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Upgrading Nigeria Bitumen for constructing of pavements

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Abstract— The occurrence of bitumen deposits in Nigeria has been estimated to be about 42 billion tones, almost twice the amount of existing reserves of crude petroleum" Nigerian Investment Promotion Commission(NIPC). The failures of the Nigeria bituminous pavements are not only due to increase in traffic but also due to extreme climatic conditions prevailing in the country. For proper planning and usage of Nigeria bitumen for construction of roads in Nigeria, there is the need to upgrade and optimise the bitumen in order to meet the foreign international standard for constructing Nigeria pavements. The polymer modification of the bitumen can improve the quality of binders and enhance the properties of binders used for the construction of pavements.

This paper presents the physical properties of sulphur modified bitumen and EVA (ethyl Vinyl Acetate) modified bitumen and compares with unmodified Bitumen and European produced bitumen. It shows that the measured properties of the sulphur modified Nigerian bitumen and EVA modified Nigeria bitumen, compared favourably with the measured properties of the European produced bitumen, which is of international standards.

The results obtained revealed that additive modification of the Nigeria bitumen can improve the quality of binders and enhance the properties of the binders used for construction of pavements

. **Key Word:** Upgrading, Nigeria Bitumen, Pavement, bitumen Modification, road contruction, binder, European produced bitumen.

1 INTRODUCTION

The development of Nigeria economy demands for sophicated and technically satisfied bituminous mixture or binder to reduce rutting at high temperature and thermal cracking at low temperature that mostly causes weather induced stresses on roads, airport runways and parking lots [1], [2], [3]. The response of bitumen to stress depends on temperature and loading time. At low temperatures, and short loading times, bitumen behave predominantly elastic [4]. At high temperature and long loading times bitumen behaves like a liquid (viscous behavior). For typical pavement temperatures and load conditions, bitumen generally exhibits both viscous and elastic behavior [4]. The behavior of bitumen can be modified (improved) by adding modifiers to the bitumen. Bitumen modification is usually aimed at improving the stiffness and the elasticity of the asphalt bitumen at high pavement temperatures and reducing stiffness and elasticity of the bitumen at low temperatures. The quality of bituminous road surfacing and its performance depends upon the properties of bitumen and these arecontrolled by composition of bitumen [1], [5].

The characteristics of heavy crude that indicate their suitability for bitumen manufacture are a high weight percentage of carbon residue, high specific gravity, sulphur content of more than 5% weight, low wax content and high asphaltene content. Generally, Nigerian crude do not meet these characteristics; hence, the bitumen produced from them do not meet up to international specifications [6]. Studies have also shown that the main limitation of the bitumen produced by blowing Nigerian crude is its high susceptibility to temperature rise, thereby not making it ideal for all weather roads paving [7].

Many researchers have shown their interest in studying the properties of the modified binders and evaluating their advantage over the conventional bitumen. Modification of bitumen after a treatment with 2% sulphur, at 160^{0}C was carried out [8]. The chemical bonding of sulphur to bitumen leads to a new binder in which asphaltenes present a more gel-like type of structure resulting from a higher ability to form aggregates [8]. The decrease in dynamic mechanical properties, with respect to the pure binder is due to parent plastification of the material. It was reported that the sulphur-substituted asphalt mixes exhibit significantly higher fatigue life than comparable conventional mixes [8]. The behavior of sulphur containing pavements is more elastic compared with conventional pavements (at the same loading time). The addition of sulphur makes it possible for softer asphalts to be used in order to reduce low-temperature cracking without the high-temperature deformation, which occurs when virgin asphalt is used [8]. It has been found that the use of sulphur extended asphalt with 30%-40% of sulphur in paving mixes leads to the reduction in deformation approximately by a half [7], [8]. Paving materials based on sulphur-asphalt and binder exhibit a better resistance to water as compared to conventional mixes. The use of sulphur in asphalt aggregate mixes permits the design of impervious materials being suitable for hydraulic applications [8]. A saving of 20% asphalt can be reached by incorporating sulphur into an asphalt paving mix. Olutoye (2005) carried out an experimental work on the improvement of Crude Residue [6]. His work involved obtaining the crude residue; oxidation (blowing) of distillation residue, sulphurisation of crude residue and blending [6]. During the oxidation process, 2115g of the sample residue from vacuum distillation was measured into the vessel and heated to 260^{0}C on the electro mantle. The flask was covered with a bored rubber cork, which has compressed air passed through it at the rate of 18.33E10^{-6} to 35E10^{-6} m^3/sec. (i.e. 2.1 to 1.1 liter/min) into the preheated sample. This was run for about 8.617 hours. Sulphurisation was carried out at atmospheric pressure, by adding 8g of sulphur to a batch of 100g of petroleum crude residue. The measured crude residue and sulphur were mixed vigorously in a flask containing boiling chips. The reaction took place in fume box and in a well-ventilated environment. The reaction mixture was heated up quickly to about 260^{0}C and kept at this temperature for 2 hours. The heat was then turned off. The content of the flask was allowed to cool and was decanted. In the case of blending, it involved the blending of the petroleum crude residue with a foreign crude petroleum residue and/or the blending of the petroleum residue with the naturally occurring bitumen. The required amount of each upgraded residue sample was then measured. Heating was done at 45^{0}C and at constant stirring rate for 30mins. He also carried out specific gravity and viscosity determination experiments. At the end of his experiments, he was able to establish that the tested crude residue was either light or medium according to the API method of classification and residue from distillation were general of poor bitumen qualities. The petroleum crude residue experimented on was made suitable for bitumen production when the results obtained were compared with the property of foreign petroleum crude suitable for bitumen production, which indicated the non-sustainability of the crude. Praveen Kumar et al (2013) reported on the effect on physical properties in terms of penetration, softening point, weight loss and rheological properties of bituminous binders in terms of their complex modulus before and after aging were measured [9]. They tested at temperatures ranging from 40^{0}C to 70^{0}C in increments of 6^{0}C at a frequency of 10rad/sec using dynamic shear rheometer (DSR) [9]. Their results showed that after aging, softening point increases and penetration decreases with increasing percentage of modifier [9]. The modulus was found to increase with increase in percentage of modifier after ageing indicating higher rutting resistance [9], [10]. They also reported on the evaluation of physical properties of sulphur-modified bitumen and its resistance to ageing [10]. They reported that the addition of sulphur to the bitumen could improve the quality of bitumen and enhance its properties as far as its use in the road construction was considered he also discussed the effect of addition of sulphur on the properties of the bitumen and the optimum dose of sulphur to be added to the bitumen was determined. They also determined the effect of aging on the physical properties of sulphur-modified bitumen [9], [10].

TESTS CONDUCTED

The following tests were conducted on the modified and unmodified binders [11], [12]:

PENETRATION TEST

The penetration of a bituminous material is the depth in units of tenths of millimeter that a standard needle will penetrate vertically into a sample of the material under standard condition of temperature (25^{0}C), load (100g) and time (5secs). Penetration test is the most commonly used test on bitumen to grade the material in

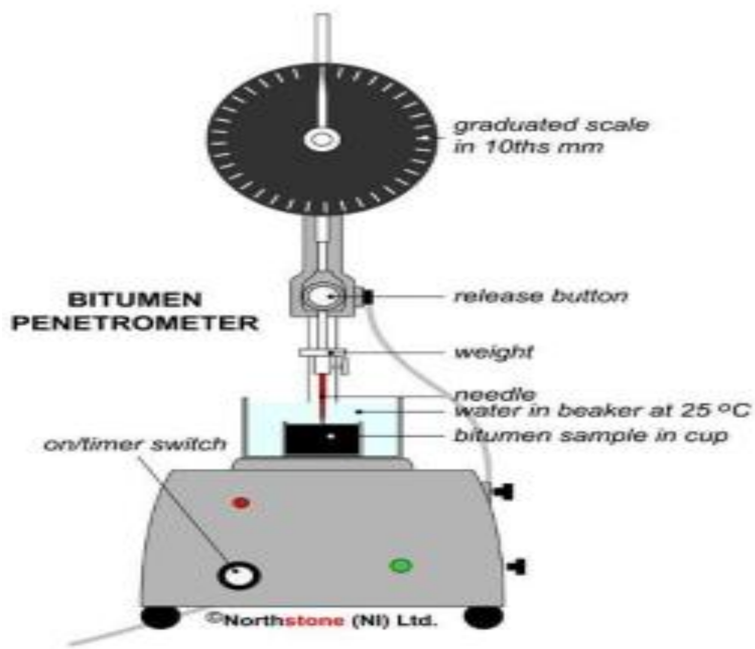

Figure 1 showing an illustration of the penetration test

FLASH POINT TEST

The flash point test is usually carried out to determine the temperature at which asphalt can be heated safely in the presence of an open flame. The test is performed by heating asphalt sample in an open cup at a specified rate and determining the temperature at which a small flame passing over the surface of the cup will cause the vapors from the asphalt sample temporarily to ignite or produce a flash of flame [13].

Flash point tests are used to detect materials such as gasoline or kerosene, which are contaminants in crude residue. A substantial drop in flash point can indicate contamination of crude residue by such materials.

In recent years, the flash point tests results have been related to the hardening potential of the asphalt. Asphalt with a high flash point is more likely to have a lower hardening potential in the field.

SOLUBILITY TEST

Bitumen is a hydrocarbon with a high molecular weight soluble in carbon disulfide.

In the standard tests for bitumen content, a small sample of 2g of the asphalt is dissolved in 100ml of carbon disulfide and the solution is filtered through a filtering mat in a filtering crucible. The material remained on the filter is then dried and weighed, and used to calculate the bitumen content as a percentage of the weight of the original asphalt. Because of the extreme flammability of carbon disulfide, solubility in trichloroethylene, rather than solubility in the carbon disulfide is used usually in asphalt cement specifications[9], [10].

The solubility test is also used in detecting contamination in asphalt. Specifications for asphalt cement usually require a minimum solubility in trichloroethylene, of 99.0%. Carbon disulfide was used in this experiment [10], [13].

VISCOSITY

The viscosity test measures the viscosity of asphalt. Both the viscosity test and the penetration test measure the consistency of an asphalt of some specified temperatures and are used to designate grades of asphalt [13]. The advantage of using the viscosity test as compared with the penetration test is that the viscosity measures the fundamental physical property rather than an empirical value. Viscosity is defined as the ratio between the applied shear stress and induced shear rate of a fluid. When shear rate is expressed in units of 1/sec, and shear stress is in units of Pascal, viscosity will be in units of Pascal-seconds [10].

EXPERIMENTAL PROCEDURES

EXPERIMENT A

I. The penetration test was carried out on the European Produced bitumen and the following results were obtained after three trials:

TABLE 1: SHOWING THE PENETRATION TEST VALUES OF THE EUROPEAN PRODUCED BITUMEN

PENETRATION TEST @ 25^0C	PENETRATION VALUE (DMM)
TEST 1	18
TEST 2	18.5
TEST 3	17

Average penetration value is equal to 17.833

The average penetration value of the European produced bitumen shows its quality as high-grade bitumen.

II. The flash point test carried out on the European produced bitumen resulted in a flash point value of 306^0C.

III. Solubility test carried out on the by dissolving 2g of the European bitumen sample into 100ml carbon disulfide yielded the following result:

Residue weight after filtration = 0.02g
Solubility = 99%

IV. The viscosity test carried out on the European produced bitumen measured the viscosity of the bitumen as 3025 centipoise

EXPERIMENT B

The same tests that were performed on the European produced bitumen were performed on the Nigerian produced bitumen from Agbagbu, Ondo State, and the following results were obtained.

I. The penetration test was carried out on the Nigerian Produced bitumen and the following results were obtained after three trials:

TABLE 2: SHOWING THE PENETRATION TEST VALUES FOR THE UNMODIFIED NIGERIAN PRODUCED BITUMEN

PENETRATION TEST @ 25^0C	PENETRATION VALUE (DMM)
TEST 1	68
TEST 2	70
TEST 3	65

Average penetration value is equal to 67.67

The average penetration value of the Nigerian produced bitumen shows its quality as low-grade bitumen.

II. The flash point test carried out on the Nigerian produced bitumen resulted in a flash point value of 280^{0}C.

III. Solubility test carried out on the by dissolving 2g of the Nigerian bitumen sample into 100ml carbon disulfide yielded the following result:
Residue weight after filtration = 0.326g
Solubility = 83.7%

IV. The viscosity test carried out on the Nigerian produced bitumen using the vacuum capillary viscometer at 135^{0}C measured the viscosity of the bitumen as 575centipoise.

EXPERIMENT C

For the upgrade of the bitumen using sulphur, a measured percentage by mass 1%, 2%, 3%, 4% and 5% of sulphur were added to the 1.5kg of bitumen respectively. (i.e. 1%, 2%, 3%, 4%, 5% of 1.5kg of bitumen).

I. Penetration test was carried out for each of the percentage by mass 1%, 2%, 3%, 4% and 5% of sulphur.

For 1% sulphur (15g), the penetration results obtained were:

TABLE 3: SHOWING THE PENTRATION TEST VALUES FOR 1% SULPHUR (15g)

PENETRATION TEST @ 25^{0}C	PENETRATION VALUE (DMM)
TEST 1	43
TEST 2	45
TEST 3	44

Average penetration value is equal to 44

For 2% sulphur (30g), the penetration results obtained were:

TABLE 4: SHOWING THE PENTRATION TEST VALUES FOR 2% SULPHUR (30g)

PENETRATION TEST @ 25^{0}C	PENETRATION VALUE (DMM)
TEST 1	31
TEST 2	33
TEST 3	33

Average penetration value is equal to 32.33

For 3% sulphur (45g), the following penetration results were obtained:

TABLE 5: SHOWING THE PENTRATION TEST VALUES FOR 3% SULPHUR (45g)

PENETRATION TEST @ 25^{0}C	PENETRATION VALUE (DMM)
TEST 1	25
TEST 2	26
TEST 3	26

Average penetration value is equal to 25.67

For 4% sulphur (60g), the following results were obtained:

TABLE 6: SHOWING THE PENTRATION TEST VALUES FOR 4% SULPHUR (60g)

PENETRATION TEST @ 25^{0}C	PENETRATION VALUE (DMM)
TEST 1	21
TEST 2	21
TEST 3	21

Average penetration value is equal to 21.00

For 5% sulphur (75g), the following results were obtained:

TABLE 7: SHOWING THE PENTRATION TEST VALUES FOR 5% SULPHUR (75g)

PENETRATION TEST @ 25^{0}C	PENETRATION VALUE (DMM)
TEST 1	19
TEST 2	19
TEST 3	17

Average penetration value is equal to 18.33

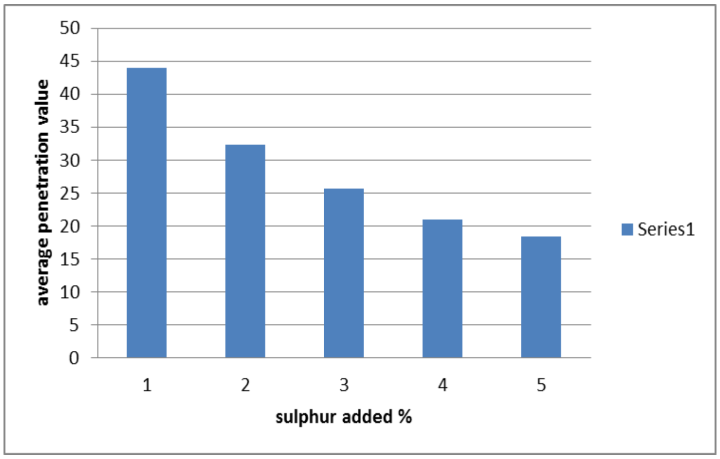

Figure: 2: Show a plot of varying amounts of sulphur in percent against the corresponding penetration values.

It was observed at the end of the penetration tests that as the percentage by mass of sulphur added to the bitumen was increased, the grade of the bitumen increased as the bitumen containing 5% percentage by mass sulphur was tested to have the lowest penetration value which compared favorably to the tested penetration value of the European produced bitumen indicating a successful upgrade.
Therefore, the remaining tests were carried out on the bitumen containing 5% percentage by mass sulphur.

II. ***Flash point test***: The flash point test was carried out and the first flash of flame was observed and measured to have come up at a temperature of 300^0C. Therefore, the flashpoint was measured as 300^0C

III. ***Solubility test:***Solubility test carried out on the by dissolving 2g of the upgraded Nigerian bitumen sample using 5% sulphur into 100ml carbon disulfide yielded the following result:
Residue weight after filtration = 0.025g
Solubility = 98.75%

IV. ***Viscosity test***: The viscosity test was carried out using the vacuum capillary viscometer at 135^0C and a viscosity value of 3017centipoise was obtained.

EXPERIMENT D

500g of bitumen crump rubber and two types of polymers, ethylene vinyl acetate (EVA) and styrene butadiene styrene (SBS) with varying percentage of 2%, 5% and 8% were used in this experiment to upgrade the Nigerian Produced Bitumen.

I. Penetration test using EVA polymer, SBS polymer, and crump rubber.

Using EVA polymer
For 2% EVA (10g), the following results were obtained:

TABLE 8: SHOWING THE PENTRATION TEST VALUES FOR 2% EVA (10g)

PENETRATION TEST @ 25^0C	PENETRATION VALUE (DMM)
TEST 1	45
TEST 2	45
TEST 3	45

Average penetration value is equal to 45

For 5% EVA (25g), the following results were obtained:

TABLE 9: SHOWING THE PENTRATION TEST VALUES FOR 5% EVA (25g)

PENETRATION TEST @ 25^0C	PENETRATION VALUE (DMM)
TEST 1	39
TEST 2	40
TEST 3	41

Average penetration value is equal to 40

For 8% EVA (40g), the following results were obtained:

TABLE 10: SHOWING THE PENTRATION TEST VALUES FOR 8% EVA (40g)

PENETRATION TEST @ 25^0C	PENETRATION VALUE (DMM)
TEST 1	30
TEST 2	34
TEST 3	35

Average penetration value is equal to 33

For 11% EVA (55g), the following results were obtained:

TABLE 11: SHOWING THE PENTRATION TEST VALUES FOR 11% EVA (55g)

PENETRATION TEST @ 25^0C	PENETRATION VALUE (DMM)
TEST 1	27
TEST 2	26
TEST 3	26

Average penetration value is equal to 26.3

For 14% EVA (70g), the following results were obtained:

TABLE 12: SHOWING THE PENTRATION TEST VALUES FOR 14% EVA (70g)

PENETRATION TEST @ 25^0C	PENETRATION VALUE (DMM)
TEST 1	18
TEST 2	19
TEST 3	19

Average penetration value is equal to 18.67

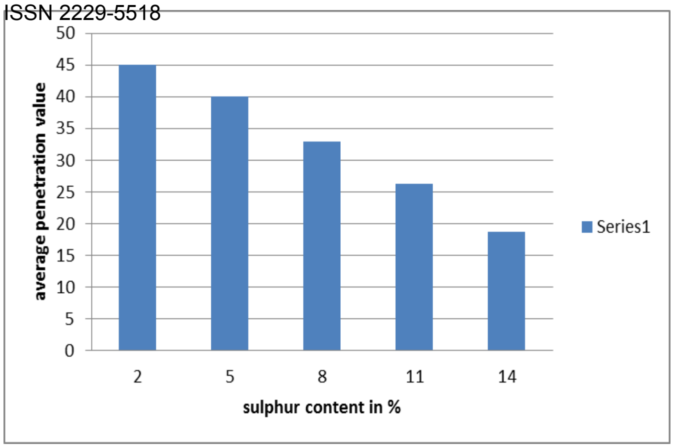

Figure: 3: Showing a plot of varying amounts of Ethylene Vinyl Acetate against the corresponding penetration values

I. The Ethylene vinyl Acetate gave the best upgrade results when 14% of EVA was used therefore, the remaining tests were carried out on the upgraded bitumen at 14% EVA polymer mixed.

II. Flash point test: The flash point test was carried out and the first flash of flame was observed and measured to have come up at a temperature of 303^0C. Therefore, the flashpoint was measured as 303^0C

III. Solubility test: Solubility test carried out on the by dissolving 2g of the upgraded Nigerian bitumen sample using 14% EVA polymer into 100ml carbon disulfide yielded the following result:
Residue weight after filtration = 0.021g
Solubility = = 98.95%

IV. Viscosity test: The viscosity test was carried out using the vacuum capillary viscometer at 135^0C and a viscosity value of 3014 centipoise was obtained.

TABLE 13: SHOWING THE TEST RESULTS FOR THE TESTS CARRIED OUT ON THE MODIFIED AND UNMODIFIED SAMPLES

TEST	UNMODIFIED NIGERIAN BITUMEN	UPGRADED WITH EVA	UPGRADED WITH SULPHUR	EUROPEAN PRODUCED BITUMEN
PENETRATION (DMM)	67.67	18.67	18.33	17.83
FLASH POINT ^{0}C	280	303	300	306
SOLUBILITY %	83.7	98.95	98.75	99

The table 13 above shows a comparison between the results obtained after carrying out the various experiments on the unmodified Nigerian bitumen, the upgraded Nigerian bitumen using EVA and Sulphur, and the European produced bitumen. It was observed that the upgraded Nigerian sample with sulphur compared most favorably with the European produced bitumen which was used as the standard.

CONCLUSIONS

After a comparative analysis carried out on the unmodified Nigerian bitumen, the EVA modified bitumen, the Sulphur modified bitumen, and the European produced bitumen, the upgrade can be said to be successful. This is because the measured properties of the upgraded Nigerian bitumen with Sulphur and EVA respectively, compared favorably with the measured properties of the European produced bitumen, which is of international standards. The use of Sulphur, Crump rubber, Ethylene Vinyl Acetate (EVA), and Stryene Butadiene Stryene (SBS) shows that the process is not so expensive in terms of the raw materials required.

5.1.2 RECOMMENDATION

Upgrading our locally produced bitumen should be encouraged rather than importing from other countries to help conserve our foreign reserves. Also in the nearest future, our locally produced bitumen could be exported to countries whose bitumen does not meet up with the international standards

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