Investigation of the Properties of "Pure Water" Sachet Modified Bitumen

Bamidele I. O. Dahunsi, Olufemi S. Awogboro*, Mutiu Akinpelu and Oladipupo S. Olafusi
Civil Engineering Department, University of Ibadan, Nigeria
*E-mail of corresponding author: olafusidipo@yahoo.com

ABSTRACT

The increasing volume of traffic loads on our roads is currently a challenge on flexible pavement design and construction. Factors such as durability, strength and economic needs have to be considered in the design and construction of road pavement. Many researches have been conducted to explore supplementary material that can make a durable asphalt pavement.

It is not unfamiliar that the modification of bitumen with the use of polymers enhances its performance characteristics but at the same time significantly alters its rheological properties.

One of the environmental issues in most regions of Nigeria is the large number of polymeric wastes made from polyethylene water sachet (PWS) popularly called "Pure Water" Nylon deposited in domestic wastes and landfills.

This study was conducted to investigate the effect of PWS on the properties of conventional bitumen and suitability of discarded PWS as bitumen modifier and to reduce the environmental effects of PWS disposal. Bituminous blends containing PWS at various percentages 2.5%, 5%, 7.5%, 10%, 12.5% and 15% weight of conventional bitumen.

Penetration, softening point and float tests were carried out on the samples to evaluate the penetration index, viscosity, stiffness modulus and the suitability of PWS as bitumen modifier. Sieve analysis and infrared spectroscopy of the shredded PWS sample were also carried out. Result obtained from tests was compared between control sample (0% PWS) and PWS modified samples.

The test results show that PWSs influence more on the penetration of the modified sample with the increase in the viscosity of the bitumen as can be observed by the decrease in the value of penetration with the increase in concentration of PWS. The penetration index values of Samples 2.5% PWS and 7.5% PWS makes them to be classified as blown bitumen and the PI value of Sample 5% PWS makes it less susceptible to temperature changes and can be classified as oxidized bitumen.

PWS is a cheap and readily available material in construction when used appropriately in bitumen and the recycling of PWS for asphalt base roads helps alleviate an environmental problem and saves energy.

Keywords: Bitumen, pure water sachet (PWS), infrared spectroscopy analysis, penetration test, softening point, viscosity test

1. INTRODUCTION

Bitumen is a viscous liquid consisting mainly of hydrocarbons of complex molecular structure. It is found as a natural deposit, as a component of naturally occurring asphalt in which it is associated with mineral matter or as a product derived from the fractional distillation of crude oil. Only a few sources of crude oil are capable of producing good quality bitumen compared with the many oil producing areas in the world. The terms bitumen and asphalt are mostly interchangeable, except where asphalt is used as an abbreviation for asphalt concrete. The thermoplastic nature (stiff when cold liquid when hot) of bitumen makes it a very useful material for road construction (including cutback bitumen and bitumen emulsions for surface dressing). It is manufactured in different viscosities, and the appropriate viscosity should be chosen for the particular material, site conditions, and proposed traffic characteristics. Bitumen (or asphalt) is primarily used, when mixed with mineral aggregates, to produce paving materials. Its other main uses are for bituminous waterproofing products, including production of roofing felt and for sealing flat roofs. Most natural bitumen contain sulfur and several heavy metals such as nickel, vanadium, lead, chromium, mercury and also arsenic, selenium, and other toxic elements. Bitumen can provide good preservation of plants and animal fossils. The paving grades of bitumen is 30/40, 60/70 and 80/100. The grade 80/100 is commonly used in Nigeria but for lower temperatures other grades are preferable.

Nigeria has abundance of bitumen. Her deposit is put at 42.74 billion metric tons. It is the second largest in the world. It covers 120 kilometers costal belts of Lagos, Ogun, Ondo and Edo States (Environment Right Action, 2003). But, the poor performance of bituminous mixtures under increased traffic volume and heavier axle load has led to the increased use and development of modified binders. Development of modified bitumen especially the use of discarded Pure Water Sachets (PWS) in pavement construction is one of the steps to reduce environmental concern in many countries. The research and development of modified bitumen (MB) began in Europe and its use has spread around the world. It has been recognized that the physical and mechanical properties and rheological behavior of conventional asphalt compositions can be improved by the addition of Polyethylene (Lu and Isaccson, 1997).

Meanwhile, almost every nook and cranny in Nigeria is littered with sachet water nylon, popularly called "pure water", the large volume of which in ordinary parlance, constitutes pollution and termed negative externality or economic 'bad' in economics. (Adetunji *et al*., 2010). This is as a result of millions of used sachets being thrown on daily basis onto the streets of virtually every city, town, and village in Nigeria. As noted by Edoga *et al*. (2008); about 70 percent of Nigerian adults drink at least a sachet of pure water per day resulting in about 50 to 60 million used water-sachets disposed daily across the country. Presently the greatest environmental problem facing developing countries, especially Nigeria, is municipal and public waste management. The cities are stinking from heavy unmanageable solid waste. Due to the present economic situation in Nigeria, water is packaged in low-density polyethylene (LDPE) sachet, this is popularly known as Pure Water. Pure Water Sachet (PWS) serves as the cheapest packaging material. It has become popular in almost all the communities but unfortunately this has led to new source of solid waste since the LDPE has extremely low rate of degradation. (Ademiluyi *et al.*, 2007). This prompted this research; to study the performance and characteristics of waste polyethylene "Pure Water" sachet as partial replacement in hot mix bitumen so as to determine its suitability for modified bitumen and for use in asphalt roads and other construction works.

2. MATERIALS AND METHODS

2.1 Sampling

The bitumen used for the entire tests were provided by the Lagos State Asphalt Yard Ojodu, Lagos State, Nigeria. The grade of the bitumen collected was 80/100. Table 1 shows the specification of the normal bitumen before it was modified. The discarded pure water sachets (PWS) used was collected in sacks (batches) from hostels, residents, restaurants and canteens within the University of Ibadan. These were sun-dried and sorted out in stacks for shredding. The dried and sorted PWS sachets were grinded to the size of a rice grain (pellets) by a milling machine as shown in figures 1 and 2. The hot mix blend of PWS and bitumen was achieved by partially replacing the bitumen with shredded PWS at 2.5%, 5%, 7.5%, 10%, 12.5% and 15% weight replacements; thereafter, heating and manually stirring the mixture at a constant rpm on a kerosene-fueled stove at a temperature range 240^oC – 295^oC for 15 minutes. The PWSMB became blended on heat at 280^oC manually and each sample placed in a stainless steel bowl and properly labeled with inscription (% replacement modified and date). The prepared samples were kept in the oven for five hours at 160^oC and brought out to cool at room temperature and hardened for 24 hours so that the mixed heated PWS and bitumen can react chemically considering the heat of exchange between the two substances.

2.2 Laboratory Tests

The tests carried out on the prepared PWS modified bitumen samples and the shredded PWS were; Sieve Analysis, Infrared Spectroscopy Analysis, Penetration Test, Softening Point and Viscosity / Float Test.

I. Sieve Analysis of Shredded PWS

This is also known as the Mechanical Analysis of Aggregates (DRY) according to BS 410. This test was aimed at analyzing the shredded PWS particles according to their aggregate (diameter). The method of dry sieving was used. The sieves were arranged such that the coarse sieve was at the top and the finest sieve at the bottom all placed on a sieve receiver. The test sample was then transferred into the top sieve and shacked for about 5minutes. The particles retained in each sieve was transferred into the crucibles and labeled. The weight of shredded PWS particles retained on each sieve (i.e. % Passing) is recorded against the corresponding diameter. The dust ratio D_R can be determined from the Particle Size Distribution curve. The grain size parameters to be considered were D_{10}, D_{30}, D_{60}, Coefficient of Uniformity C_u and Coefficient of Gradation C_c.

II. Infrared Spectroscopy Analysis

Infrared spectroscopy (IR spectroscopy) is the spectroscopy that deals with the infrared region of the electromagnetic spectrum, i.e. light with a longer wavelength and lower frequency than visible light. It covers a range of techniques, mostly based on absorption spectroscopy. As with all spectroscopic techniques, it can be used to identify and study chemicals. A common laboratory instrument that uses this technique is a Fourier transform infrared (FTIR) spectrometer.

III. Penetration Test

It is the most widely used method of measuring the consistency of a bituminous material at a given temperature. It is a means of classification rather than a measure of quality. (The engineering term *consistency* is an empirical measure of the resistance offered by a fluid to continuous deformation when it is subjected to shearing stress). The consistency is a function of the chemical constituents of bitumen, viz. the relative proportions of asphalt (high molecular weight, responsible for strength and stiffness), resins (responsible for adhesion and ductility) and oils (low molecular weight, responsible for viscosity and fluidity). The type and amount of these constituents are determined by the source petroleum and the method of processing at the refinery. Penetration is related to viscosity and empirical relationships have been developed for Newtonian materials. If penetration is measured over a range of temperatures, the temperature susceptibility of the bitumen can be established. The consistency of bitumen may be related to temperature changes by the expression

$$Log\ P = AT + K$$

Where;

P = penetration at temperature T,

A = temperature susceptibility (or temperature sensitivity)

K = constant

IV. Softening Point Test

Softening point is the temperature in which bitumen change from solid to liquid.

Bitumen is a viscoelastic material without sharply defined melting points; they gradually become softer and less viscous as the temperature rises. For this reason, softening points must be determined by an arbitrary and closely defined method if results are to be reproducible. The softening point is useful in the classification of bitumen, as one element in establishing the uniformity of shipments or sources of supply, and is indicative of the tendency of the material to flow at elevated temperatures encountered in service.

V. Float Test for Bitumen (Dynamic Viscosity)

This test method is useful in determining the consistency of bitumen as one element in establishing the uniformity of certain shipments or sources of supply. The float test characterizes the flow behavior or consistency of certain bituminous material. Normally the consistency of bituminous material can be measured either by penetration test or viscosity test. But for certain range of consistencies, these tests are not applicable and Float test is used. The apparatus consists of an aluminum float and a brass collar filled with bitumen to be tested.

The most commonly-used viscosity test on bitumen similar to float test is the Absolute Viscosity Test by Vacuum Capillary Viscometer. The standard test temperature is 60 °C. The absolute viscosity test measures the viscosity in units of Poise.

3. RESULTS AND DISCUSSIONS

I. Sieve Analysis Results

From the results of the Dry Mechanical Analysis of Aggregates for the shredded PWS samples according to BS 410; the percentage of materials passing through Sieve No. 7 (2.36mm diameter) is 51% which is the highest % passing. The % passing for Nos. 14 (1.18mm) and 25 (0.6mm) sieves are 11% and 2% respectively and the percentage sample loss is 0.05%. From the particle size distribution (PSD) curve, the grain size parameters are as follows; The Dust Ratio D_R, the value of D_{10}, D_{30} and D_{60} are 1.30, 1.70 and 2.80 respectively.

So, the value of Coefficient of uniformity C_u (i.e. the measure of the particles size range) from the formula below is 2.2 indicating that the shredded PWS particles are very uniform in size ranges. This conforms to F.M.W & H. 1970.

$$C_u = {}^{D_{60}}/_{D_{10}}$$

(Note, $C_u < 5$ – Very Uniform, $C_u = 5$ – Medium Uniformity and $C_u > 5$ – Non Uniform)

The Coefficient of gradation C_c (the measure of the shape of the particle size curve) calculated from the formula below is 0.79 indicating the PWS particles is not well graded.

$$C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$$

Note, C_c range from 1-3 means it is well graded.

II. Infrared Spectroscopy Results

Fluka library was supplied by Perkin-Elmer. Figure 4 shows the IR graph of the mirror, Frequency in wave number (cm^{-1}) on the horizontal axis and the amount of light detected, Transmittance (%T) on the vertical axis, the following results were deciphered;

i. N-H (3430): Amine N-H stretch (3500-3300). Possibility of secondary amine, since it is only one band at that value.
ii. C-H bond, Aromatic (724): Aromatics, amine and amide (900-650)
iii. C=C bond, Aromatic (1567.56): Polyolefin, Characteristic feature of aromatic
iv. Absorption peaks above 3000 cm^{-1} are frequently diagnostic of unsaturation.

From the above results, it can be assumed that the PWS sample contains Polyolefin, Secondary Polyamine and Polyamide. Also, the PWS sample can be classified as a Linear Low Density Polyethylene (LLDPE). There is still need to carry out Neutron Magnetic Radiation tests (NMR) in order to be specific on the chemical components of the waste PWS.

III. Penetration Test Results

Grading of bitumen helps to assess its suitability in different climatic conditions and types of construction. From Table 5, Sample A (0% PWS) is 80/100 grade bitumen because its penetration value is 92.7 d-mm. Sample B (2.5% PWS) is of 70/80 grade, Samples C and D are of 30/40 grade and Sample E grade 20/30 while Samples F and G belongs to the penetration grade 10/20. It was also observed that there is a consistent decrease in penetration grade with increase of modifier in bitumen sample. Non modified sample has the highest penetration grade of 92.67; thereafter, 2.5% modified sample. Furthermore, there is a sharp decrease in the trend as observed in 5% modified sample having about 51% reduction to the sample B. The penetration trend reduces in the order of their viscosity. (Fig. 5 and Fig. 6)

This means that the addition of PWS makes the modified bitumen harder and more consistent. This implies an advantage in improving the rutting resistance of the mix, but on the other hand this may affect the flexibility of the bitumen by making the asphalt much stiffer, thus the resistance to fatigue cracking can be affected.

From the results above, the following were satisfied; Samples A and B are suitable in cold climates where high penetration grade (softer consistency) is being required. Samples C, D, E, F and G of low penetration grades (harder consistency) are suitable in hot climates or used in the summer to avoid softening under high temperature. It is to be noted that Penetration values lower than 20 have been associated with bad cracking of road surfacing, while cracking rarely occurs when the penetration exceeds 30.

IV. Softening Point Tests Results

The results, chart and graph of Softening Points of the blended PWS modified bitumen are shown in Table 5, Fig. 7 and Fig. 8 respectively.

The Softening point values of the conventional bitumen (0%PWS) was 46 ^{o}C and that of the modified bitumen 2.5%, 5% and 7.5% are 79^{o}C, 82^{o}C and 95^{o}C respectively. S.P test for modified bitumen sample at 10%, 12.5% and 15% were not applicable. Softening point (S.P) of non-modified bitumen increases when modified with PWS. There was a consistent increase in the order of increasing modifier. 2.5% modified sample had about 58.2% increases in the softening point. Sample C, (5% modified PWS) had about 1.2% of S.P temperature higher than sample B. At a higher temperature, Sample D (7.5% modified PWS) had the ball falling at a temperature of 95^{o}C. Sample E, F and G was not soft enough at the boiling point temperature of water at about 100^{o}C to allow the ball to fall. High softening points were evident in Samples B, C and D. This is useful as it implies the reduction in temperature susceptibility of the bituminous material.

The results clearly showed that the addition of PWS to bitumen increases the softening point value, and as the PWS content increases the softening point also increases. This phenomenon indicated that the resistance of the binder to the effect of heat is increased and it will reduce its tendency to soften in hot weather. Thus, with the addition of PWS the modified binder will be less susceptible to temperature changes. The effect of softening point of a binder on resistance to permanent deformation, of bituminous pavement mixes, has been studied by various researchers. An example is hot rolled asphalt where it was found that the rate of rutting in the wheel tracking test at 45°C, was halved by increasing softening point by approximately 5ºC (Fernando *et al*, 1984). Therefore it is expected that the use of PWS in the bituminous mix will reduce rutting significantly due to the increased softening point.

The linear relationship between the Penetration grade and the softening point of the PWS modified bitumen is inversely proportional. The penetration grades decreased as the value of PWS increased in the blends while the values of the softening point (^{o}C) increased with respect to increase in PWS.

Penetration Index Results (Temperature Susceptibility)

From the formula below, the Penetration Index values was calculated with respect to the values of the penetration grade and softening point of the blended bitumen. (See Table 6)

$$\frac{\log 800 - \log pen}{T_{R+B} - T} = \left(\frac{20 - PI}{10 + PI}\right)\frac{1}{50}$$

Where log *pen* is the logarithm (to base 10) of the measured penetration, T_{R+B} is the softening point in degrees Celsius and T is the temperature at which the penetration test was carried out, usually 25^{o}C. The Penetration Index is an indicator of the temperature susceptibility of the asphalt. A high PI indicates low temperature susceptibility. Higher PI means harder bitumen.

From Table 5, it was estimated that the indication of the PI value of Sample A (-0.71) makes it acceptable for road bitumen grades used in construction showing some elasticity and little thixotropic.

The PI values of Samples B (5.48) and D (5.25) indicated that the samples are blown bitumen and the PI value of Sample C (4.01) indicated that the sample is non-Newtonian, showing considerable elasticity and thixotropic; less susceptible to temperature changes; this group includes oxidized bitumen.

V. Float Test Results

Viscosity rises in presence of large molecule of polymer (ASTM D5-97, 1998).

The viscosity of a liquid is the property that retards flow so that when a force is applied to a liquid, the slower the movement of the liquid, the higher the viscosity. Float test is the pure measure of consistency, where time is measured for a fixed quantity of the binder liquid to flow from a collar through a standard orifice float under an initial standard head and at known test temperature.

The float value is one of the prime characteristics for identifying "high float" asphalt emulsions. This high float characteristic enables softer asphalt materials to remain in place on the roadway without running off. The higher the float test value, the stiffer the material.

Dynamic viscosity is a measure of the resistance to flow of a liquid under an applied force, or how thick is the fluid. Modified asphalt binders are usually more viscous than unmodified ones (Aflaki *et al*, 2008). Dynamic or absolute viscosity (in Pa.s or Poise) is estimated from the float test using the Dynamic Viscosity conversion factor. Considering the variables of the Float device, the collar i.e. the wetted area of the collar (mm^2), mass of collar (g) and the float value (seconds) and converting the parameters using the following factor;

$$Kg.s/_{m^2} = 9.80664\ Pa.s = 98.06649\ poise$$

The estimated values of the dynamic viscosities of the PWS modified blends are shown in Table 5 and the corresponding relationships of viscosity with penetration, temperature and softening point values are also represented.

Viscosity increases with increasing modifier (PWS) content. If sample of low viscosity is used with the aggregates, it may flow off the stone. Conversely, if the viscosity is too high, the mix may be unworkable by the time it reaches the site. In case of handling, mixing & spraying, the lower the binder viscosity, the better it would be. In case of the low-viscosity binders, there is less chance of pipes being blocked; mixing and application temperature can be kept lower. Asphalt aggregates will be more easily coated.

Penetration is considered as a consistency parameter in the service range of bitumen temperature, while viscosity is considered a consistency parameter in the liquid phase, and thus important for the application temperature range.

4. CONCLUSION

In this study, the effect of PWS on the properties of bitumen was determined by experimental and empirical methods. For this study, 7 different modified blends were prepared by replacing bitumen with shredded PWS (by weight) and subjected to different consistency tests. The shredded PWS samples were also subjected to grading and infrared spectroscopy tests.

After the experimental studies, the empirical methods were used to estimate the necessary parameters of the modified bitumen and the PWS samples. Based on the test results and the analysis of the PWS and the blended PWS modified bitumen sample, the following conclusions can be drawn:

i. The gradation of the used shredded PWS particles showed it is very uniform in size ranges but not well graded.

ii. The infrared spectroscopy indicated that the PWS sample possibly contains Polyolefin, Secondary Polyamine and Polyamide**.** Also, the PWS sample can be classified as a Linear Low Density Polyethylene (LLDPE).

iii. The waste Pure Water Sachet showed potential for enhancing the properties of bitumen, particularly between 2.5% and 7.5%. The higher percentage blends tends to be unworkable and unstable.

iv. The low penetration grades of Samples C and D are suitable in hot climates like Nigeria or used in the dry season to avoid softening under high temperature.

v. High softening points were evident in Samples B, C and D. This is useful as it implies the reduction in temperature susceptibility of the bituminous material.

vi. The penetration grades decreased as the value of PWS increased in the blends while the values of the softening point increased with respect to increase in PWS.

vii. The Penetration Index values of Samples B and D makes them to be classified as blown bitumen and the PI value of Sample C makes it less susceptible to temperature changes and can be classified as oxidized bitumen.

viii. The stiffness modulus of blends was estimated from nomograph considering the values of penetration, softening point, temperature and loading time.

ix. This high float characteristic of the PWS modified bitumen enables softer asphalt materials to remain in place on the roadway without running off. The higher the float test value, the stiffer the material**.**

x. The dynamic viscosity of the modified bitumen increased with increasing modifier (PWS) content.

xi. PWS is a cheap and readily available material in construction when used appropriately in bitumen.

xii. It is obvious from the observation that PWS influence more on the penetration with the increase in the viscosity of the bitumen as can be observed by the decrease in the value of penetration with the increase in concentration of PWS.

5. RECOMMENDATIONS

From the observations made and laboratory results obtained, the following recommendation should be taken into consideration:

i. Studies should be carried out on the effect of variation of grain sizes of the PWS.

ii. Polymeric wastes produced as by-products in polymer plants are annoying waste which should be recycled or reused safely.

iii. Adequate and necessary bitumen testing equipment must be readily available for effective research purposes.

iv. There is need to carry out Neutron Magnetic Radiation tests (NMR) in order to be specific on the chemical components of the waste PWS and to study the thermal degradation behavior of the waste PWS using the Thermal Gravimetric Analyzer (TGA).

v. The blends that showed promise should be subjected to further detailed investigation to evaluate their performances in an asphaltic mix.

vi. The waste PWS menace should be tackled, be recycled and be fully integrated as a construction material.

vii. The aging of the PWS modified bitumen must be performed and other necessary tests should be carried out so as to compare the present performance results to the forecasted (modeled) performance results.

REFERENCE

[1] Ademiluyi, T. and Adebayo, T. A. 2007. Fuel gases from pyrolysis of waste Polyethylene sachets: J. Appl. Sci. Environ. Manage. JASEM ISSN 1119-8362. Vol. 11 (2) 21 - 26. June 26, 2007. Full-text Available Online at www.bioline.org.br/ja

[2] Adetunji M. B. and Ilias B. M. 2010. Externality Effects of Sachet Water Consumption and the Choice of Policy Instruments in Nigeria: Evidence from Kwara State.: Journals of Economics, 1 (2): 113-131

[3] Aflaki, S. and Tabatabaee, N. 2008. Proposals for modification of Iranian bitumen to meet the climatic requirements of Iran. Journal of Construction and Building Materials, vol. 2, No. 1. 1-10

[4] ASTM. 1998. ASTM D5-97 Standard test method for penetration of bituminous materials. 1998. Annual Book of ASTM Standards, Volume 04.03, American Society for Testing and Materials, Philadelphia 19103-1187.

[5] Edoga M. O., Onyeji L. I., Oguntosin O. O. 2008. Achieving Vision 20:2020 through Waste Produce Candle. Journal of Engineering and Applied Sciences, 3(8): 642-646.

[6] Environmental Rights Action. 2003. FALSE START IN THE BITUMEN BELT: "Livelihoods and Bitumen Exploitation in Nigeria": Proceedings from The Environmental Rights Action /Friends of the Earth, Nigeria (ERA/FoEN) two-day National Consultation on Bitumen Exploitation in Lagos Nigeria. November 6-7 2003.

[7] F.M.W & H. 1970. General Specification for Roads and Bridges. Federal Ministry of Works, Nigeria. 1970

[8] Lu X and Isacsson U. 1997. *Journal of Construction and Building Material.* Nov. 23, 1997.

Figure 1 drying, sorting and stacking of PWS

Figure 2 Shredded PWS used for modification

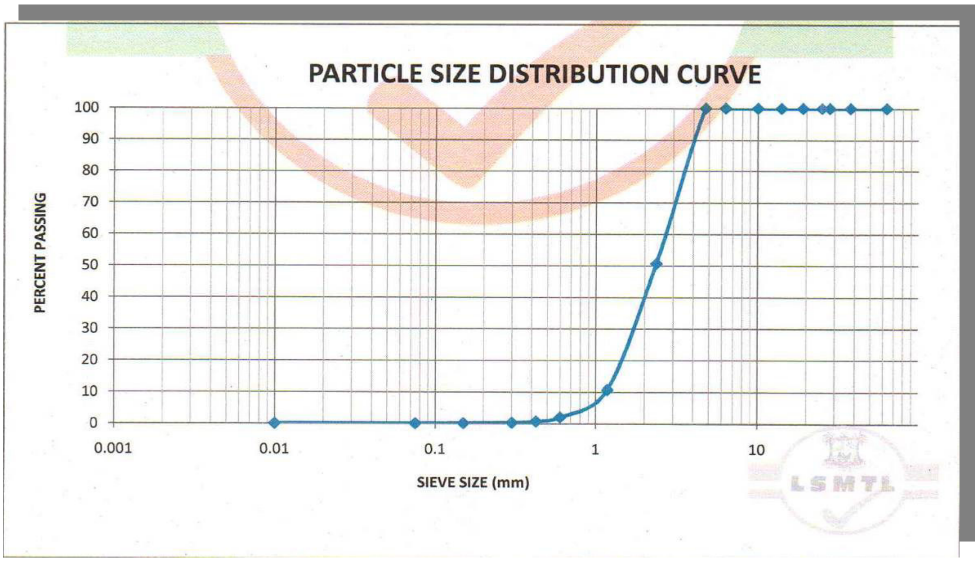

Figure 3 PSD Curve of PWS sample used

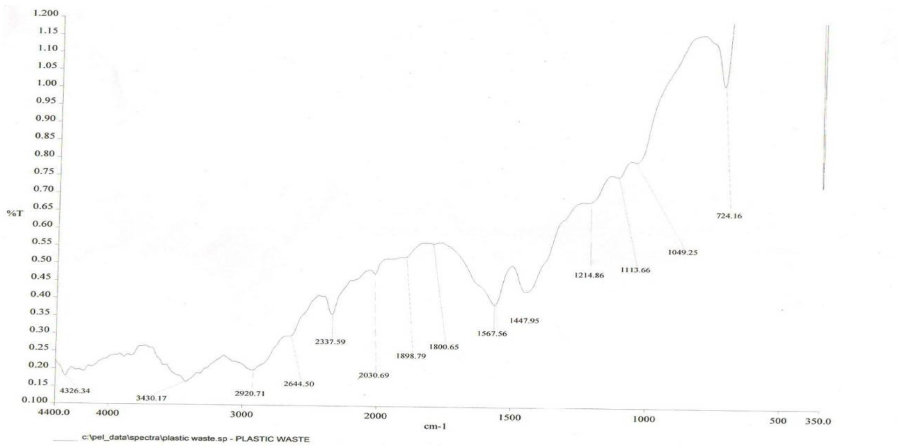

Figure 4 IR graph of Transmittance (%T) against Frequency (cm^{-1})

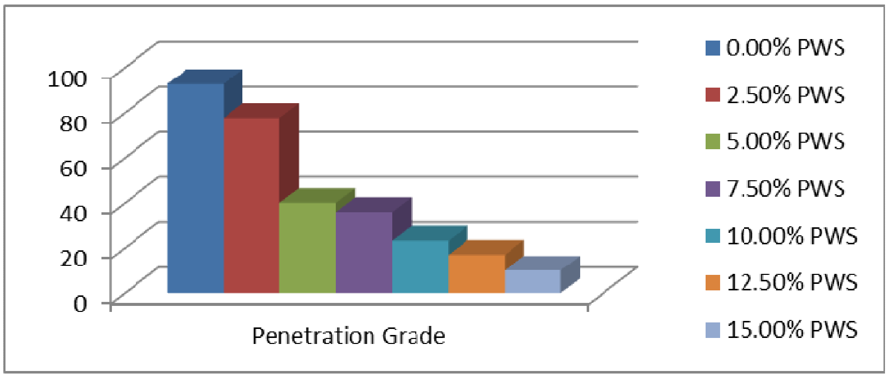

Figure 5 Chart of Penetration Test results for %PWS Modified Bitumen

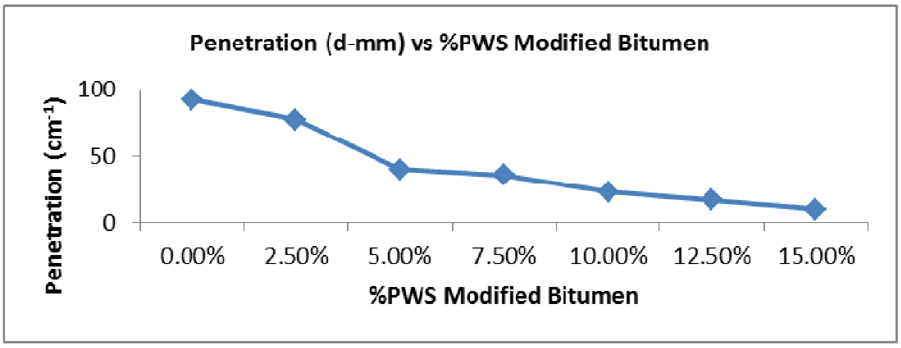

Figure 6 Graph of Penetration (d-mm) against %PWS Modified Bitumen

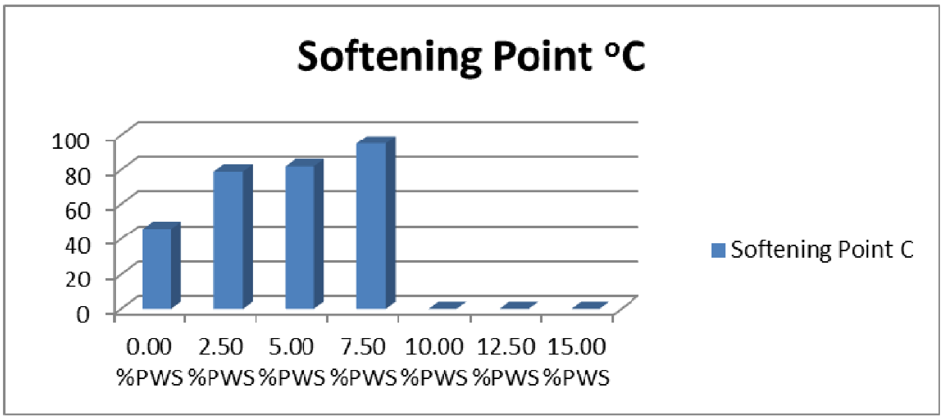

Figure 7 Chart of the Softening Point Test results for %PWS Modified Bitumen

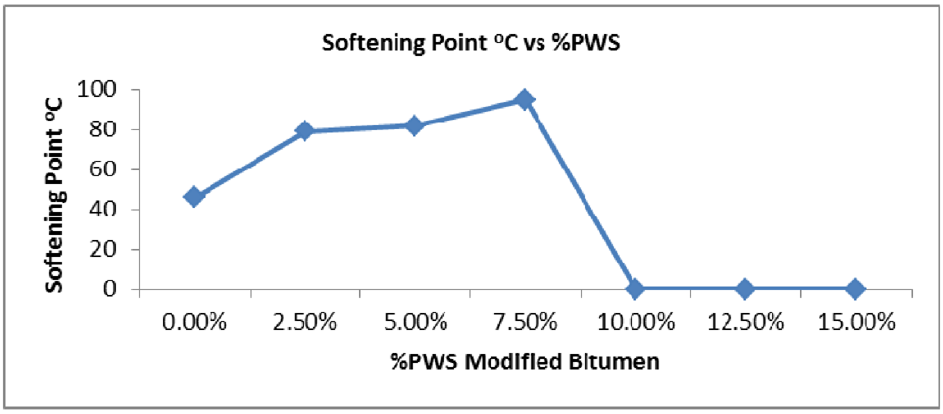

Figure 8 Graph of Softening Point (°C) against %PWS Modified Bitumen by weight

Table 1 Specification of Bitumen Provided (Unmodified)

Bitumen 80/100	
Test Method	**Specification**
Specific Gravity @25 C	1.01-1.05
Penetration @ 25C	80/100
Ductility @ 25 C	100 min
Loss on heating (wt)%	0.5 max
Drop in penetration	20 max
Flash point C	232 max
Solubility in CS_2 (wt)%	99.5 min
Softening point °C	41 min – 51 max

Source: Lagos State Asphalt Yard, Ojodu

Table 2 Percentages at which Normal Bitumen was modified with shredded PWS

Sample No	**Normal Bitumen (%)**	**Polyamides Used (%)**	**Modified Bitumen**
A	100	0	Not Modified
B	97.5	2.5	2.5%
C	95	5	5%
D	92.5	7.5	7.5%
E	90	10	10%
F	87.5	12.5	12.5%
G	85	15	15%

Table 3 Sieve Analysis of the Shredded PWS

Weight Retained	% Retained	Sieve Size	% Passing
0.00	0.00	63.00	100
0.00	0.00	37.50	100
0.00	0.00	28.00	100
0.00	0.00	25.00	100
0.00	0.00	19.00	100
0.00	0.00	14.00	100
0.00	0.00	10.00	100
0.00	0.00	6.30	100
0.00	0.00	4.75	100
247.2	49.38	2.36	50.62
200.16	39.99	1.18	10.63
43.31	8.65	0.60	1.98
6.54	1.31	0.425	0.67
2.05	0.41	0.30	0.26
0.93	0.19	0.15	0.07
0.28	0.06	0.075	0.02
0.09	0.02	PAN	0.00
500.56	**100**		

Table 4 Percentage Sample Loss

Weight of Original Sample (g)	**500.82**
Weight of Sample Loss (g)	0.26
Sample Loss (%)	0.05

Table 5 Summaries of All Relative Variables (Properties) of the Modified PWS Bitumen

Sample	%PWS	Penetration (d-mm)	Softening Point (^oC)	Penetration Index (P.I) (mm)	Float (seconds)	Temperature of Float (C)	Stiffness modulus (Sb) (N/m2)	Viscosity (Dynamic) (Pa.s)
A	0.00%	92.7	46	-0.71	796	60	5.00E+07	7.65E+04
B	2.50%	77.67	79	5.48	2647	78	6.00E+06	2.54E+05
C	5.00%	40	82	4.01	3109	85	6.00E+06	3.00E+05
D	7.50%	36	95	5.29	3796	92	4.00E+07	3.64E+05
E	10.00%	23.17	N/A	N/A	Resist flow	>100	N/A	N/A
F	12.50%	17	N/A	N/A	Resist flow	>100	N/A	N/A
G	15.00%	10	N/A	N/A	Resist flow	>100	N/A	N/A

Table 6 Relationship between Penetration grade and Softening Point

Sample	%PWS	Penetration (d-mm)	Softening Point (^oC)
A	0.00%	92.7	46
B	2.50%	77.67	79
C	5.00%	40	82
D	7.50%	36	95
E	10.00%	23.17	N/A
F	12.50%	17	N/A
G	15.00%	10	N/A