PERFORMANCE EVALUATION OF BITUMEN MODIFIED WITH WASTE POLYETHYLENE WATER SACHETS

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ABSTRACT

In recent times, consumption of sachet water has increased tremendously in Nigeria. However, due to its non-biodegradable nature, the disposal of waste polyethylene water sachet (WPSW) constitutes an environmental problem. This research seeks to explore the potential of using waste polyethylene water sachet made of "Low Density Polyethylene" (LDPE) in improving the desirable properties of bitumen in our country Nigeria. The materials collected were pure water sachets and bitumen. Investigation carried out are penetration test, softening point test, flash point and fire point tests, ductility test, as well specific gravity for both conventional and modified bitumen to ascertain their properties. The bitumen was modified at 0%, 2%, 4%, 6% and 8% by weight of bitumen respectively for each of the experiments mentioned above. Penetration decreases from 68.89mm to 68.33mm, softening point increased from 48.50 °C to 70.50°C, Flash and Fire Point Test increased from 230°C to 276°C, 256°C to 307°C, Ductility test increased from 105.00mm to 118.67mm, while specific gravity increases from 1.040 to 1.050. From the results it showed that modified bitumen had improved properties in terms of load bearing capacity, safety, and ability to withstand heavy traffic, and road construction cost than conventional bitumen. One-Way analysis of variance (ANOVA) carried out statistically on the results of the modified bitumen showed that the WPSW had a significant effect on all the properties except for specific gravity.

Keywords: Pure Water Sachet Waste, Bitumen, ANOVA analysis.

INTRODUCTION

Increase in the amount waste pure water sachet is one of the environmental pollution problems facing our country Nigeria. As such, modification of bitumen using water sachet as modifier will go a long way in reducing the effect of this waste in our environment. According to Dahlbo, (2018); Melotti, (2013) Only about 30 percent of plastic are been received and recycled by plastic recycling facilities, while 70 percent end up been discarded in landfills. Flexible pavement properties can be improved through the use of this waste as a modifier. Waste polyethylenes water sachet (WPSW) are low density polyethylene (LDPE) material that has extremely low rate of degradation (Ademiluyi et al., 2007).

Bitumen is a semi-solid, black sticky and highly viscous form of petroleum. It may be refined from crude oil or found in natural deposit also known as pitch (Jones et al., 2011). Bitumen is a dark black semisolid material, obtained from the atmospheric and vacuum distillation of crude oil during petroleum refining. Being a thermoplastic visco-elastic adhesive, it is mainly used for pavement construction, primarily because of its good waterproof properties and cementing power (Rozeveld et al., 1997). According to Smith et al., (2018), conventional bitumen exhibits low tensile strength and high temperature susceptibility, making it susceptible to cracking and rutting. Holy and Remisova (2019) showed that methods of production and nature of crude oil from which it was derived affect the initial behaviour of bitumen. According to Chen et al., (2018), permanent deformation under loading, rutting resistance are being enhance through the use of polythene modification of bitumen. It is estimated that Nigeria has about 42.72 metric tons of bitumen deposit which is the second largest in the continent. It covers 120 kilometers costal belts of Edo, Ondo, Ogun and Lagos States respectively (Environment Right Action, 2003).

Bitumen modification using polymer has been found to be more useful than the unmodified one due to its improved breaking points, fatigue life, softening points, aging resistance and increased life of the overlay, resulting in decrease in maintenance cost (Tayfur et al., 2007, Isacsson et al, 1998, Gorkem and Sengoz, 2009, Alatas and Yilmaz 2013, Ponniah and Kennepohl, 1996 and Von Quintus et al, 2007). It is utilized as a binding agent when constructing roads and sometimes for roof covering. Typically, when at ambient temperature, bitumen is delicate; having a density value yielding to $1 g/cm^3$ while at high temperature it moves just like a sticky fluid. Primarily, bitumen is composed of approximately one percent nitrogen, one percent oxygen and three percent sulphur plus ninety five percent hydrogen and carbon. As well, they are very compacted polycyclic chain like hydrocarbons. With a boiling point of 977 ^{0}f and the largest fraction of crude oil (Wu et al., 2021). Bitumen modified with polymer appears to have the potential for successful design and application for pavement to improve the durability and service life of pavement or to reduce the pavement base thickness or layer thickness. Ahmadinia et al., (2012) investigated the cracking resistance of polythene-modified bitumen and observed improved resistance to thermal cracking.

Presently, with technological advancement and the ever-growing population, the continuous increase in traffic cannot be over emphasized, particularly in terms of automobiles. Also, global warming problem has left us with no other option than to discover better alternatives that will bring about enhancement of asphalt pavement features by making use of some essential alternatives which addresses both structural durability and economic viability. Hence, this has led to the development of modified bitumen, by introducing polymeric substance (the use of WPSW). This research is trying to fill gap by using statistical analysis to determine the reliability of the result, beyond descriptive comparison.

MATERIALS AND METHODS

Materials for this research are as follows:

i. Pure water sachet waste
ii. Bitumen

Pure water sachet waste was sourced from Hostels at Federal Polytechnic, Bida and its environs, while the binder (bitumen) was obtained from ARAB Contractors Construction Company, Ltd, Bida, Niger State, Nigeria.

The following tests were carried out in accordance to the (ASTM) standard specifications, in Civil Engineering Department Laboratory, The Federal Polytechnic, Bida, penetration test, softening point test, ductility test, flash and fire point test and specific gravity test. The discarded pure water sachet waste (PWSW) used was collected in sacks from Hostels. These were sun dried and sorted out in sacks for shredding. One-Way Statistical Analysis of Variance (ANOVA) was also carried out.

Penetration Test: The softness or hardness of bitumen binder is measured through penetration test, so as to know in one tenth of millimeter (0.1 mm) in which a loaded standard needle will vertically penetrate in 5 seconds, maintained at a temperature of 25 ^{o}C in a bitumen sample (ASTM D5, 2005). Penetrometer set up is consists of a needle assembly with a total weight of 100 g and a mechanism for releasing and locking in any position. The bitumen is heated to a pouring consistency, stirred thoroughly and poured into containers at a depth at least 15 mm in excess of the expected penetration. The test should be conducted at a specified temperature of 25 ^{o}C.

Softening Point Test: To know the degree of softness or hardness of bitumen, softening point test is the test used to denotes the particular temperature a bitumen will reach to start behaving like less solid or more like liquid under standard test (ASTM D36/D36M, 2009). Ball and Ring apparatus is used to conduct this test. A brass ring containing test sample of bitumen is suspended in liquid like water or glycerin at a given temperature. A steel ball is placed upon the bitumen sample and the liquid medium is heated at a rate of 5 ^{o}C per minute. Temperature is noted when the softened bitumen touches the metal plate which is at a specified distance below.

Flash and Fire Point Test: Flash and fire point test helps us to the safe temperature at which bitumen sample can be exposed to. It also determines the temperature at which bituminous material is at risk of catching fire. In accordance to (ASTM D92, 2005). Cleaveland Open Cup (COC) apparatus is used to determine this test. Heat the bitumen sample gradually in the Cleveland Open Cup, an ignition source is passed horizontally over the surface of the liquid while the liquid and cup are being heated. Apply a test flame at intervals; the flash point is when a brief flame appears, and the fire point is when the sample ignites and burns continuously for 5 seconds.

Ductility Test: Is a test carried out to determine how long in centimeter (cm) bitumen can stretch before breaking in standard specification (ASTM D113, 2007). The bitumen sample is heated and poured in the mould assembly placed on a plate. These samples with moulds are cooled in the air and then in the water bath at 27 °C temperature. The excess bitumen is cut and the surface is leveled using a hot knife. Then the mould with the assembly containing sample is kept in the water bath of the ductility machine for about 90 minutes. The sides of the moulds are removed, the clips are hooked on the machine and the machine is operated. The distance up to the point of the breaking of thread is the ductility value which is reported in cm.

Specific Gravity: Bitumen specific gravity can be defined as the ratio of the mass of given volume of bitumen of known content to the mass of the equal volume of water at 27 °C. It can be determined using a pycnometer and an ultra-precision weighing scale to nearest 0.001 g of a material (bitumen / modifier) with respect to water is a ratio of the mass of a given volume of that material at 25 °C to that of an equal volume of water at the same temperature. This test helps us to know if a material is relatively denser or lighter than liquid it is submerged, in this case, the liquid is water.

RESULTS AND DISCUSSION

Table 1: Test Conducted on Conventional Bitumen

S/N	Test Conducted	Unit	Result	Specification
1	Penetration	0.1mm	68.89	60/70
2	Softening point	°C	48.50	48-56
3	Ductility @ 25°C	cm	105.00	100 min
4	Specific gravity	NIL	1.040	1.01-1.06
5	Flash-point	°C	230	232 min
6	Fire-point	°C	256	NIL

The results of the consistency test carried out on conventional bitumen are shown in Table 1. It is observed that the entire tests conducted fall within the specification by Nigerian General Specification for Road and Bridges, 2016. A grade of 60/70 bitumen means the penetration value is in the range 60 to 70 at standard test conditions. In hot climates, a lower penetration grade is preferred. As such, the bitumen can be used for traffic design.

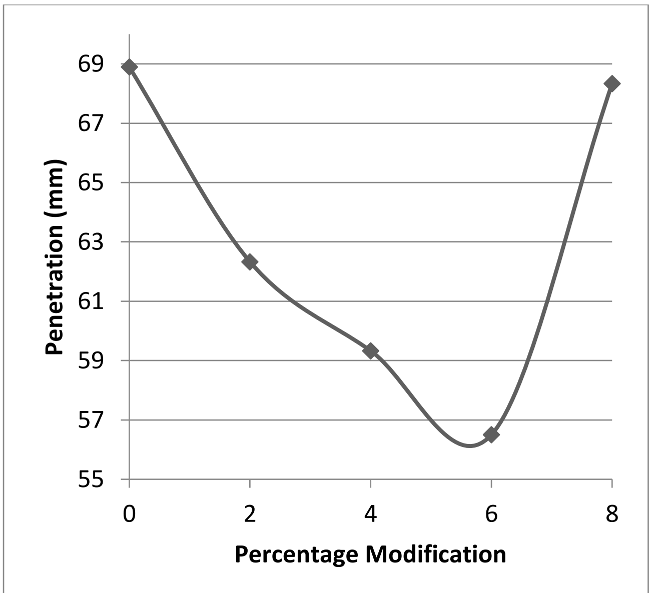

Figure 1: Penetration test.

In Figure 1, addition of Waste polyethylene water sachet (WPSW) at 2, 4 and 6 percent modification decreases the value from 62.33 to 56.50 while at 8 percent, it increased to 68.33. The decrease in penetration indicates that the modification of conventional bitumen becomes harder and more resistance to deformation with increase in WPSW. Similar trend was observed in the work of (Razali et al., 2018), (Ho-Fai et al., 2021) who works on laboratory performance comparison of polypropylene (PP) modified bitumen with different additives.

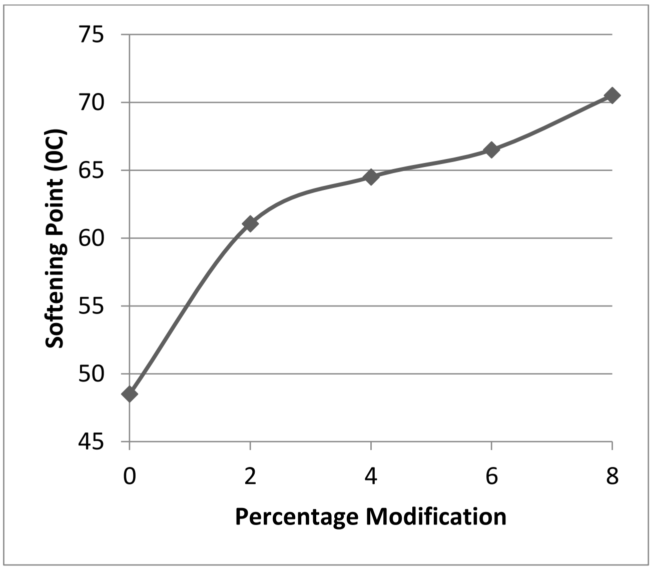

Figure 2: Softening Point.

The softening point had an increase in temperature as WPSW increases in percentage from 0 to 8 percent modification. The temperature of the softening point increase from 48.50 ºC to 70.50 ºC a as shown in figure 2. The addition of WPSW improves the thermal resistance of the modified bitumen. These in turn make the modified bitumen to become less susceptible to softening at an elevated temperature. This trend was equally observed in the work of (Khan and Gundaliya, 2011), (Arvin and Mishra, 2020), (Al-Hadidiy and Yi-Qui, 2009) who all observed that the temperature of modified bitumen increased as compared with conventional bitumen.

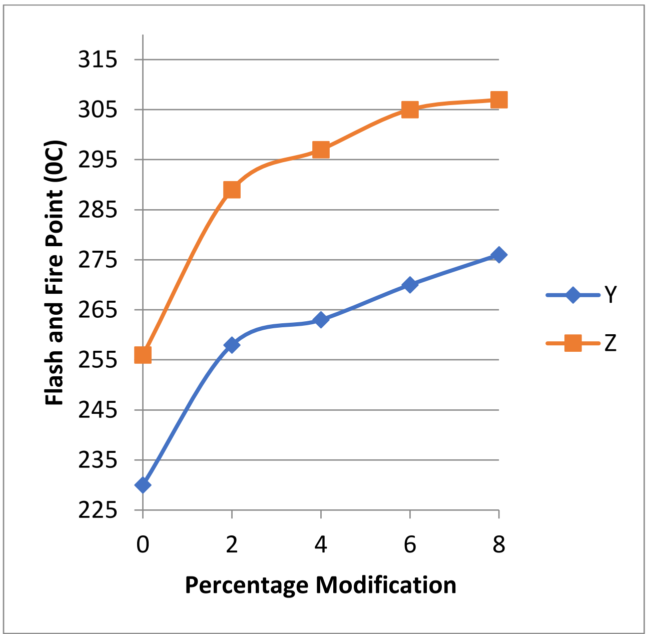

Figure 3: Flash and Fire point.

From Figure 3, it was observed that flash and fire point test values increases from 230 ºC to 276 ºC and 256 ºC to 307 ºC as per increase in the percentage of WPSW in modified bitumen. This implies improve in heat bearing capacity of the modified bitumen (Arvin and Mishra, 2020)

From Figure 4, shows that ductility of bitumen decreases slightly with an increase in WPSW. At 0 to 2 percent modification, the values drop to from 105 cm to 92.61 cm which indicate reduction in elongation capacity (the brittleness increase and elongation ratio ductility decreases). While at 4, 6 and 8 percent modification, there was an increase in ductility value beyond standard stipulated value making it slightly stiffer but still maintaining adequate flexibility (Ho- Fai et al., 2021). 2-4 % provide moderate level of modification that gave an optimal balance between enhanced stiffness for rutting resistance and sufficient flexibility to prevent cracking.

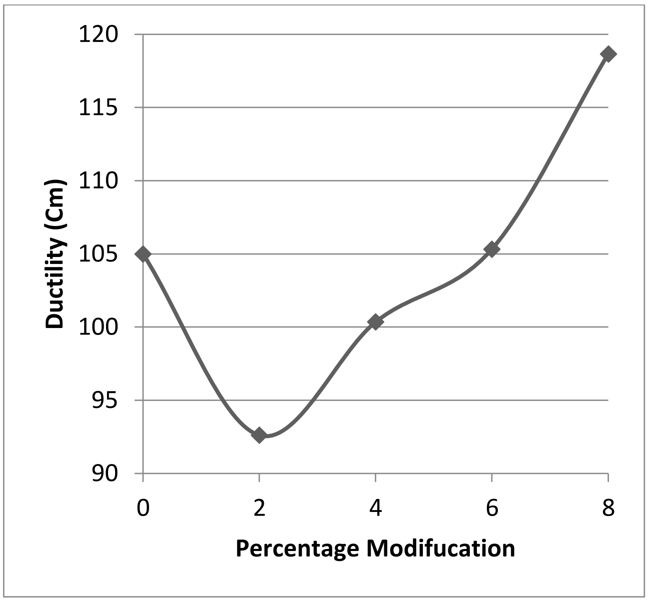

Figure 4: Ductility.

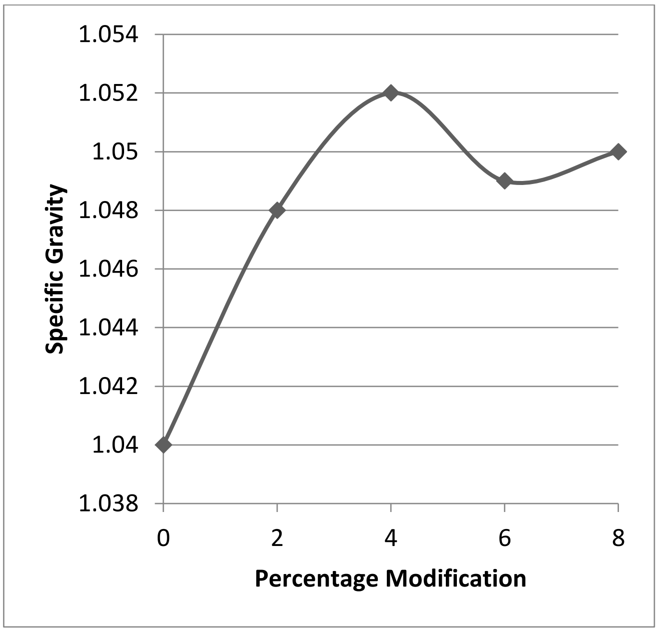

Figure 5: Specific Gravity.

The specific gravity results in the Figure 5, shows that the percentage modification increases the specific gravity of the bitumen. The specific gravity of the unmodified bitumen, at zero percent modification is 1.04. At 2 percent modification, the specific gravity result was 1.048. The incorporation of pure water sachet waste into bitumen enhanced the specific gravity of the bitumen.

Result of One-Way Analysis of ANOVA for Modified Bitumen

Table 2: One-way ANOVA on the properties of the modified bitumen

MODIFIER CONTENT (%)	PENETRATION (mm)	SOFTENING POINT (ºC)	FLASH POINT (ºC)	FIRE POINT (ºC)	DUCTILITY (cm)	SPECIFIC GRAVITY
0	68.89	48.50	230	256	105.00	1.04
2	62.33	61.05	258	289	92.61	1.048
4	59.33.	64.50	263	297	100.35	1.052
6	56.50	66.50	270	305	105.33	1.049
8	68.33	70.50	276	307	118.67	1.050
F calculated	438.329	215.3609	936.4093	749.5773	503.5952	4.357733
F critical	5.317655	5.317655	5.317655	5.317655	5.317655	5.317655
P value	2.84×10^{-8}	4.57×10^{-7}	1.41×10^{-9}	3.41×10^{-9}	1.65×10^{-8}	0.070289
Comment	Significant effect	Significant effect	Significant effect	Significant effect	Significant effect	No Significant effect

The outcome of statistical analysis that is, one-way ANOVA at a 95 % confidence level and 5 % significance level on both conventional and modified bitumen are shown in Table 2, for penetration, softening point, flash and fire point, ductility and specific gravity respectively. In one way ANOVA if F calculated is greater than F critical and P value is less than 0.05, it implies that it has significant effect. As observed from Table 2, it has significant effect on all the properties except for specific gravity which has no significant effect.

CONCLUSION

From this research work, the following conclusions were drawn:

1. Reduced penetration values from 68.89 mm to 56.50 mm indicating improved hardness and more resistance to deformation, softening point from 48.50 ºC to 70.50 ºC implies that it would be less susceptible to temperature, flash and fire point from 230 ºC to 276 ºC and 256 ºC to 307 ºC implies that it can withstand higher temperature, ductility from 105 cm to 118.67 cm implies increase in load bearing capacity of the modified bitumen.

2. At 5 % significant level since the P value is less than 0.05 (significant value < 0.05), one way ANOVA had a significant effect on the modifier, except for specific gravity.

RECOMMENDATION

A 6 % blending ratio is recommended as the optimum level for modification, as it provides the best balance between penetration (stiffness), ductility, and temperature resistance without compromising workability. This will help greatly in reducing non-biodegradable waste in the environment and equally reduce the cost of road construction.

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