

Development of Bituminous Paint from Agbabu Natural Bitumen for Coat-Protecting the Underparts of Automobile Chassis against Corrosion and Wear

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Abstract: To date, there has been continued demand for more effective, less expensive, and accessible coating systems for durable corrosion and wear protection of auto-bodies, with a research need to meet the demands. The rationale behind this study was to create a high-quality, low-cost bituminous paint for use in protecting the underparts of automobile chassis against corrosion and wear, particularly in Nigeria. Five paint blends containing various proportions of 70–100% Agbabu natural bitumen, 02–5% kerosene, 0–8.5% cobalt, 0–1% pigment, and 0–2.1% lead drier were produced and characterized by their basic physicochemical properties. The blends were brush-coated to a 1.78-mm average thickness on plate samples of mild steel, a commonly and widely applied but highly corrosion-susceptible chassis material type. Corrosion and wear tests performed on the steel samples under 1.78-mm-thick hard-dried coatings of the paint blends revealed that the blend with 75% bitumen, 15% kerosene, 8% cobalt, 0.6% pigment, and 1.4% lead drier content could perform exceptionally well in protecting the steel at the coating thickness. X-ray fluorescence and scanning electron microscopy analyses of that paint blend were conducted to understand its distinct chemical compositions and microstructural homogeneity level. The 1.78-mm-thick coating of that paint blend's adhesion adequacy to the steel was also investigated. Analyses of the collected data revealed that the blend contained 25 different chemical species that are benign to steel corrosion, had a more or less uniform microstructure demonstrating its homogeneity, had minimal intergranular boundaries indicating minimal ingress of corrosion-causing agents to the steel underneath its coatings, and its hard-dried thin coatings would have excellent adhesion to any ferrous chassis material.

Keywords: Bitumen, Kerosene diluting, Paint, Physicochemical properties, Chassis materials, Deterioration protection, Optimal values.

I. Introduction

The chassis is a crucial component because it is the structural foundation of all the other vehicular components, such as the engine, axle assemblies, tires, brakes, steering, and suspension [1, 2]. It also provides strength and stability to the entire vehicle under its various operational conditions and ensures low levels of noise, vibration, and harshness in the whole vehicle.

The underpart of the chassis is located directly facing the ground and serves as an anchor for the side frames, silencer, gusset plates, axles, and power-transmitting shaft [1, 2]. The chassis and its parts are usually made of ferrous materials that can include cast iron, high-carbon steel, medium-carbon steel, mild steel, austenitic steel, ferritic steel, stainless steel, galvanized steel, and aluminized steel [1, 2].

Corrosion and wear of vehicle body parts are two of the most serious issues confronting the automotive industry [3, 4]. Various types of

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corrosion, such as stress corrosion cracking, rusting, corrosion fatigue, and pitting, and their different combination levels, can deteriorate automobile chassis in synergism with wear and cause the vehicle to perform abnormally in service with excessive vibrations and noise, wobbling, motion instability, failure, poor aesthetic impression, etc. The problem can be worsened by poor maintenance of the vehicle, improper distribution of carried weight, and bad road conditions [3, 4, 5]. The critical causes of vehicular corrosion are road debris, sand, gravel, and, most importantly, deicing materials that sandblast its body, especially the underbody or chassis [5]. These actions leave chips in the protective coatings of the vehicles and predispose the undercoat substrate and other exposed parts to corrosive atmospheric moisture and severe temperatures [5]. The combined corrosive actions of atmospheric moisture and chemical compounds such as chlorides, sulfur oxides, nitrogen oxides, carbon oxides, and acidic substances further contribute to the breakdown or deterioration of the exposed areas of auto-body parts. Exposed areas of the front understructure, suspension and axle assembly, rear frames, gussets, rear underride guards, front aprons, threshold plates, upper couplers, and main frame assembly are typically affected by environmental chemicals and sandblasting [5]. As an automobile is driven over various distances from time to time for many years in different climatic regions and road conditions, carrying people and/or loads, its structural components, especially the underpart of its chassis, can experience significant corrosion and wear [6, 7, 8].

Most autobody parts are protected and regularly maintained against wear and corrosion, but the chassis is much more difficult and expensive to protect and maintain against corrosion and wear due to accessibility difficulties to it, cost of painting it, and the general infeasibility or impracticability of other protective methods such as cathodic or anodic protection, use of inhibitors, and use of metallic and inorganic coatings for automobile

body parts [5, 9]. Protecting an automobile against corrosion and wear is crucial for its overall longevity and aesthetic and financial value. The use of coating systems is a simple and effective method of preventing or minimizing corrosion and wear of autobody parts [9]. Many different anti-corrosion and anti-wear coating systems can be formulated and synthesized by blending different proportions of various suitable materials [10, 11]. However, synthesizing such a paint necessitates detailed research to determine the optimal-performing blend through assessments of the physicochemical qualities of its different possible blends, as well as corrosion and wear tests. Autobody parts are mostly protected and routinely maintained against corrosion and wear using coating systems, but to date, no permanently effective and cheapest coating system has yet been developed for protecting autobody parts against corrosion and wear from the possible blends of all the existing suitable material proportions [4, 11]. The usage extents of the existing protective coating systems are essentially determined by their comparative degrees of effectiveness and cost, with continued demand for more effective, cheaper, and dependably available coating systems [11]. The commonly used method of protecting an automobile chassis involves cleaning it with a bristle steel brush and detergents and/or rust killers on a regular basis and spray-coating it with a chemical substance or paint that rust-inhibits the chassis. However, the cleaned and spray-coated chassis can be scrubbed, delaminated, deteriorated, and lose its protective coat and aesthetics as the vehicle is driven on rough, muddy, and dirty roads over time [9, 12].

Bituminous paints are high-quality special paints used in construction work for water or damp-proofing and corrosion-protection of various structural parts. They are usually produced by dissolving bitumen or coal tar in mineral spirit or naphtha and applying it in a liquid or semi-liquid state to the requisite structures. This paint type can also be created by diluting bitumen with petroleum hydrocarbon or kerosene to reduce its viscosity and



allow it to penetrate surfaces more easily. The paint type is commonly used to coat iron, steel or metal structures, castings, asbestos, cement sheeting, and structural concrete [12]. It is a versatile coating system that can be used below and above ground. The following are the general characteristics of bituminous paint that make it appealing for wear and corrosion coat-protection of automobile chassis [12, 13, 14]:

1. They can be treated with polyurethane or acrylic polymer ingredients to improve their durability and flexibility.
2. They excellently protect materials from weathering and corrosion because they are insoluble in water and impermeable to air and chemical ingress. They operate as tight sealants to prevent all these corrosion agents from coming into direct contact with materials under their coating protection.
3. They have good adhesive characteristics and operate as good air and moisture barriers with practically any material, boosting their versatility.
4. They are resistant to alkalis and many other chemical pollutants.
5. They are sturdy, waterproof, long-lasting, and can withstand harsh production chemicals and UV rays.
6. They durably protect surfaces from rusting and pollution, even in harsh environments.
7. They can be applied on smooth and dry surfaces that need not be cleaned elaborately.
8. They are ready-to-use, thinning-free materials that may be applied with a brush or sprayed.
9. They are currently suitable for corrosion and wear protection of many engineering systems or structures, such as pipelines, underground tanks, and other unexposed systems or parts, where their usually black color is aesthetically immaterial.

Bituminous paints can be produced in different qualities because the bitumen used for producing them can be sourced from different natural locations or companies with wide differences in quality. Different quantities of mineral spirits, naphtha, petroleum hydrocarbon or kerosene, and additives are therefore needed to dissolve or dilute the same quantity of bitumen from the various respective sources to produce paints of different respective optimal properties and performances. The optimal paint properties and performance need to be established in each case of bitumen from a particular source [14, 15, 16]. Cobalt, pigments, and lead driers are among the several additives that have reportedly been used in different small quantities to enhance the properties of oil-based paints, especially for improving corrosion inhibition, drying time, color, etc. These additives can also be tried for bituminous paints as oil-based paints [14, 15, 17].

Nigeria is fortunate to have large reserves of natural bitumen. Her bitumen reserves are second only to the Canadian bitumen deposit in the world. However, the chemical composition and quality of Nigerian bitumen vary from one region to another. Bitumen was discovered in Nigeria for the first time in 1910 in Agbabu, a village in Ondo State with coordinates E004°48-491 and N06°34-361. The bitumen deposit in the territory of the village is among the top five major bitumen deposits in the world, but the deposit has essentially remained undeveloped, ungraded, and unexploited [18]. The aim that underlay this research work was to develop a high-quality and low-cost brush-applicable bituminous paint with Agbabu-sourced natural bitumen in Nigeria by diluting it with optimal proportions of kerosene, cobalt, pigments, and lead drier in blended form for protecting the underparts of automobile chassis against corrosion and wear, especially in Nigeria.

II. Materials and Methods

A. Materials

The following materials were used for the

research work:

1. 20kg of clear natural bitumen sample sourced within the region of Agbabu village in Ondo State.
2. A mild steel plate of about 500 mm by 500 mm by 2.5 mm thickness sourced at AREMCO, a metal construction company in Kaduna city for the corrosion, wear, and adhesion tests.
3. 20 liters of kerosene, 6 kg of black pigments, one kg of clinical grade cobalt, and one kg of lead drier.

B. Formulation and Production of the Paint Blends.

The Agbabu-sourced natural bitumen sample was heated in a steel container with a kerosene stove to a thermometer-monitored temperature of 60 to 80°C to reduce its viscosity for transport. Thereto about 150 g of the heated bitumen was fetched

with a small steel ladle and poured separately into five similar steel mixing cans. The bitumen in each can was then heated to 130°C to further reduce its viscosity for mixing. Different required quantities of kerosene, black pigment, cobalt, and lead drier were determined by weight measurements and added to the heated bitumen in each can and thoroughly mixed with a stainless-steel rod to homogeneous blends in the cans. The quantities of kerosene, black pigment, cobalt, and lead dryer were determined to achieve their desired percentage compositions in the blended mix according to the formulations shown in Table 1. The produced bituminous paint blends were stored under ambient laboratory environmental conditions for later use in tin cans with letters A, B, C, and D affixed on the tin cans to identify the contents therein according to Table 1. Plate I was a view of the natural bitumen sample in a container and the various measured quantities of additives to be blended with it in the other containers. Plate II shows the produced paint blends being stored in tin cans prior to use.

Table 1: The paint blends A to E and their components' percentage proportions

Component	Paint blend and components' compositions (%)				
	A	B	C	D	E
Bitumen	70	75	80	90	100
Kerosene	25	15	10	5	0.0
Cobalt	3.8	8.0	8.5	1.9	0.0
Pigment	0.2	0.6	0.8	1	0.0
Lead drier	1.0	1.4	1.7	2.1	0.0



Plate I: The prepared bituminous paint blends in various containers



Plate II: The as-stored bituminous paint blends in tin cans

C. Ascertainment of the Procured Steel Plate Sheet

The procured mild steel sheet for the study was subjected to a test analysis of its nominal composition to accept it or reject it as a mild steel material using the made-in-Japan Shimadzu-model PDA-700 optical spectrometer metal analyzer in accordance with its manual.

D. Production and Preparation of the Steel Samples

The confirmed mild steel sheet was used to produce 51 plate samples, each of about 40 x 40 x 2.5 mm, by mechanically sawing them out with a steel cutter tool. The number of plate samples produced for the various types of tests was as shown in Table 2, while Plate III shows some of the steel plate samples sawn out of the parent steel sheet. The sawn out samples were similarly cleaned to smooth and shiny surface finishes prior to using them in accordance with the ASTM 98 standard method for cleaning metallic materials prior to coating and corrosion tests.

Table 2: No of mild steel plate samples produced for various tests

Test type	Adhesion test	Corrosion test	Wear test
No. of plate samples	40	6	5

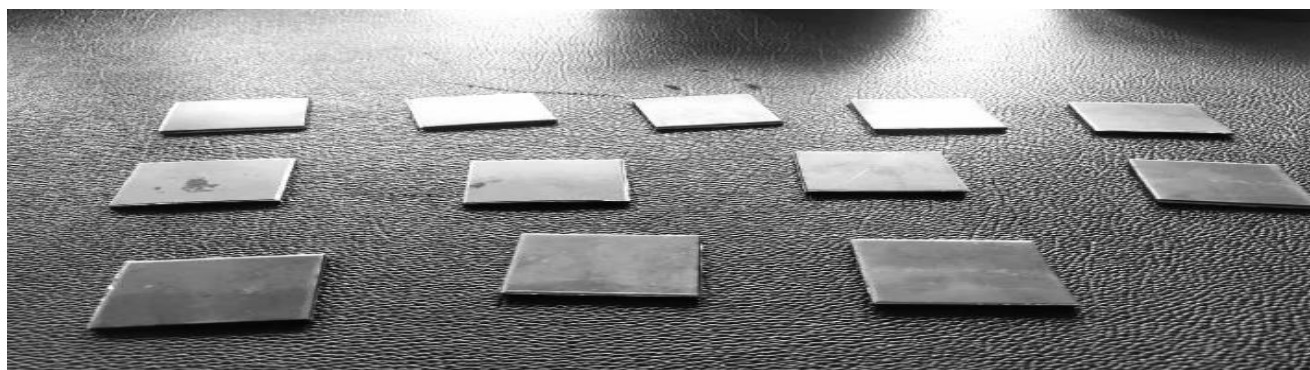


Plate III: Some as-sawn samples from the mild steel plate

E. Determination of Physiochemical Properties of the Paint Blends

The coat-drying times of the paint blends were determined in accordance with the ASTM D-1640 standard method [19]. The paints were carefully applied onto the prepared mild steel plate samples

with a paint brush at an ambient room temperature of 20°C to 25°C to an average film thickness of 1.78mm. The drying times of the samples' coatings was determined by periodically observing whether a slightly placed piece of wool on the coated surfaces got stuck or not to them. The observations were



recorded as touchable, handleable, and hard-dried as measures of drying times and by noting the time lapses between the initial exposure of the paint coatings to the atmosphere and the times the observations were made.

The average coating thickness of the paint blends on the mild steel plate samples was determined by measurements taken with the aid of a Dualscope-259 thickness gauge. The thickness measurements were made randomly at 20 different locations on each coated hard-dry sample and an uncoated steel sample. The average coating thickness in the coated and the uncoated cases were determined. The difference between the coated and the uncoated cases was evaluated to be 1.78 mm and taken as the average thickness of the paint coatings.

The penetration tests were carried out to determine the hardness of the paint blends using the semi-automatic dial penetrometer type B057-10 in accordance with the ASTM D5-97 penetration test procedure [15]. A paint blend was poured to a depth of 15 mm into a cylindrical, flat-bottomed steel container and maintained at 25°C. A 1 mm-diameter standard needle with a hardness number in the range C54–C60 was released from a calibrated height under a vertical load of 100 g on the penetrometer to penetrate the paint blend in the steel container. The indicator scale of the penetrometer instantly gave the penetration value of the paint blend in decimeters. The procedure was repeated with the same blend, and the average of the two values was taken to be the penetration of the blend. The paint blend that contained 100% bitumen was however first heated to 100°C in a water bath to reduce its viscosity and poured to a depth of 15 mm into the cylindrical flat-bottomed steel container and allowed to cool to 25°C before similarly testing its viscosity.

The flash and fire points were determined in accordance with the ASTM D93 tag close cup procedure and the Biobase BK-FP261 close cup flash point tester [15, 16]. The tester had a mercury-in-glass thermometer and an adjustable heating device. A sample of the paint blend whose flash and fire points were to be determined was

poured into the test cup to a standard level and then sealed off from the outside atmosphere. The cup content was then heated to higher temperatures at a rate of 5°C/min while being stirred and periodically introducing a low-flame ignition source into the sealed container until a flash was observed. The "fire point" was taken as the temperature at which further heating ignited the blend sample, and it continued to burn for at least five seconds. The flash and fire points were read directly from the control panel of the tester at the instances in which they were observed. The procedure was repeated with each of the other developed paint samples.

The ASTM D36-95 test procedure for determining the softening points of bituminous materials was used with the ring and ball apparatus to determine the softening points of the produced paint blends [15]. The paint blends were vigorously stirred and individually poured into a brass ring; each ring set-up was suspended in a standard water bath filled to a level of 600 mm and kept at ambient temperature of 25°C for 15 minutes. A 9.53-mm-diameter steel ball bearing of mass 3.55 g was placed centrally on the ring set-up, and the water bath was heated electrically to raise its temperature by 5°C per minute. The temperature at which the ball fell until it just touched a standard metal plate below in the bath was noted and recorded as the "softening point" of the paint sample. The procedure was conducted with each of the paint blend samples except the 100% bitumen-contained blend, which was heated to 100°C to reduce its viscosity for pouring into the brass ring and allowed to cool for 30 minutes before the subsequent stages of the test procedure.

The viscosities of the produced paint blends were determined using the Brookfield DV1 digital rotary viscometer in accordance with its manual and the ASTM D-445 procedure [16]. Each of the paint samples was poured separately into a 600ml low-form beaker and the viscometer spindle was immersed in the sample in the beaker. The viscometer rotational speed of 0.3rpm was initially selected, and the start button was pressed for the spindle to rotate at an angle of 73°. The viscosity



value of the sample and the operating temperature (25°C) were displayed on the output panel of the viscometer.

The resistances to blistering of the paint blends were determined in accordance with ASTM D4585 procedure for testing the water resistance of coatings [20]. Accordingly, samples of the individual paint blends were separately applied to glass panels to a wet film thickness of about 120µm in each case and allowed to dry for 24 hours. At the end of the drying time, 4 mL of distilled water was heated to 70°C and placed on the film. Observations of the film were made with magnifying eyeglasses for 30 minutes to find out and report any presence of blistering, wrinkling, swelling, and cracking on it. The test was conducted for each paint blend.

The cross-scratch test procedure was carried out in accordance with the ASTM 3359 method to understand the hardness and adhesion levels of the paint blends. Each of paint blend samples was applied to a mild steel plate sample to an average wet film thickness of about 120 micrometers and allowed 48 hours to hard-dry. A multi-edged cutting blade was used to make a cross-lattice pattern on the film all the way down to the substrate, then a masking tape was placed on top and pressed down with fingers for a minute, and the tape was quickly ripped off to see if any paint came off the panel. The test results were used to classify the paint blends using the ASTM standard for automobile base specifications [21].

The chemical resistances of the paint blends were determined in accordance with ASTM D1308 standard method. A mixture of acetone, demineralized water and isopropyl alcohol was randomly dropped on five of the test mild steel plate samples each separately coated with the paint blends and kept at room temperature for 24 hours. The samples were thereto examined under high magnification eye glasses for film failures, alterations or discoloration, and any stains that could result to corrosion or reduce the life spans of the coatings. The observation for each sample was rated and compared with the Peugeot Automobile

Nigeria (PAN) Plc and the ASTM standard specifications [21].

The weathering resistances of the paint blends were investigated in accordance with the method used by Guma [22]. Portions of the paint blends were heated to a suitable softening point and poured separately to the same depth level of 30 mm into similar transparent glass containers that were graduated in depths in millimeters. The containers were kept on a fence top with their open ends exposed to very cold atmospheric weather conditions. The paint thickness in each container was noted and recorded weekly for four weeks. The weathering resistance of each paint sample was adjudged by its thickness resistance level to variability in the container for the 4-week period.

The adhesive bond strengths of the paint blends were determined in accordance with ASTM D4541 procedure for pull-off adhesive bond strength testing of bituminous materials [18]. The 20 produced mild steel plate pairs for the test were procedurally cleaned to very smooth and similar surface finishes and dried in the oven at 60°C for two hours to ensure that they were free of any moisture on them prior to use. A paint blend sample coating was applied and achieved in-between pair surfaces of the prepared steel plate samples to a thickness of 1.78mm. The pair assembly was properly aligned, and allowed to set for 10 minutes. In that way, four coated sample pairs were produced with each of the five separate paint blends. One coated sample pair in each case was subjected to curing times of 6, 12, 24, and 36 hours at an ambient laboratory temperature of 25°C. Each as-cured pair assembly was loaded onto the specimen holder of the Universal testing machine (UTM) and subjected to gradual increasing tensile loading in the direction of the coating thickness until there was a detachment of the coating either between the coating and substrate steel plate (adhesive failure) or within the coating (cohesive failure). The mode of failure for each case were observed and recorded as "C" for cohesive failure and "A" for adhesive failure. The respective bond strengths of the coated assembly



pairs were determined in mega Pascals by dividing the detachment loads in Newtons by the coated surface area of one plate in a pair in millimeters.

The relative density of each paint blend was determined in accordance with the ASTM D70-17 procedure for determining the relative densities of semi-solid bituminous materials [15]. A 250-milliliter glass container of internal diameter 75 mm, an electronic digital weighing scale, a Vernier depth gauge, and a small steel slab that could fit in the container were used for the experimental process. The slab was completely immersed in water poured to a suitable level in the container. The combined mass of the container and its content (M_1) was determined with the digital weighing balance. The change in volume of water in the container (V_1) was also determined in cubic millimeters according to equation 1.

$$V_1 = \frac{\pi D^2}{4} (H_2 - H_1) \dots \dots \dots (1)$$

Where; D was 75mm, and H_2 and H_1 were the vertical depths in millimeters of water in the glass container measured with a Vernier depth gauge before and after the slab was immersed in the glass water. The slab was then removed and wiped off any moisture on it with a clean dry towel. A small portion of paint was detached from the paint in question and placed on the slab, and the previous procedure was repeated to obtain another volume (V_2) and mass (M_2). The relative density of the paint sample (ρ) was then determined according to equation 2.

$$\rho = \frac{M_2 - M_1}{V_2 - V_1} \dots \dots \dots (2)$$

The microstructure of the paint blend, which provided the best corrosion and wear protection of the test mild steel, was analyzed using the made-in-USA 4200e Quantachrome Nova in accordance with its manual and the ISO 9001 (2008) standard procedure [23]

The XRF analysis of the paint blend that provided the best corrosion and wear protection of the test mild steel was conducted using the Genius-IF XRF analyzer in accordance with its manual at 25-kV voltage and 15-uA current settings. The chemical

elements or groups present in each sample were automatically printed out in weight percentages after systematically operating the analyzer.

F. Wear Test

The wear test was conducted using the Taber 5135 abrader in accordance with the ASTM D4060 method for organic coatings [24]. The produced mild steel plate samples were systematically prepared and coated separately with the produced paint blends. The paint coatings were allowed to dry for 48 hours at temperatures that ranged from 21°C to 25°C. The initial weights of the coated and uncoated samples were determined to the nearest 0.001g using a digital electronic weighing scale. The uncoated steel sample was first placed on the abrasion tester with the S11 abrasion disk. A 500-gram load was placed on top of the disk, and the abrader was operated to spin the disk. The machine was paused after 500, and 1000 cycles of the disk to assess the wear of the sample. After the rotation cycles, the abraded sample was lightly rubbed with a bristle brush to remove any loose particles on it, reweighed, and its weight loss determined.

G. Corrosion Test

Accelerated corrosion test of an uncoated and coated mild steel samples with 1.78-mm thick hard-dry coatings of the paint blends was conducted in 0.1-M analytical grade hydrochloric acid (HCL as corrodent using an Armfield corrosion studies kit. The weights of the steel samples were determined and recorded using a highly accurate electric weighing scale with an accuracy capability of up to 0.001 g. analytical grade hydrochloric acid (HCL). The samples were soaked in the corrodent for 35 days whilst the corrodent were continuously circulated. The weight loss of each sample, at the end of the 35-day duration including the uncoated steel, was obtained by subtracting its final weight from its respective initial weight. The weight loss in each case was used to calculate the corrosion penetration rate (CPR) of the steel material undercoat in mm/yr. in accordance with equation 3 [25].



$$CPR = \frac{87.6W}{\rho AT} \dots \dots (3)$$

Where: W was the weight loss in milligrams of the coupon, ρ was 7.78, the density of the mild steel sample in g/cm³; A was 160, the exposure area of the mild steel coupon in square centimeters; and T was 840, the exposure time of the coupon in hours. The evaluated CPR results were used to determine the percentage protection efficiencies (PP) of the steel coupon by each coating in accordance with the equation 4 [25].

$$PP = \left(1 - \frac{CPR}{CPR_o}\right) 100\% \dots \dots (4)$$

Where; CPR was the corrosion rate of the coated steel, and CPR_o was the corrosion rate of similar but uncoated steel.

III. Results and Discussion

A. Results

Result of the analyzed nominal composition of the procured mild steel plate used for the study is shown in Table 3. Results of the different physicochemical properties of synthesized bituminous paint samples are presented in Tables 4 to 6, and Figs. 1 to 9. The result of the conducted scanning electron microscopy of the synthesized paint sample that best protected the test mild steel against corrosion and wear is shown in Plate VIII while that of its x-ray fluorescence (XRF) analysis is shown in Table 7.

Table 3: The nominal composition of the study mild steel plate

Element	C	Si	Mn	P	S	Fe	Al	Cu	Mg	Ca
Wt (%)	0.032	0.015	0.79	0.009	0.015	97.8	0.059	1.07	0.001	0.0068

Table 4: Drying times in hours (Hrs.) of 1.78-mm average paint coating thickness on the study mild steel

Indicator with time	Bitumen composition of the paint (%)				
	70	75	80	90	100
Touchable (Hrs.)	4	3	6	7	8
Handle (Hrs.)	7	6	9	12	14
Hard-dried (Hrs.)	18	17	20	23	26

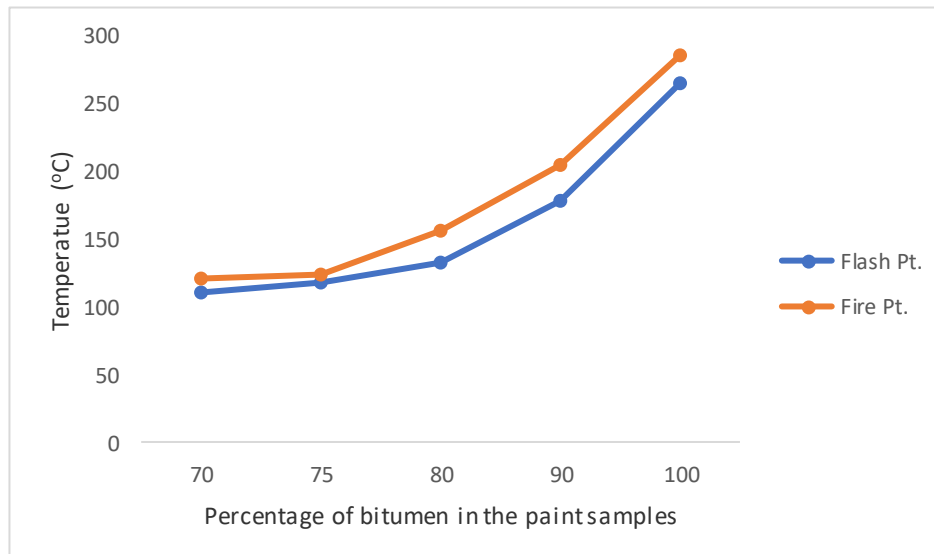


Fig 1: Flash and Fire point (Pt.) levels of the paint samples

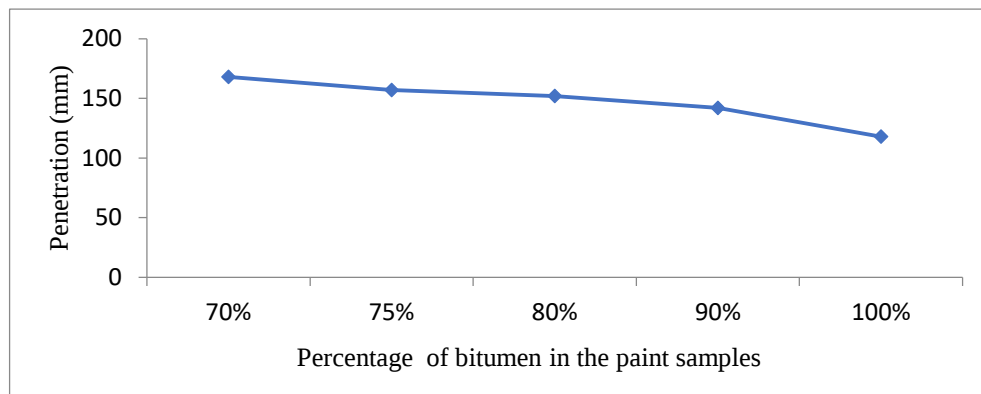


Fig 2: Variation of penetration values among the paint blends

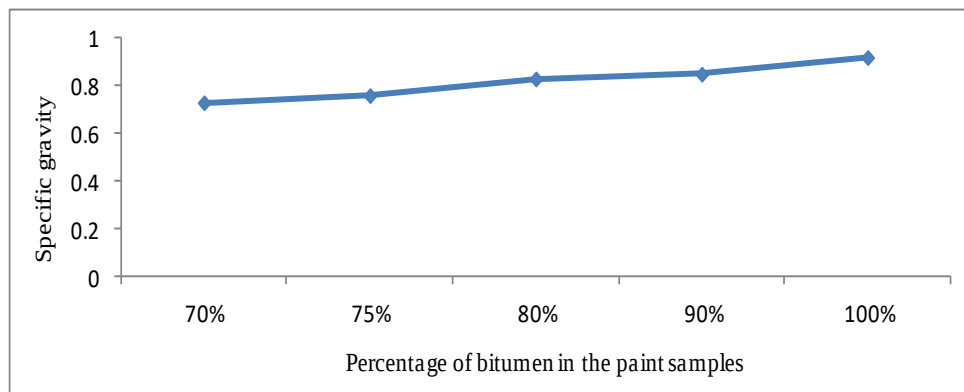


Fig 3: Specific gravities of the paint blends

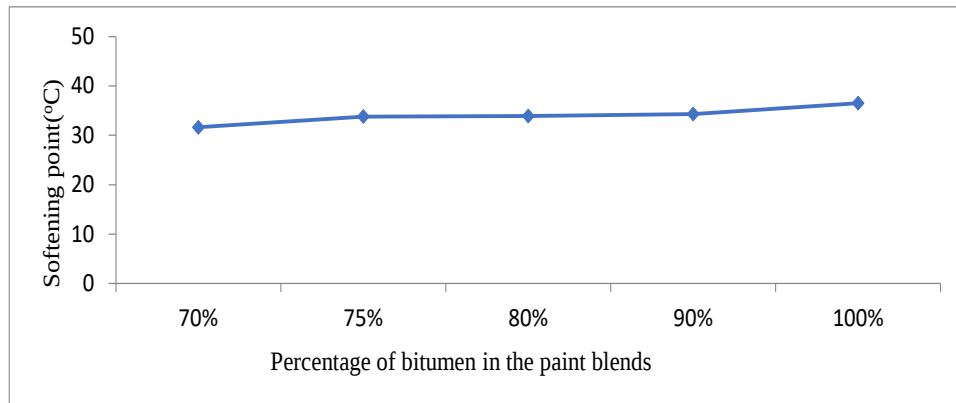


Fig.4: Softening points of the paint blends

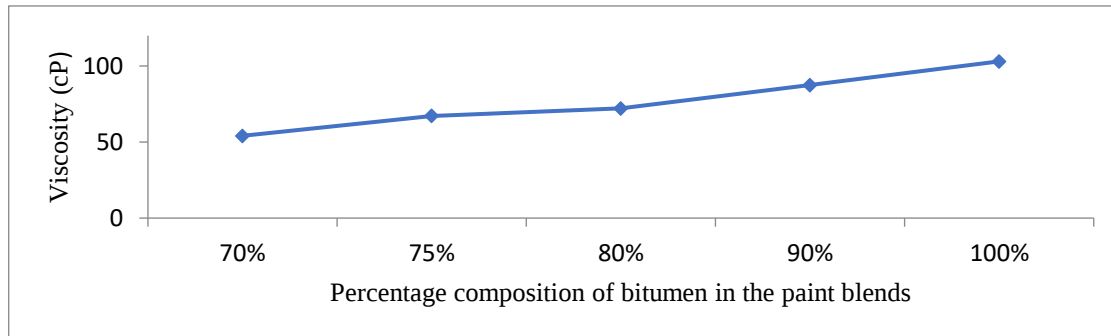


Fig. 5: Viscosities at 40°C of the produced bituminous paint blends

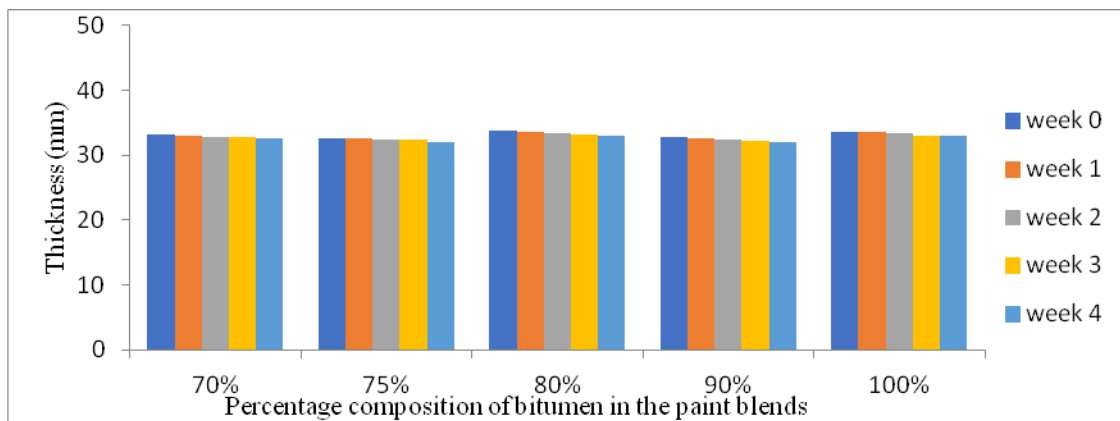


Fig. 6: Comparative weathering levels of the paint blends.

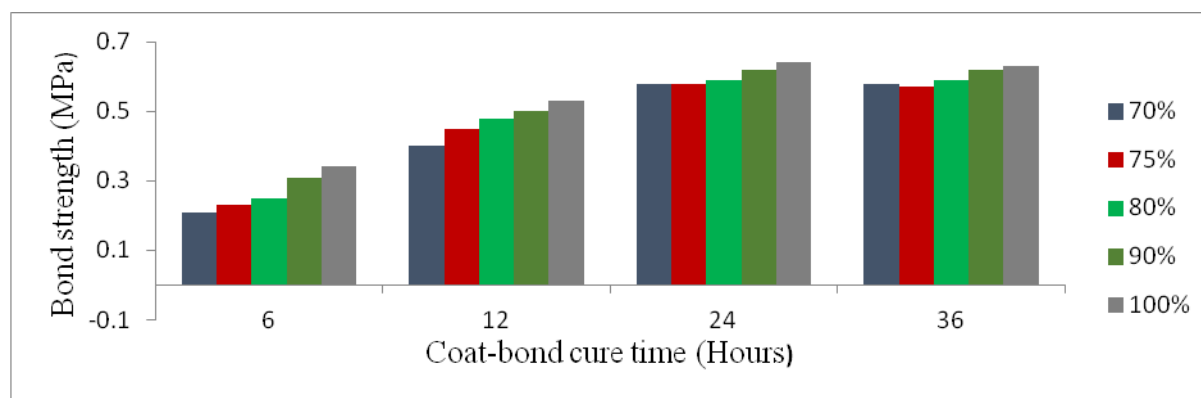
Table 5: Chemical resistances of the paint blends coated on the mild steel samples

Paint blend bitumen content	Response	Remark
70%	0	Accepted

75%	0	Accepted
80%	0	Accepted
90%	0	Accepted
100%	0	Accepted

Table 6: Cross scratch test analyses of the paint blends coated on the mild steel samples.

Paint blend bitumen content	Response	Remark
70%	1	Passed
75%	1	Passed
80%	1	Passed
90%	1	Passed
100%	1	Passed
ASTM Specification:	1 & 2	Passed
	3 & 4	Failed

**Fig. 7: Adhesive bond strength of 1.78mm-thick coating of the paint blend that contained 75% bitumen****Table 8: Bond failure modes of 1.78mm-thick coatings of the paint samples on the test mild steel**

Paint sample bitumen content	Coat-bond conditioning time (Hours)	Dominant failure mode
70%	6	C
	12	A
	24	A
	36	C
75%	6	C
	12	C
	24	A
	36	A
80%	6	C
	12	C
	24	A
	36	C
90%	6	A

100%	12	C
	24	C
	36	A
	6	A
	12	A
	24	C
	36	C

*A = Adhesive failure (failure between the bituminous paint and steel plate)

*C = Cohesive failure (failure that is entirely within the bituminous paint)

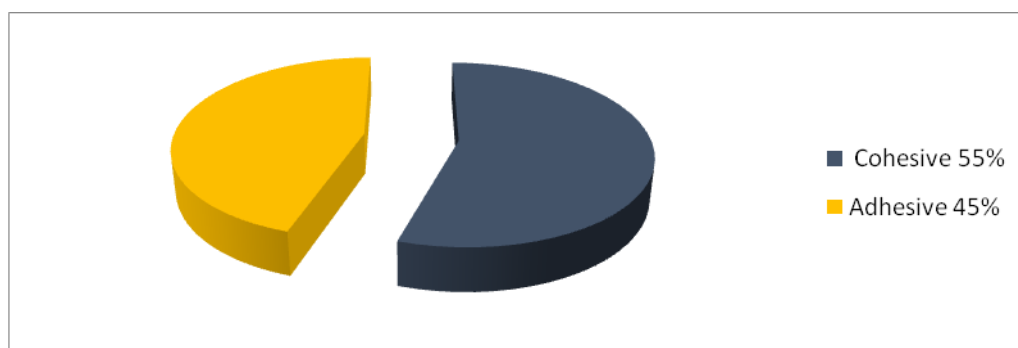


Fig. 8: Failure modes [%] of the coat-bond between the steel plate pairs samples

Table 9: XRF-analyzed chemical composition of paint sample (B)

Oxides (%)	Content	Error
SiO ₂	1.457	0.0457
V ₂ O ₅	0.185	0.026
Cr ₂ O ₃	0.002	0.015
MnO	0.128	0.015
Fe ₂ O ₃	0.160	0.017
Co ₃ O ₄	12.001	0.084
NiO	0.277	0.028
CuO	0.058	0.023
Nb ₂ O ₃	0.033	0.052
MoO ₃	0.015	0.065
WO ₃	0.218	0.259
P ₂ O ₅	0.000	0.000
SO ₃	64.965	0.962
CaO	0.416	0.053
MgO	7.235	11.690
K ₂ O	0.031	0.074

BaO	0.000	0.000
Al ₂ O ₃	3.149	1.695
Ta ₂ O ₅	0.000	0.000
TiO ₂	0.029	0.024
ZnO	8.250	0.072
Ag ₂ O	0.000	0.000
Cl	1.362	0.0177
ZrO ₂	0.028	0.043
SnO ₂	0.000	0.000



Plate VIII: Microscopy of paint blend (B)

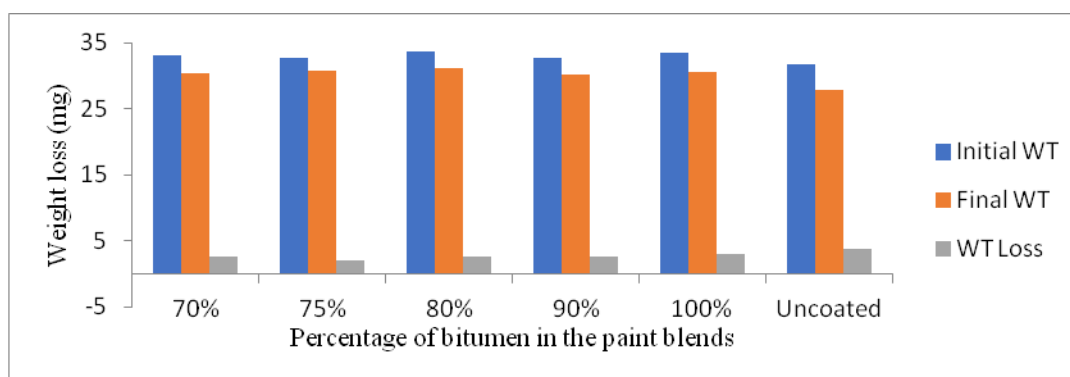


Fig 9: Initial and final weight losses of the uncoated steel and coated steel with the paint blends

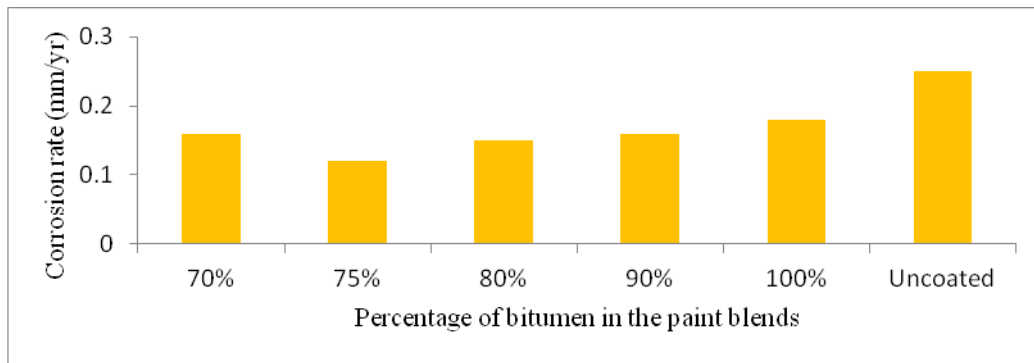


Fig. 10: Corrosion rate of the uncoated and coated steel with the paint blends

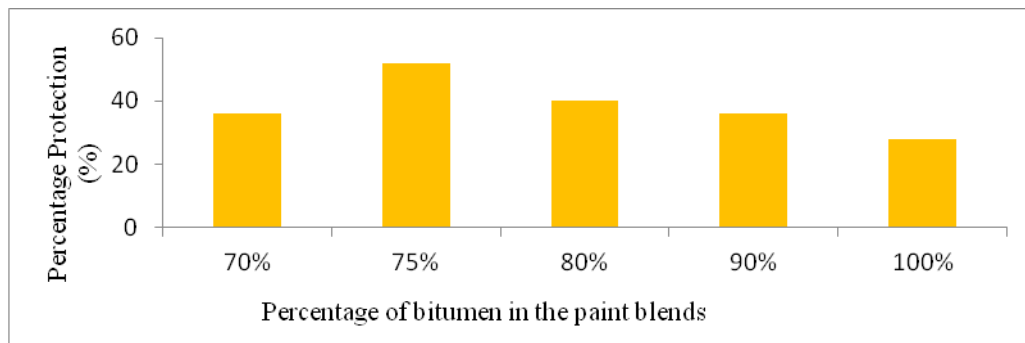


Fig. 11: Protection efficiency of the steel coated samples by the paint blends

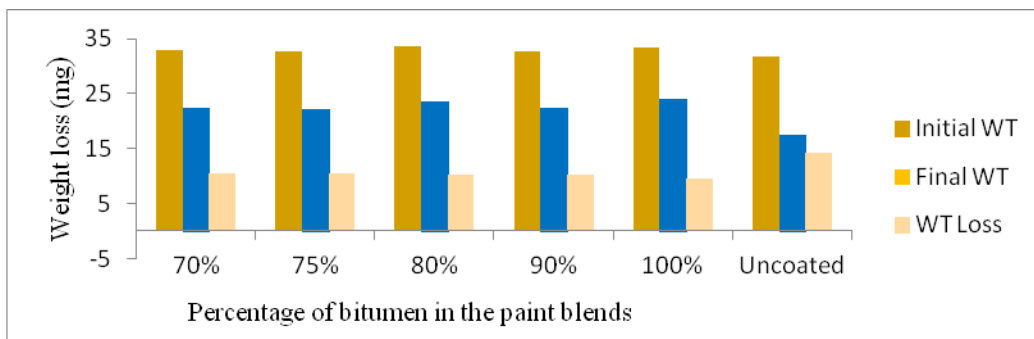


Fig. 12: Comparative weight losses of the uncoated and coated mild steel samples with the paint blends after 500 cycles of wear tests.

B. Discussion of Results

Table 3 shows the carbon content of the steel is 0.032%. The carbon content is within the range of 0.05 to 0.032% specified for mild steel materials [25]. The result also shows negligible contents of the trace elements Ti (0.001%), Cu (1.07%), Cr

(0.06%), S (0.015%), and P (0.009%) in the steel, all of which can influence the corrosion behavior of the steel. This shows that the steel used for the study was a plain, mild steel type that can have the least corrosion resistance out of all the ferrous materials that are used as automobile chassis material [25].



Table 4 shows that the hard-dry times of the 1.78-mm thick coating of the separate paint blends on the study mild steel vary from 17 to 26 hours for the paint blend that contained 75% bitumen to the paint blend that contained 100% bitumen respectively. This indicates that the paint blend with 75% bitumen content or 15% content of the additives can have the least coat-drying time in service usage. The drying times are comparable to the drying time value of 24 hours for the Berger commercial bituminous paint [26]. This indicates that all the paint blends can have satisfactory coat drying times in service usage.

Fig. 1 shows that the flash points of the paint blends are lower than their corresponding fire points. The flash points of the paint blends vary from 110 to 265°C as the percentage bitumen content of the paint blends increases from 70 to 100% or the percentage contents of the additives in them decrease from 30 to 0%, respectively. The flash points of the paint blends are much above the values for organic liquids that are known to have low flash points such as -43°C for petrol, 16.6°C for ethanol, and 38°C for kerosene, but close to or much greater in values for many organic liquids that are known to have high flash points such as 130°C for biodiesel and 187°C for lube oil, according to information from Storemasta [27]. This shows that the produced paint blends can have adequately high flash points for coating usage. It can also be observed from Fig. 1 that the fire points of the paint blends range from 121 to 285°C as their percentage bitumen content increases from 70 to 100% or the percentage contents of the additives in the paint blends decrease from 30 to 0%, respectively. This indicates that all the paint blends have very high and better fire points for safety in service usage in comparison to other organic liquids with adequately high fire points, such as Jatropha biodiesel with a fire point of 192°C and AMC Jatropha with a fire point of 175°C [27].

Fig. 2 shows that the penetration values of the produced paint blends reduce from 168 to 118 as the percentage bitumen contents in the paint

blends increase from 70 to 100%, respectively. This indicates that the paint blends become softer with increase in their contents of the additives within the range of 0 to 30%. In other words, the more the additives in the natural bitumen, the less hard the produced paint with the bitumen will be. According to Haseeb Jamal [28], the less hard a bituminous paint is, the greater the ease of its application by brushing, spraying, and rolling at ambient temperatures. This suggests that the 70%-bitumen-contained paint blend is best followed by the 75%-bitumen-contained blend.

Fig. 3 shows that the specific gravities of the paint blends increase from 0.732 to 0.924 with an increase in their bitumen contents from 70 to 100% or as the percentage contents of the additives in them decrease from 30 to 0%, respectively. The lower the specific gravity of a paint, the greater its ability to flow and ease of application [15, 28]. This suggests that the paint blend that contained 70% bitumen is the best for application, followed by the blend that contained 75% bitumen.

Fig. 4 shows that the softening points of the paint blends increase from 31 to 36.5°C as their percentage bitumen contents increase from 70 to 100% or as the percentage content of the additives in them decrease from 30 to 0%. The softening points of the paint blends that contained 70%, and 75% bitumen are very good comparisons with the softening point value of 30°C for the commercially available Berger bituminous paint [26]. This indicates that all the paint blends, including the 70% bitumen-contained paint blend, which has the lowest softening point of 31°C can be satisfactory in their practical usage with regards to the softening point requirement.

Fig. 5 shows the viscosities of the produced paint blends. It is evident from Fig. 5 that the viscosities increase from 54 to 103 centipoise (cP) for the paint blends that contained 70 to 100% of the natural bitumen or 30 to 0% of the additives, respectively. The lower the viscosity of paint, the greater its ease of flow and application. The viscosities of the paint blends are reasonably close to the rule-of-thumb value of 100 centipoise for



brushing and spraying [29]. The best values, however, are from 90% and 100% bitumen-contained paint blends, as can be observed from Fig. 5.

Fig. 6 shows the weathering resistance indices of the produced paint blends. It is observable that all the paint blends have excellent weathering resistance due to minimal variation in their weathered levels, as can be observed from Fig. 6. The result also shows that the paint blend with 75% bitumen content weathered the least, followed by the blend with 70% bitumen content, with total weathering thickness reductions of only 0.5mm and 0.54mm respectively, during the 4-week exposure time of the paint blends to the atmosphere [15].

Tables 5 and 6 show that all the produced paint blends have satisfactory chemical resistance and hardness values in accordance with ASTM standard specifications and PAN Plc standards [20, 21].

Fig. 7 shows that the coating bond strengths of all the paint blends increased with their curing times of up to 24 hours. The bond strengths of the blends increased in a narrow band from 0.58 to 0.64 MPa for the blend that contained 70% bitumen to the blend that contained 100% bitumen. All the paint blends displayed good adhesive bond strengths, with their optimum strength values attained after curing them for 24 hours, according to Guma and Ishaya [18]. Guma and Ishaya [18] also observed a similar pattern of behavior with the Agbabu natural bitumen in its unmodified form. On the other hand, Table 5 and Fig. 8 show that the cohesive failure (C) is the dominant failure mode of the coat-bonds of the paint blends, with 55% of cases compared to the adhesive mode (A) with 45% of cases.

The physicochemical properties from the foregoing have given rudimentary information on the safety, coating degradability, ease, and effectiveness levels of the usage or application of the produced paint blends. From the analyses carried out, it is apparent that all the produced paint blends exhibited considerable variation in properties. This shows that the quantity of the additives blended with the natural bitumen has effects on the paints'

properties. The optimal improvements in the physicochemical properties, however, evidently came from the paint blend that contained 75% bitumen.

Fig. 9 shows the corrosion weight losses of the uncoated steel sample and the coated steel samples with the produced paint blends. It can be observed from Fig. 9 that the weight loss of the uncoated steel sample in the test hydrochloric acid medium after 35 days was the greatest, followed in order by the steel sample coated with the paint blend that contained 100% bitumen, the steel samples coated with the blends that contained 70% and 90% bitumen, which had the same weight loss, the steel sample coated with the paint blend that contained 80% bitumen, and the steel sample coated with the paint blend that contained 75% bitumen. This trend of variation is also similar to the corrosion rates of the coated steel samples, as shown in Fig. 10. As can be observed from Fig. 10, the corrosion penetration rates of the steel samples coated with paint blends that contained 70%, 75%, 80%, 90%, and 100% bitumen and the uncoated steel samples were 0.16, 0.12, 0.15, 0.16, 0.18, and 0.25 mm/yr, respectively. This translates into percentage protection levels of 36%, 52%, 40%, 36%, and 28% of the steel by the paint blends' coatings, respectively, as shown in Fig. 11. Generally, mild steel corrosion rates of less than 1.3 mm/yr are considered good corrosion control in atmospheric environments [5]. From these results, it is inferable that the coating of the paint blends provided satisfactory protection of the steel in all cases, and the paint blend that contained 75% of the natural bitumen has higher protection potential against corrosion and wear of mild steel than all the other paint blends.

Fig. 12 shows the comparative wear weight losses of the uncoated steel sample and coated steel samples with the produced paint blends after 500 cycles of wear testing. The result shows that the coatings of the paint blends prevented wear of the steel samples, as evidenced by the minimal weight losses of the blends' hard-dried coatings on the samples. It is evident from these results that the



1.78-mm-thick coatings of all the paint blends protected the mild steel samples from wear, but the coating of the paint blend that contained 90% bitumen provided the best wear protection, followed respectively by the coatings of the paint blends that contained 80%, 75%, and 70% bitumen. This indicates that a higher proportion of the natural bitumen content is required in the paint blends to make their coatings more wear-resistant for the steel.

Table 6 shows the x-ray fluorescence analysis of the paint blend that contained 75% bitumen, which exhibited the best physicochemical properties for protective coating application, and whose 1.78-mm hard-dry coating exhibited the best corrosion protection for mild steel with a very low satisfactory wear rate. It can be seen from Table 6 that the paint blend contained 25 different chemical species at different weight percentages. It can also be seen that the 25 chemical species are mostly metallic oxides or compounds. Such oxides have had their energies spent, so they have minimal energy levels and corrosivity to cause any meaningful corrosion of ferrous materials, according to Guma and Abubakar [30]. These exceptional anti-corrosion attributes could be the main reason why the paint blend that contained 75% bitumen is outstanding out of all the synthesized paint blends.

Plate X shows that the microstructure of the 75% bitumen-contained paint blend, which exhibited the best properties and corrosion protection for mild steel, is more or less uniform in appearance. This indicates the compatibility of the additives and bitumen mixture in the paint blend, the more or less homogeneity of the blend, and the blend's minimal intergranular boundaries for the ingress of corrosion-causing agents to the steel underneath the blend's coating [15].

IV. Conclusion

Five brush-applicable bituminous paint blends containing various proportions of Agbaba-sourced natural bitumen, kerosene, cobalt, pigments, and

lead drier were produced and characterized by their basic physicochemical properties. Laboratory corrosion and wear tests of mild steel, a commonly and widely used automobile chassis material type that is well known to have very low corrosion and wear resistance, were conducted under hard-dry coatings of the paint blends with the assumption that, if the blends' coatings could sufficiently protect the steel undercoat, then they could also sufficiently protect automobile chassis made of any ferrous material types. The overall results indicated that the paint blend that contained 75% bitumen, 15% kerosene, 8% cobalt, 0.6% pigment, and 1.4% lead drier could perform exceptionally well in physicochemical characteristics and in protecting the steel and hence automobile chassis under a hard-dry coating of 1.78 mm thickness at ambient temperatures of less than 26°C.

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