a towel and subjected to appropriate mechanical property test using the relevant facilities in accordance to the detailed procedures covered by; Doyle (1979), ASM (1975), Choudary (2003), Guma et al (2010; 2011a-b; 2012).

Mechanical Properties Testing of Specimens and Evaluation of Inhibition Efficiencies: Each tensile specimen was slowly subjected to elongation until fracture occurred. During this, the measurement of applied stresses and corresponding strains were determined at 10 different stress loads. The average inhibition efficiency () of resistance to corrosion deterioration of the tensile strength by the two tensile specimens of the steel for a particular case of treatment concentration of the sodium benzoate (i) is determined from (Guma et al 2011a):

$$\eta_i = \sum_{n=1}^{n=10} \frac{\left(\frac{\Delta\varepsilon_i}{\Delta\varepsilon_0}\right)^{100}}{n} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where; $\Delta\varepsilon_i$ is the difference between the average strain (ε) of two as-procured steel specimens that were not immerse-exposed, or corroded in any medium and average strain (ε_i) of two others exposed in the corrosive medium treated with a particular concentration (i) of sodium benzoate under the same applied stress value; and $\Delta\varepsilon_0$ is the difference between the average strain of two specimens immerse-exposed in the untreated corrosive medium (ε_0) and (ε). $n = 10$ is the number of average applied stress values at which the strains were appropriately obtained for each for all specimen pairs. The values of ε_0 ε and are given by Guma et al (2011a) in Appendix B. The fatigue endurance of each specimen of a given five-set and treatment was evaluated at a different fatigue load of 250, 275, 300, 325, and $350N/mm^2$. The resulting data was used to evaluate the average inhibition efficiency (η_i) of resistance to corrosion fatigue strength of the two five-set specimens for each case of sodium benzoate treatment concentration (i) as (Guma et al, 2012):

$$\eta_i = \sum_{n=1}^{n=5} \frac{\left(\frac{\Delta S_i}{\Delta S_0}\right)^{100}}{n} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where: ΔS_i is the difference between the average number of stress cycles to failure (S) of two as-procured steel specimens that were not immerse-exposed or corroded in any medium and two others immerse-exposed in the test corrosive medium treated with a particular concentration (i) of sodium benzoate (S_i) at the same fatigue load; and ΔS_0 is the difference between (S) and average number of stress cycles to failure (S_0) of the two specimens immerse-exposed to the corrosive medium without any treatment in it as evaluated at the same fatigue load; n is the number of fatigue stress loads considered for each case of sodium benzoate treatment concentration (i). The values of S and S_0 are given by Guma et al (2012) in Appendix B. The impact fracture energy of each specimen was evaluated using the Hounsefield balanced impact strength testing machine in accordance with American Standards for Testing Materials (ASTM) (Doyle, 1969; ASM, 1975; Guma et al 2011b). The inhibition efficiency () of corrosion deterioration of impact strength of the steel by the benzoate treatment is given by Guma et al, (2011b).

$$\eta = \left(\frac{\Delta\varepsilon_i}{\Delta\mu_i}\right)^{100} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where: E_i is the difference between the average impact fracture energy (E) of two as-procured steel specimens that were not immerse-exposed to any medium or corroded and two others immerse-exposed in the corrosive medium treated with a particular concentration (i) of sodium benzoate (E_i); and ΔE_0 is the difference between (E) and impact fracture energy (E_0) of the two specimens exposed to the corrosive medium without any treatment in it; for each case of sodium benzoate treatment concentration (i). The values of E and E_0 are given by Guma et al (2011b) in Appendix B. The Knoop microhardness of each hardness specimen was determined in accordance to ASTM specifications (Doyle, 1969; Guma et al, 2010).

$$\eta = \left(\frac{\Delta HK_i}{\Delta HK_i} \right)^{100} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where: ΔHK_i is the difference between the average Knoop microhardness (HK) of two as-procured steel specimens not immerse-exposed in any medium or corroded and two others immerse-exposed in the corrosive medium treated with a particular concentration (i) of sodium benzoate (HK_i); and is the difference between (HK) and average Knoop microhardness (HK_0) of the two specimens immerse-exposed in the corrosive medium without any treatment in it; for each case of sodium benzoate treatment concentration (i). The values of HK and HK_0 are given by Guma et al (2010) in Appendix B.

RESULTS AND DISCUSSION

The results of inhibition efficiencies of corrosion deterioration of each mechanical property of a low carbon steel by different treatment concentrations of sodium benzoate to a very high sodium chloride-borne aqueous corrosive medium under continuous aeration and circulation studied under laboratory test methods is presented in Tables 1a-d. Comparison of the results with the efficiencies by coatings of bitumens from some critical sources in Nigeria, shown in Appendix A, it is demonstrable that the inhibition efficiencies increase with the quantity of the benzoate treatment of the medium likewise with the coating thickness of the bitumen. The highest inhibition performance (27%) of the benzoate at its 250ppm concentration treatment of the medium is much lower than the least (53.36%) from the 0.81mm bitumen coating thickness inhibition of corrosion fatigue strength. In the atmosphere, corrosion of steel increases with any chloride and moisture contents of the air depending on the distance from the natural source, prevailing temperature and humidity. At a very high chloride content of 11.1% and 50 yards from the tropical surf beach and high humidity in Lagos, Nigeria; the corrosion rate for ingot iron is 0.95mm/yr as obtained by the Former Tropical Testing Establishment, Ministry of Supply Britain on behalf of BISRA (Shreir, 1979a). By continuous aeration and circulation of the corrosive admixture of 30% NaCl, 5% H_2SO_4 and 65% water proportions, the corrosive medium simulates atmospheric condition of the tropical surf beach environment at 100% relative humidity. By the aeration and circulation of the medium more of the benzoate inhibitor, the dissolved sodium chloride and oxygen are supplied in contact with the specimens. This enhances the effectiveness of the inhibitor, whilst by the continuous contact supplies of oxygen and the sodium chloride the corrosion agents are invigorated. In aerated distilled water, as little as 0.007% of sodium benzoate concentration effectively inhibits steel corrosion, but inhibition is not observed in deaerated distilled water. The increase in corrosion with sodium chloride concentrations in all aqueous environments is due to enhanced solution conductivity.

However, in aqueous medium that is not continuously aerated and circulated increase in sodium chloride concentration lead to higher dissolved salt and this lead to decrease in solubility of dissolved oxygen and corrosion rate decrease steadily beyond 3% by weight of the sodium chloride (Alwan, 2010). High inhibition performances with 100ppm treatment concentration of 3% by weight sodium chloride solution prepared separately at different pH levels of 3, 5, 7, 9 and corresponding temperatures of 25, 30 and 40°C have also been obtained by Alwan (2010). He found that the inhibitor effect decreased with temperature of the solution but increase with pH values. The highest inhibition performance value (88%) was obtained at the solution condition of 25°C and pH = 9, while the lowest (74%) at 25°C and pH = 3. The comparative poor performance of the sodium benzoate treatment concentrations of the test corrosive medium in inhibiting the corrosion deterioration of the steel properties is because it is negatively affected by of sodium chloride even in small concentrations as low as 0.1% in any environment (INTERNET, 2011) but the prepared corrosive medium contains as much as 30% of sodium chloride, though its acidity is low at 11.2. Moreover, it is due to the continuous aeration and circulation of the medium.

CONCLUSION AND RECOMMENDATIONS

Nigerian economy is petroleum dependent, and a lot of wastages occur through corrosion process in it. A previous study has shown that properly sourced bitumens from the country's resources will provide effective resistance to corrosion deterioration of mechanical properties of low carbon steel, when it is properly coat-protected by bitumens. The study attempted to open up potentials for utilizing the country's abundant bitumen resources in various suitable coating forms for corrosion protections of the steel at economical cost as applicable to petroleum or other chemical and water industries in the country's economy. Sodium benzoate is a common standard inhibitor of steel corrosion and is generally well known for high effectiveness even when applied in low concentrations to applicable environment whose pH can be as low as 5.5 (Yawas, 2005; INTERNET, 2012). Corrosion of any material results in impairment of its properties which are cherished and must be preserved in structural usage. Any corrosion test assessment on the basis of direct damage or improvement in the properties will enable one to appreciate better the level of damage done to the material or its achieved protection. The corrosive effects of a very high NaCl-borne acidic, continuously aerated and circulatory aqueous environment was used to test the performances of the bitumen coatings on corrosion deterioration of mechanical properties of low carbon steel, and which per se has been treated with each of various concentrations of sodium benzoate on the same properties of the same steel immerse-exposed to each has been properly studied and compared with those by the different coatings. The intention has been a further search to appreciate better the corrosion coat-inhibition performance levels of bitumens from Nigerian resources in a high NaCl-borne aqueous aerated circulatory environment. The obtained results have shown that despite the known high effectiveness of sodium benzoate as a corrosion inhibitor in most environments, the inhibition that can be provided by coatings of properly harvested bitumens from Nigerian resources in the thickness range of 0.81mm and higher will be much superior to those that can be provided by treating such an environment with up to 250ppm of the benzoate.

The test-evaluations of the inhibition performances of the bitumen coatings and sodium benzoate treatment concentrations were each carried out using similar corrosive test media of higher factor of aggressiveness in comparison to worst natural corrosive environments, low carbon steel material, specimen preparation and the same 50-day exposure duration in the media, test of the basic mechanical properties and analyses. The results are therefore meaningful and posited for consideration in applications of the inhibitors to steelwork protections in the petroleum or other chemical and water industries. Despite the well known high corrosion inhibition performances in most environments of even high acidity by sodium benzoate of even small-quantity treatment concentration of the environments, any bitumen coatings whose inhibition performances are comparable with those of clear natural bitumen harvested around the region of Agbabu village in Ondo State, and a KRPC-manufactured bitumen with the blend of Nigerian and Iran's Basra crudes; in Nigeria, are recommended to be exploited as better and economical inhibitors of any suitable steelwork corrosion in any high NaCl-borne environment of aqueous nature.

Table 1: Test-determined Parameters and Inhibition Efficiency (?) of the specified Mechanical Property of Low Carbon Steel Specimens after a 50-day continuous Exposure to the Corrosive Medium 30% Nacl + 5% con. H2SO4 + dew point air Treated with Various Specified Concentrations (ppm) of Sodium Benzoate.

(a) Tensile strength

Applied Stress (N/mm^2)	50ppm		100ppm		150ppm		200ppm		250ppm	
83.5	0.000314	3.5	0.000320	5.09	0.00031962	7.0	0.000319	10.00	0.000318	15.00
140.5	0.000534	3.1	0.000533	6.25	0.000533	6.25	0.000531	12.5	0.000530	15.60
203.5	0.000747	4.2	0.000746	6.38	0.000706	8.51	0.000744	10.6	0.0007474	14.00
258.7	0.000961	4.2	0.000959	6.35	0.000957	7.94	0.000956	11.1	0.0009535	15.10
310.5	0.001174	4.6	0.001173	6.15	0.001172	7.69	0.001170	10.77	0.01167	15.40
348.3	0.001606	3.8	0.0001606	5.17	0.001602	7.62	0.001598	10.88	0.001595	14.30
354.6	0.002583	4.1	0.0025103	7.00	0.00250	7.96	0.00247	10.73	0.002424	14.99
358.4	0.004057	3.9	0.0040527	5.22	0.004046	7.81	0.004037	11.33	0.00403	14.10
401.8	0.00427	4.5	0.004265	6.82	0.00462	8.1	0.004256	10.91	0.004246	15.50
405.3	0.106667	3.7	0.106415	6.5	0.10656325	7.5	0.10601	11.0	0.105632	15.20
Average	3.98	Average	6.146	Average	7.0		10.982	Average	14.92	

(b) Hardness

Sodium benzoate treatment concentration (ppm)	Knoop microhardness (HK_i)	
50	121.44	10.8
100	121.69	13.2
150	122.1	17.1
200	122.64	22.3
250	123.18	27.4

(c) Impact Fracture

Impact Fracture Energy (Joules)	
87.33	2.4
87.44	3.6
87.60	5.2
87.85	7.9
87.97	9.1

(d) Fatigue Strength

Applied stress loads and corresponding average No. of stress cycles to failure of two similar specimens in each case at the specified stress load and concentration treatment (ppm)

Applied Cyclic stress load (N/mm²)	50ppm		100ppm		150ppm		200ppm		250ppm	
	S_i		S_i		S_i		S_i		S_i	
250	201312	1.4	201554	3	201705	4	202023	6.1	202356	8.3
275	165542	1.3	165741	2.9	165903	4.2	166164	6.3	166388	8.1
300	93078	1.4	93183	2.9	93267	4.1	93414	6.2	93561	8.3
325	53246	1.5	53291	3	53322	4.0	53392	6.3	53449	8.2
350	29439	1.3	29474	2.9	29503	4.2	29545	6.1	29593	8.3
Average	108523.4	1.38	108648.6	2.94	108740	4.1	108907.6	6.2	109069.4	8.24

APPENDIX A: Percentage Corrosion Inhibition Performances by Coating Thicknesses of Some Whole Bitumen Samples From Nigerian Resources on the Corrosion Deterioration of the Basic Mechanical Properties of a Low Carbon Steel (Guma et al, 2010; 2011 a-b; 2012)

Mechanical property of the steel	Bitumen Sample	Coating thickness (mm)					
		1.46	1.29	1.13	0.93	0.81	
Tensile	Ondo S-A (%)	91	86	72	67	63	
strength	Ondo S-A (%)	93	88	75	69	65	
Corrosion	KPB (%)	97	95	81	76	69	
Hardness	Ondo S-A (%)	93.47	89.29	83.71	75.16	69.53	
Corrosion	Ondo S-B (%)	94.91	92.63	89.84	79.13	72.65	
	KPB (%)	97.43	94.34	89.64	85.32	77.54	Impact
	Ondo S-A (%)	84.31	78.19	62.56	59.70	57.26	
strength	Ondo S-B (%)	86.94	80.32	65.28	61.86	58.93	
Corrosion	KPB (%)	90.47	84.58	70.14	64.63	62.17	
Fatigue	Ondo S-A (%)	82.45	74.53	62.92	56.88	53.36	
strength	Ondo S-B (%)	83.96	78.14	64.32	59.13	55.21	
Corrosion	KPB (%)	86.89	80.94	67.81	63.78	59.85	

Appendix B: Average property values of the as-procured untreated and uncorroded low carbon steel material and those corroded in the corrosive medium without any treatment of the medium or bitumen-coating the specimen (Guma et al 2010, 2011a-b, 2012).

Property

Tensile (Guma et al, 2011a)
Average strain values for the same similar two specimens at specified stress values

Fatigue (Guma et al, 2012)
Average No. of stress cycles to failure for two similar specimens in each case at the specified stress values

Stress (N/mm²)	Strain ()	Strain ()		S	S0	
83.4	0.000301	0.000321				
140.5	0.000503	0.000535	250	216230	201100	203.5
	0.000702	0.000749				
358.7	0.0009	0.000961	275	177830	165380	
310.5	0.001112	0.001174				
348.3	0.001505	0.001606	300	99980	92980	
354.6	0.002513	0.002585				
358.4	0.003810	0.004057	325	56240	53200	
401.8	0.00406	0.00427				
405.3		0.107	350	31620	29410	

Average Knoop microhardness of two similar specimen each **Hardness** (Guma et al, 2010) (HK) = 130.78, HK0 = 120.3
Average Impact fracture energy of two similar specimen each **Impact** (Guma et al, 2011b) (E) = 93.63 Joules, E0 = 87.1 Joules

REFERENCES

Alwan, H. H. (2010). Corrosion Inhibition of Carbon Steel by Sodium Benzoate in 3% by Weight NaCl Solution. *Journal of Babylon University Pure and Applied Sciences*, 18, 4.

ASM (1975). Metals Handbook Volume 10: Analysis and Prevention. Published by the ASM Handbook Committee, American Society for Metals, Metals Park Ohio, pp. 168-227.

Barton, K. (1976). *Protection Against Atmospheric Corrosion: Theories and Methods.* London: John Wiley and Sons Limited, England, pp. 1-182.

Callister, W. D. (2004). *Material Science and Engineering: An Introduction* (5th Edition). New York: John Wiley and Sons Inc. PP. 357-601.

Choudary, R. B. (2003). *Material Science and Metallurgy.* India: Khanna Publishers, Delhi.

Doyle, L. E. (1979). *Manufacturing Processes and Materials for Engineers.* New Jersey: Prentice Hall Inc, Englewood Cliffs, United State of America PP. 52-107.

Enetanya, A. N. (2004). Loss of Adhesion and Formation of Blisters in Organic Coatings on Mild Steel Submerged in Corrosive Media. *Nigerian Journal of Engineering Research and Development (NJERD)*, 3, 3.

Guma T. N., Madakson P. B., Yawas D. S. and **Aku S. Y.** (2010). Effects of Some Bitumen Coating Treatments on the Hardness Corrosion of Low Carbon Steel. *International Research Journal in Engineering Science and Technology*, 7, 1.

Guma T. N., Madakson P. B., Yawas D. S. and **Aku S. Y.** (2011a). Assessment of Capability Levels of Bitumen from Nigerian Sources to Coat-inhibit Tensile Strength Corrosion of Low Carbon Steel. *International Journal of Engineering Science*, 3, 1

Guma, T. N, Madakson, P. B., Yawas, D. S. and **Aku S. Y.** (2011b). Assessment of Capability Levels of Bitumen from Nigerian Sources to Coat-inhibit Impact Strength Corrosion of Low Carbon Steel. *International Journal of Mechanical Engineering*, 3, 1

Guma T. N., Madakson P. B., Yawas D. S. and **Aku S. Y.** (2012). Effects of Some Bitumen Coating Treatments on the Corrosion Fatigue Strength of Low Carbon Steel. Accepted for Publication *International Journal of Science and Advanced Technology*, Dhaka, Bangladesh.

Hassan, B. O. Abdul-Kadar, H. D. and **Abdul-Jabber, M. F.** (2011). Experimental Study of Carbon Steel Corrosion Using Sodium Benzoate Under Different Operating Conditions. *Iraqi Journal of Chemical and Petroleum Engineering*, 12, 3.

Illston J. M., Dinivoodie J. M. and **Smith A. A.** (1979). *Concrete, Timber and Metals; the Nature and Behaviour of Structural Materials.* London: Van Nostrand Reinhold Company Ltd, England.

(INTERNET). en.wikipedia.org/wiki/sodium_benzoate-cached-smilar (extracted, 20/06/2011).

INTERNET (2012). Nigerian bitumen. Website http://farriconsulting.blogspot.com/2011/02/bitumen-exploitation-and-exploration-in.htme (5/10/2012)

Kahraman, R. (2002). Effect of Sodium Benzoate Application on Atmospheric Corrosion of Mild Steel. The 6th Saudi Engineering Conference KFUPM Dhahran, December, .

Oshinowo T., Ademodi B. and **Adediran A. S.** (1982). Bitumenous Tarsands of Nigeria: Analysis of Oils Part I. *Journal of Nigerian Society of Chemical Engineers*, 1 (1), 44-48.

Shreir, L. (1979a). *Corrosion Volume 1: Principles of Corrosion and Oxidation.* London: Butterworth Publishers.

Shreir, L. (1979b). *Corrosion Volume 2: Principles of Corrosion Control.* London: Butterworth Publishers.

Yawas, D. S. (2005). Suitability Assessment of Some Plant Extracts and Fatty Acid Vegetable Oils as Corrosion Inhibitors. Ph.D Dissertation (Unpublished) Department of Mechanical Engineering Ahmadu Bello University, Zaria, Nigeria.