International Journal of Engineering Research and Development
e-ISSN: 2278-067X, **p**-ISSN: 2278-800X, www.ijerd.com
Volume 6, Issue 12 (May 2013), PP. 91-98

Characterization of Working Thicknesses of Some Bath-Dip-Produced Corrosion–Protective Bitumen Coatings on Polish-Prepared Low Carbon Steel Specimens

T.N. Guma[1], P.B. Madakson[2], D.S.Yawas[3], S.Y. Aku[4]
[1]Department of Mechanical Engineering Nigerian Defence Academy, Kaduna Kaduna State, Nigeria
[2,3,4]Department of Mechanical Engineering Ahmadu Bello University, Zaria Kaduna State, Nigeria

Abstract:- The coating thickness is an important variable that plays a role in product quality, process control and cost. Determination of the required working thicknesses for different service requirements is however a complicated task in the product finishing field. A previous study has shown that Nigeria is blessed with abundant bitumen resources for sustained exploitation as common, economical and effective coat-inhibitors of steelwork corrosion in her economy. This paper presents a test-determination of the expected range of working thicknesses of coatings with proper bitumens from the resources. Bitumen samples were harvested at three different critical bitumen resource sites in the country for the tests. 30 specimens of the steel were properly prepared. Coatings of different thicknesses were produced on the specimens by dipping a different pair of them in each bitumen sample heated to each of five different temperatures in the range of 170 – 230^{O}C and removing and cooling them to 38^{O}C-room-temperature. The thickness of each produced coating was properly determined with a micrometer through dimensional change before and after coating. Analysis of the overall obtained data shows that the average working thicknesses of coatings with any bitumens of comparable quality to the as-harvested from the resources using temperatures in the range will decrease with increase in temperature from about 1.46 to 0.81mm respectively, and thicknesses of coatings with the separate bitumens using the same bath temperature will have minimal variations.

Keywords:- Structural steelworks, mechanical properties, corrosion protection, bitumen coatings, bath-dipping process, working thicknesses.

I. INTRODUCTION

Corrosion of carbon steel as the basic structural material is the most important corrosion problem to contend with in all quarters worldwide. The most commonly, economical and widely used method to counteract it is by paint or organic coatings. It is estimated that about 90% of all steels are corrosion-protected by the coatings. The coatings do provide the barrier between the environment and the substrate, and the thicker a coating the more impermeable it is to moisture and the environmental corrodants. Generally, the service performance of any protective coating on a metal for a given environmental exposure depends greatly on the coating material, method, thickness, adhesion to the substrate, etc (Laque, 1975; Pludek, 1977; INTERNET, 2012; Guma et al, 2010, 2011a-b, 2013a). The thickness of any protective coating applied to a substrate steel for corrosion protection is one of the most important parameters in the metal finishing industry. There are several reasons for the importance but primarily they are (Von Fraunhoffer, 1975; INTERNET, 2012c):

i. Generally the cost of a coating increases with its thickness especially if the material used for it is a costly one or a large surface area is to coated, and one of the cardinal principles in engineering demands that materials and all other resources should be utilized economically to meet desired services.
ii. The thicknesses of many coatings determine their corrosion-protective action, and coatings of inadequate thicknesses for some service requirements may only be decorative without conferring any protection.
iii. Some industrial finishing specifications such as those of naval military and civil aviation must be followed for many coating processes and the specification limits for the coating thickness tolerances must be strictly adhered to for acceptance.
iv. Frequently components that have been engineered to be within close tolerances are then coated and application of such coatings must not result in loss of dimension or inaccuracy of fit.
v. Proper maintenance of coatings for some services requires understanding of their working thicknesses.

From the foregoing discussions it is demonstrable that some form of control of coating thickness and accuracy in estimating it is essential in the protective finishing of steelworks or parts. Coatings are however generally discontinuous with defects such as porosities, segregation, holidays, thinned areas etc; and the substrate itself may not be flat and straight with parallel edges but be characterized with curved surfaces. These make accurate estimation of working thicknesses of coatings for different service requirements difficult and any inaccuracy in such estimation or lack of proper information on the working thickness of a coating will complicate the coating's protection reliability for a given service requirement, optimal cost and maintenance. The difficulty can further be compounded by variations in the nature of the interface between the coating and the substrate steel. This is because industrial coatings are applied to steel surfaces that may be very smooth, hot-rolled or abrasive-brasted, and the natures of such as-produced surfaces can also influence the accuracy and repeatability of a coating thickness measurement (Von Fraunhoffer, 1975; INTERNET, 2012a,c).

Because of the needs for accurate determination of working thicknesses of coatings, a wide range of techniques with different levels of benefits have been developed to meet them and can be exploited for any particular case. Two broad categories of coating thickness measurement techniques are used, namely; destructive and non-destructive. Companies using destructive techniques face challenges that can result in inaccurate, expensive and time-consuming measurements. Typically testing the thickness of paint or organic coating is performed using non-destructive measurement principle. The non-destructive techniques include; determination of dimensional change before and after coating, use of depth gauges, magnetic gauges, back-scattered beta-radiation and ultrasound. Some procedures based on these techniques are even standardized by different reputable Authorities such as the American Society for Testing Materials (ASTM) and National Association for Corrosion Engineering (NACE) for different types of workpiece and coating conditions. The simplest and most direct measurement of coating thickness is however by determination of dimensional change. Average of thickness measurements at several points like 10 or more in number depending on the surface size of the coating with this technique will indicate the uniformity of the coating (Von Fraunhoffer 1975, INTERNET 2012a,c) The accuracy achievable with this method is however primarily limited by the resolution of the measuring device and the operator error. Micrometers and vernier devices are readily available which can measure dimensional differences of the order of 2.5 micron with accuracies of up to 0.1 micron (Von Fraunhoffer, 1975; Timings & Alabi, 1994; INTERNET, 2012b,d)

Bitumen is an important material in today's technological world. It exists naturally or is synthesizable in different qualities in a number of locations worldwide. It has been used in various forms such as bituminous wrappings, bituminous tapes, bituminous paints, admixtures in concrete encasements, 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 based on its excellent resistance to industrial pollution (Jackson and Ravindra, 1996; Guma et al, 2010, 2011a-b, 2013a). Bituminous coatings are heavy-bodied materials and in industries are applied as hot melts, solvent cutbacks, or water emulsion. In general the hot melt applications provide the best moisture and chemical resistance followed in order by solvent cutback and water emulsions. The hot melt method involves heating the bitumen to a temperature of 177 – 246^{O}C to reduce its viscosity for application by mop or swap by brush, roller or spray, or by flow coating of the interiors of pipes and small vessels. The solvent cutback method is however the more widely used method, mainly because of some cost benefits. It involves dissolving asphaltic or coal tar bitumen in a suitable aliphatic or aromatic hydrocarbon solvent to lower its viscosity for application by spray, brush or roller. The solvent then volatilizes and the bitumen solidifies into a film (Illston et al, 1979; Pain. Dec. Con, 1995).

Nigeria's economy is about 85% dependent on petroleum and a lot of wastages occur in it through the corrosion process. Previous surveys and results from properly conducted tests have shown that Nigeria is blessed with abundant natural and synthetic bitumen resources for sustained exploitation as common, economical and effective coat-inhibitors of steelwork corrosion in the key sectors of her economy. Very clear natural bitumen deposits are found underground and on the ground surface in waterlogged areas in the country in Ondo, Lagos, Ogun, Edo and Enugu States; and the country's Kaduna Refining and Petrochemical Company (KRPC) synthesizes large quantities of bitumen each working day with the blend of the country's and suitable crudes from some other countries (Oshinowo et al, 1982; Olalere, 1991;; Sheikh, 2003; Fed. Min. Sol. Mine. Dev, 2006; Field Survey, 2009; Guma et al, 2010, 2011a–b, 2013a; INTERNET, 2012c). Bitumen is a highly viscous and sticky material whose viscosity and thickness changes with weather conditions (Guma et al, 2012a). This makes it difficult to determine its coating thickness by even standard methods such as the ASTM D4414 procedures for wet film thickness using notch gauges (INTERNET 2012d). In industrial coat-protection usage, applied bitumen coatings are further oxidized to dry and solid state to prevent their temperature-dependent changes in properties (Illston et al, 1979). The prime objectives in this paper are therefore as follows:

i. To present the detailed test-determination of the different coating thicknesses of semi-wet bath-dip-produced corrosion-protective bitumen coatings; on ASTM low carbon steel fatigue specimens with bitumen samples from Nigerian resources through dimensional change using a micrometer.
ii. To disseminate information on the expected range of working thicknesses of the as-applied coatings with any bitumen of comparable quality to the as-harvested from Nigerian resources or elsewhere for the application interests of any researcher, practitioner, industry, student, educationist, etc.

II. METHODOLOGY MATERIAL SOURCING

Low carbon steel rods of diameters 8-10mm and of ascertained similar chemical compositions and microstructures were purchased from a supplier in the Iron and Steel Market in Lagos, Nigeria while two natural bitumen samples with identification names Ondo S-A and Ondo S-B, and a synthetic bitumen sample with the name KPB were collected in sufficient quantities from critical Nigerian bitumen sources for the tests. Ondo S-A was collected from a clear bitumen deposit on the ground surface in a waterlogged area in Ondo State on the outskirts of Agbabu village that adjoined Agbabu-Ore road, and Ondo S-B from a rich deposit underground within the village through a standard extraction hole drilled by early explorers of bitumen in Nigeria. KPB was from bitumen manufactured at KRPC with the blend of the Nigerian and Iran's Basra crudes as feedstock (Guma et al 2010, 2011a-b, 2013a).

III. TEST PROCEDURES

The rods were used to machine-produce 30 ASTM fatigue specimens. Differences in surface conditions can exist and result in variations in coating thickness on and among the same type of specimen and cause difficulty in accurate analysis of both corrosion and coating thickness test results, so each specimen was similarly machine-polished with various grades of polishing paper starting with the 250-grade and finishing with the 400, followed by etching it in nital to produce a profilometer-ascertained average surface finish of 25 microns on it.

A metric ruler and a clear white marker were used to lightly and clearly mark out 10 different points of about 5 - 8mm apart from one another along the length of each polished specimen. The relative positions of the points from one another were recorded and were consistent on each and among the specimens. One specimen was held in horizontal position by fixing about 4mm of its length at one end in a bench vise. Measurement of the specimen thickness was then taken at each marked out point on it perpendicular to the axis of the specimen using a hand-held outside micrometer with a measuring range of 0-13mm, main pitch of 0.005mm, and minimum resolution of 0.01mm. In each case the locking mechanism of the micrometer was undone and it was opened until it was wider than the section thickness to be measured. The anvil of the micrometer was then placed against a point on the specimen section point where measurement was desired to be taken and the micrometer thimble gently tightened until it just touched a section point opposite the one where the anvil was placed and along the same diameter. The ratchet of the micrometer was thereafter used to tighten up the opening between the anvil and thimble until the thimble clicked. The thimble was then locked to keep the micrometer's reading constant. The micrometer was withdrawn and its reading taken and recorded. For each of the same reference section positions, the above procedure was repeated with each of the remaining 29 specimens. The average reading for each of the 10 section thicknesses and 30 specimens was determined and noted as D_i as the overall measurement for that section.

The specimens were coated by the bath-dipping process within the temperature range of 150-250^{O}C stipulated by Illston et al (1979) and Pain. Dec. Con. (1995) for heating and applying most bitumens. A gas fired heating unit was used to heat Ondo S-A in a steel container to a thermometer-monitored temperature of 170^{0}C. Two fatigue specimens were each held on one of its head with a suitable thin-lip crucible tong and dipped at the same time into the heated bitumen bath for 30 seconds and removed and allowed to cool to average room temperature of 38^{0}C for two hours during a five-day test period in Kaduna, Nigeria. This produced a coating of Ondo S-A on each specimen. The coatings were still sticky so each specimen was held standing upward lengthwise by jointing one of its ends onto a prepared flat solid wooden base using araldite adhesive. This was done after using carbon disulphide and a bristle brush to gently clean the bitumen at one of every specimen's end that was dipped in the bitumen bath, to just expose its steel part for the adhesive jointing. A small metric height gauge was placed in proper parallel alignment to the held-standing specimen and position of points on it corresponding to those on the same cross-section with those marked on the uncoated specimens were indicated by gently sticking a needle to each. The section thickness of each specimen coated with each bitumen sample at each indicated section overcoat was determined with the same micrometer in the same procedure likewise the uncoated specimens but with the anvil just touching the coating at each section. This was to minimize any sticking of bitumen on the faces of the anvil and thimble and for accuracy of the measurements by avoiding pressing down the coatings. Any trace of bitumen observed on the anvil or thimble was cleaned with carbon disulphide, water and towel before the next measurement. The average of the measurements y_1, & y_2 for each pair of specimens and given corresponding sections on them as was coated with each bitumen sample and temperature was determined as $D_{O,}$ so that the measured coating thickness (y_i) at each section with each bitumen sample and coating temperature used was appropriately evaluated as,

$y_i = D_O - D_i$ ------------------------------ 1

The average coating thickness (t_b) on the specimen for the10-section thicknesses with each case of the bitumen sample and coating temperature used was evaluated as,

$$t_b = \left(\sum_{i=1}^{i=10} y_i \right) / 10 \text{ -------------------------2}$$

The range of variation of the 10 measured section thickness values (y_i) of a given coating on each specimen is given as,

$R_i = y_{i\ max} - y_{i\ min}$ ---------------------------3

Where $y_{i\ max}$ is the highest and yi_{min} the smallest measured values respectively.

The sample standard deviation of the measured coating thicknesses (y_i) for each case of bitumen sample and temperature used was evaluated in accordance to the principles of Holman (1984) and Guma et al (2012b, 2013b) as,

$$\sigma_i = \left[\sum_{i=1}^{i=10} (y_i - t_b)^2/9 \right]^{½} \text{ ----------------------- 4}$$

The co-efficient of variation (V_i) of measured coating thicknesses (y_i) for each case of bitumen sample coating and temperature used was evaluated in accordance to the principles of Holman (1984) and Guma et al (2012b, 2013b) as,

$V_i = \sigma_i / t_b$ ---------------------------------- 5

T

he overall working coating thicknesses (t) for the three bitumen samples (b) for each case of coating temperature used was determined as,

$$t = \left(\sum_{b=1}^{b=3} t_b \right) / 3 \text{ ------------------------ 6}$$

IV. RESULTS AND DISCUSSION

The results of the as-measured coating thicknesses (y_i) at each of 10 different sections on each fatigue test specimen as determined from the average pair values of y_1 and y_2 for each case of the bitumen samples-Ondo S-A, Ondo S-B and KPB; and bath temperature used are presented in Tables 1 – 5 below.

Table 1: With 170°C

Statistical parameter	Ondo S – A			Ondo S – B			KPB		
	Measured Coating Thickness (mm)			Measured Coating Thickness (mm)			Measured Coating Thickness mm)		
	Specimen			Specimen			Specimen		
	1 (No) y_1	1(No) y_2	Pair Average y_i	1(No) y_1	1(No) y_2	Pair Average y_i	1(No) y_1	1(No) y_2	Pair Average y_i
	1.43	1.45	1.44	1.50	1.44	1.47	1.39	1.47	1.43
	1.42	1.34	1.38	1.46	1.32	1.39	1.53	1.45	1.49
	1.33	1.39	1.36	1.48	1.56	1.52	1.41	1.47	1.44
	1.38	1.26	1.32	1.29	1.41	1.35	1.39	1.45	1.42
	1.35	1.23	1.29	1.43	1.33	1.38	1.58	1.54	1.56
	1.39	1.47	1.43	1.37	1.45	1.41	1.55	1.57	1.56
	1.37	1.43	1.40	1.42	1.47	1.45	1.48	1.54	1.51
	1.46	1.50	1.48	1.36	1.48	1.42	.157	1.53	1.55
	1.52	1.46	1.49	1.57	1.49	1.53	1.38	1.52	1.45
	1.48	1.54	1.51	1.41	1.35	1.38	1.62	1.56	1.59
R_i			0.22			0.18			0.17
t_b			1.41			1.47			1.50
t				1.46					
σ_i			0.0655			0.06928			0.06272
V_i			0.04645			0.04713			0.04181

Table 2: With 180°C

	Ondo S – A			Ondo S – B			KPB		
	Measured Coating Thickness (mm)			Measured Coating Thickness (mm)			Measured Coating Thickness (mm)		
	Specimen			Specimen			Specimen		
Statistical parameter	1(No) y_1	1(No) y_2	Pair Average x_i	1 (No) y_1	1(No) y_2	Pair Average x_i	1(No) y_1	1(No) y_2	Pair Average x_i
	1.07	1.25	1.16	1.30	1.38	1.34	1.26	1.32	1.29
	1.12	1.16	1.14	1.26	1.32	1.29	1.09	1.23	1.16
	1.21	1.17	1.19	1.17	1.21	1.19	1.36	1.40	1.38
	1.23	1.15	1.19	1.22	1.12	1.17	1.38	1.42	1.40
	1.26	1.30	1.28	1.26	1.18	1.22	1.41	1.37	1.39
	1.25	1.19	1.22	1.22	1.32	1.27	1.75	1.35	1.30
	1.26	1.16	1.21	1.29	1.27	1.28	1.39	1.39	1.39
	1.29	1.39	1.34	1.35	1.29	1.32	1.33	1.27	1.30
	1.35	1.39	1.37	1.28	1.38	1.33	1.40	1.36	1.38
	1.28	1.34	1.31	1.38	1.40	1.39	1.46	1.35	1.41
R_i			0.203			0.22			0.25
t_b			1.25			1.28			1.34
t				1.29					
σ_i			0.07951			0.069762			0.06272
V_i			0.06361			0.0545			0.0468

Table 3: With 200^{O}C

	Ondo S – A			Ondo S – B			KPB		
	Measured Coating Thickness (mm)			Measured Coating Thickness (mm)			Measured Coating Thickness (mm)		
	Specimen			Specimen			Specimen		
Statistical parameter	1(No) y_1	1(No) y_2	Pair Average x_i	1 (No) y_1	1(No) y_2	Pair Average x_i	1(No) y_1	1(No) y_2	Pair Average x_i
	1.00	1.01	1.02	1.17	1.21	1.19	1.09	1.13	1.11
	1.31	1.13	1.22	1.11	1.01	1.06	0.94	1.02	0.98
	0.85	1.11	0.98	1.21	1.15	1.18	1.03	1.01	1.02
	1.17	0.81	0.99	1.13	1.19	1.16	1.04	1.16	1.10
	0.98	1.20	1.09	1.12	1.16	1.14	0.91	1.01	0.96
	1.13	1.15	1.14	1.17	1.19	1.18	1.11	1.17	1.14
	0.89	0.97	0.93	1.20	1.26	1.23	1.18	1.08	1.13
	1.16	1.14	1.15	1.25	1.29	1.27	1.13	1.15	1.14
	1.17	1.13	1.15	1.28	1.38	1.33	1.18	1.12	1.15
	1.19	1.15	1.17	1.37	1.35	1.36	0.96	0.98	0.97
R_i			0.29			0.30			0.19
t_b			1.11			1.21			1.07
t				1.13					
σ_i			0.1011			0.09006			0.078
V_i			0.09108			0.07443			0.0729

Table 4: With 220^{O}C

	Ondo S – A			Ondo S – B			KPB		
	Measured Coating Thickness (mm)			Measured Coating Thickness (mm)			Measured Coating Thickness (mm)		
	Specimen			Specimen			Specimen		
Statistical parameter	1(No) y_1	1(No) y_2	Pair Average x_i	1 (No) y_1	1(No) y_2	Pair Average x_i	1(No) y_1	1(No) y_2	Pair Average x_i
	0.91	0.97	0.94	1.04	0.98	1.01	0.86	0.82	0.84
	0.96	0.99	0.97	0.81	0.75	0.78	0.79	0.85	0.82
	0.92	0.98	0.95	0.84	0.90	0.85	0.85	0.87	0.86
	1.03	0.95	0.99	0.78	0.83	0.81	0.90	0.84	0.87
	0.89	0.97	0.93	0.89	0.77	0.83	0.86	0.94	0.90
	1.05	1.03	1.04	0.88	0.94	0.91	1.00	1.06	1.03
	0.96	0.94	0.95	0.80	0.92	0.86	0.91	0.97	0.94
	0.98	1.05	1.03	0.98	0.88	0.93	0.89	0.95	0.92
	0.97	1.03	1.00	0.92	0.96	0.94	0.97	0.93	0.95
	1.07	1.13	1.10	0.93	0.99	0.96	1.02	0.92	0.97
R_i			0.17			0.20			0.21
t_b			0.99			0.89			0.91
t				0.93					
σ_i			0.05375			0.07242			0.06481
V_i			0.054293			0.08137			0.07122

Table 5: With 230^{O}C

Statistical parameter	Ondo S – A			Ondo S – B			KPB		
	Measured Coating Thickness (mm)			Measured Coating Thickness (mm)			Measured Coating Thickness (mm)		
	Specimen			Specimen			Specimen		
	1(No) y_1	1(No) y_2	Pair Average x_i	1 (No) y_1	1(No) y_2	Pair Average x_i	1(No) y_1	1(No) y_2	Pair Average x_i
	0.71	0.67	0.69	0.75	0.79	0.77	0.79	0.81	0.80
	0.65	0.79	0.68	0.79	0.73	0.76	0.89	0.89	0.89
	0.81	0.85	0.83	0.79	0.81	0.80	0.80	0.76	0.78
	0.74	0.71	0.73	0.85	0.87	0.86	0.79	0.75	0.77
	0.76	0.74	0.75	0.77	0.79	0.78	0.84	0.84	0.84
	0.75	0.79	0.77	0.80	0.84	0.82	0.85	0.81	0.83
	0.78	0.77	0.76	0.81	0.83	0.82	0.84	0.88	0.86
	0.92	0.96	0.94	0.87	0.83	0.85	0.87	0.88	0.85
	0.75	0.73	0.74	0.81	0.88	0.84	0.77	0.75	0.76
	0.89	0.93	0.91	0.92	0.88	0.90	0.88	0.94	0.92
R_i			0.26			0.14			0.16
t_b			0.78			0.82			0.83
t	0.81								
σ_i			0.0834			0.04397			0.0527
V_i			0.106923			0.053622			0.06349

The computed values of the statistical parameters of the coatings; the range (R_i) , average coating thickness (t_b), standard deviation (σ_i), and coefficient or variation (V_i,) for each case of temperature and bitumen sample used are also as appropriately shown in each table. As can be observed from the tables, the results show that for each specimen, the coating thickness on it is not uniform at all. This agrees well with Laque (1975), Pludek (1977), and Von Frounhoffer (1975), that coatings are generally discontinuous with various defects. Variation in the measured coating thickness on each specimen has resulted in variation in the average coating thickness (t) on each specimen even among specimens coated with the same bath temperature. The cause of variation of the average coating thickness among the bitumen samples as coated with the same temperature is attributable to the fact that the quality of the bitumens vary from one source to another with various levels of physiocochemical properties and service attributes (Jackson and Ravindra, 1996, Guma et al 2012a). From the average values of coating thickness (t_b), range (R_i), standard deviation (σ_i) and co-efficients of the variation (V_i) of the measured coating thicknesses for each coating produced with the bath temperature of 170^{0}C as shown in the table I, it can be observed that for the temperature and bitumen samples used, variation in each of the statistical parameters is minimal so that the overall working thickness (t) has been evaluated reasonably as the average of all the average coating thickness values for the temperature to be 1.46mm. This trend of variation in the statistical parameters is more or less similar for the case of coating produced with each of 180, 200, 220 and 230^{O}C as can be observed from tables 2-5 respectively, so that similar evaluation of the overall average coating thickness (t) was carried out in each case and the obtained values for each case are shown appropriately in each of the tables. The as-evaluated working thicknesses for the as-produced coatings are however different among the bath temperatures used in a decreasing order with increasing temperature. According to Jackson and Ravindra (1996), and Guma et al (2010, 2011a-b, 2013a), the viscosity of bitumen is temperature-dependent and decrease with increase in its temperature. The decrease in the working thickness with increase in the bath temperature used is therefore attributable to the fact that as viscosity of bitumen is lowered less bitumen is adherent to the specimens. The thicknesses of most protective coatings applied on steel range from zero to 1000µm but for adequate barrier against moisture a minimum paint film thickness of about 0.125mm of oil based paint has been found necessary for steel but in wet conditions this is not sufficient (Shreir, 1979; INTERNET, 2012c). The reasons attributable to the higher values of the working thicknesses of the as-produced bitumen coatings compared to applied paint coatings can be due to the fact that bitumen is a much more viscous and heavy-bodied material than materials used for paint preparations and hence it is not feasible to be applied to such thin thickness with the bath temperatures used. The as-produced coatings with the thicknesses of 0.81-1.46mm had been found by Guma et al (2010, 2011a-b, 2013a) to be capable of coat-inhibiting corrosion deterioration of fatigue strength and other basic mechanical properties of steelworks from at least 57.26 to 84.31% respectively in any natural environment.

V. SUMMARY AND CONCLUSIONS

The coating thickness is an important variable that plays a role in product quality, process control and cost. Most importantly its optimal determination for different corrosion coat-protection levels required for different service exposures of steelworks or parts is a critical and difficult task. Bitumen is generally a highly viscous and sticky material whose overall quality depends on its source, and it is not feasible and economical for conventional coat-application by brushing, spraying, and rolling methods in its natural state at room temperature. This paper has presented the results of non-destructively test-determined thicknesses of properly produced more or less semi-wet coatings on 30 ASTM fatigue specimens of a low carbon steel with each of three bitumen samples harvested from different critical resource sites in Nigeria. The coatings were applied on the specimens using the bath-dipping process, a popularly used method and to the large extent for hot dip galvanizing of steel (Johnson, 2001). Each of the bitumen samples was heated to five temperature stages in the range of 170 to 230^{O}C akin to the hot melt method of bitumen-coating to lower its viscosity to respectively different levels and then dipping a different pair of the specimens in the bitumen bath at each stage and removing and cooling them to 38^{0}C-room-temperature for two hours. Thicknesses of the produced coatings varied on the specimens and depended on the bitumen sample, and the bath temperatures used. The thicknesses were measured with a micrometer through the method of dimensional change. Analysis of the overall obtained data shows that coatings produced separately with each of the as-harvested bitumen samples but the same temperature have minimal variations in thickness among them. The results indicate further that the working thicknesses of coatings at the room temperature produceable by the bath-dipping process with any properly harvested bitumen from the country's resources will decrease with increase in the bath temperature from about 1.46 to 0.81mm respectively within the range of the bath temperature used. The least-in-thickness of the coatings has previously being found by Guma et al (2010, 2011a,b, 2013b) to be capable of coat-inhibiting corrosion deterioration of fatigue strength or any other mechanical property of the steel to the tune of at least 57.26% in any natural environment.

Recommendation

The information presented in this paper is basic and recommended for any research or application interest of any individual or group towards properly coat–utilizing the abundant bitumen resources in Nigeria to economically reducing the cost and effects of corrosion in the country's petroleum industries or wherever it is feasible.

REFERENCES

[1]. Johnson, K. (2001). Corrosion Resistance In: Owen, G.W. and Knowles, P.R. (Ed), Steel Designers' Manual, 5th Edition. Blackwell Science Limited Oxford, England, Pp. 998 – 1025.

[2]. Timings, R.L. & Alabi, O. (1994) Mechanical Engineering Craft Theory and Related Subjects, Longman Group UK Limited Harlow, England, Pp. 132 – 135.

[3]. INTERNET: 33 Coating Thickness measurement: http://www.ingal.com.au/IGSM/33.htm. (20/12/2012a)

[4]. INTENET: Quality Digest http:/www.qualitydigest.com/oct04/articles/02 articles.shtme (14/11/2012c)

[5]. INTERNET: Micmeters http:/www.defelsko.com/technology/coatingthinckness/coating- thickness-measurement.htm (17/12/2012b)

[6]. INTERNET: Procedures for measuring wet film thickness (ASTM D4414); www.astm.org/standards/d4414/htm (15/12/2012d

[7]. Jackson, N. and Ravindra, K.D (1996), Civil Engineering Materials. Macmillan Press Limited, London, England, Pp. 53 – 64

[8]. Oshinowo, T; Ademodi, B; Adediran, A.S. (1982); Bituminous Tarsands of Nigeria; Analysis of Oil Part I. Journal of Nigerian Society of Chemical Engineers, Vol. 1 No. 1 PP 44-48

[9]. Olalere, A. (1991). Asphat/Bitumen Production From Nigerian Crude. A HND Research Project, Unpublished, Department of Chemical Engineering, Kaduna Polytechnic, Nigeria.

[10]. Sheikh, G.M. (2003). Bitumen Exploration and Development in Nigeria, A Paper Presented to the Nigerian Society of Engineers LAGBELU by Goni M. Sheik, Secretary Nigerian Bitumen Project QTR 52. Alagbaka G.R.A Akure Ondo State, Nigeria.

[11]. Fed. Min. Sol. Mineral Dev. (2006). Technical Overview in Nigeria's Bitumen Belt and Development Potential Report, Federal Ministry of Solid Minerals Development, Abuja, Nigeria, March.

[12]. Shrier, L. (1979): Corrosion Volume 2, Principles of Corrosion Control. Butterworth Publishers, London, Pp. 10.1-20.3

[13]. Laque, F.L. (1975) Marine Corrosion. A Wiley-Interseeince

[14]. Publication, New York, Pp. 12-317

[15]. Pludek, V.R. (1977). Design and Corrosion Control. The Macmillan Press Limited, London. Pp 36 – 390

[16]. Guma T.N; Madakson P.B; Yawas, D.S; and Aku, S.Y. (2010). Effect of Some Bitumen Coating Treatments on the Hradness Corrosion of Low Carbon Steel. International Research Journal in Engineering Science and Technology Vol. 7 No. 1, Edna –Ben Publishers, Owerri, Nigeria

[17]. Guma, T.N; Madakson, P.B; Yawas, D.S; and Aku S.Y. (2011a). Assessment of Capability Levels of Bitumen from Some Nigerian Sources to Coat-inhibit Tensile Strength Corrosion of Low Carbon Steel, International Journal of Engineering Science, Vol. 3 No.1, Pan-African Book Company, Accra, Ghana.

[18]. Guma, T.N; Madakson, P.B; Yawas, D.S; and Aku S.Y. (2011b). Assessment of Capability Levels of Bitumen from Some Nigerian Sources to Coat-inhibit impact Strength Corrosion of Low Carbon Steel, International Journal of Mechanical Engineering, Vol.3, No.1. Blackwell Publication Lagos, Nigeria.

[19]. Guma T.N; Madakson P.B; Yawas, D.S; and Aku, S.Y, (2012b). Experimental Assessment of Bitumens Coated Inhibition of a Steel Corrosion Using Shewart Charts, a Paper Under Assessment Under Assessment For Publication In Journal

[20]. Guma T.N; Madakson P.B; Yawas, D.S; and Aku, S.Y, (2012a). Assessment Physiocochemical Properties of some Bitumens for Nigerian Resources, Nigerian Journal of Basic and Applied Science, Usmanu Danfodiyo University, Sokoto, Nigeria Vol. 20(2).

[21]. Guma T.N; Madakson P.B; Yawas, D.S; and Aku, S.Y, (2013a). Effects of Some Bitumen Coating Treatments on the Corrosion Fatigue Strength of Low Carbon Steel, Accepted for Publication International Journal of Science and Technology, Research Desk India.

[22]. Guma T.N; Madakson P.B; Yawas, D.S; and Aku, S.Y, (2013b). Dispersion Analysis of Corrosion Coat-Inhibition Performances by some Bitumens from Nigerian Resources on Mechanical Properties of a Low Carbon Steel. Accepted for Publication a well Applied Propramming, Technical Institute of Dadaab, Kennya.

[23]. (INTERNET). Nigerian Bitumen http://farriconsulting.blogspot.com/2011/02/bitumen.exploitation.and.exploration-in.htme (extracted, 17/10/2012c).

[24]. Pain.Dec.Con. (1995). Painting and Decoration Craftman's Manual and Textbook, 8th Edition .Published by Painting and Decorating Contractors of America, Fairfax Va, United States of America, Pp 7-45.

[25]. Illston, J.M; Dinivoodie, J.M; and Smith, A.A (1979). Concrete, Timber and Metals: The Nature and Behaviour of Structural Materials, Van Nostrand Reinhold Company Limited, London, England, Pp 569-615.

[26]. Holman, J.P. (1984). Experimental Methods for Engineers, 4th Edition, J.P. Holman and W.J. Gajda-Singapore McGrawHill Co. Pp. 15-40.

[27]. Von Fraunhoffer J.A. (1975). Instrumentation in Metal Finishing, Paul Elek Scientific Book Limited, London England, Pp. 89-143.