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Assessment of Suitability of Plastic Waste in Bituminous Pavement Construction

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Abstract
The use of plastic products is on the increase daily. The disposal of plastic wastes is a problem in many developing countries like Ghana. These are non-biodegradable products that pose environmental pollution problems to mankind. If these materials can be suitably utilized in road construction, the pollution and disposal problems may be partly reduced. In recent years, applications of plastic wastes have been considered in road construction with great interest in many developing countries. These plastic wastes are compatible with bitumen at specified conditions. This research aims at determining the suitability of using waste plastic materials as modifiers in bituminous road pavement construction. The waste polymer-bitumen blend was prepared in various proportions and the rheological properties determined in the laboratory. The results indicate that the properties of polymer-modified AC-10 viscosity graded bitumen were enhanced with better binding properties, and can be used in asphalt concrete pavement construction with improved quality and savings.
Keywords: Non-Biodegradable, Plastic Waste, Polymer-modified, viscosity graded.

1. Introduction

Bitumen is any viscous or solid mixtures of hydrocarbons that occur naturally in asphalt, tar, mineral waxes, used as road surfacing and roofing materials. In other words bitumen can be defined as any of various flammable mixtures of hydrocarbons and other substances found in asphalt and tar, and occur naturally or are produced from petroleum and coal.

Bitumen is mainly used by the asphalt industry for the construction of roads and other surfaces but also finds its use in many other industries and applications. It is estimated that the current world use of bitumen is approximately 102 million tons per year. Approximately 85% of all the bitumen produced is used as the binder in asphalt for road construction. It is also used in other paved areas such as airport runways, car parks and footways.

The modification of bitumen involves the addition of certain substances or chemicals to bitumen in order to improve upon its properties. Quite frequently, bitumen is modified in order to adapt its properties to the requirements of the individual application.

Normally, the production of asphalt involves blending fine aggregate, crushed rock with bitumen, which acts as the binding agent. Materials, such as polymers, may be added to bitumen to alter its properties according to the application for which the asphalt is ultimately intended. Road authorities throughout the world are now realizing that it is a very good business to use modified bitumen in new road projects. It simply saves a lot of money on the medium and long term because the roads are less exposed to defects. This reduces maintenance costs, which is not only a financial problem but also a traffic problem as roads have to be partly closed for remedial works.

Waste plastics (polythene water sachets, polythene carry bags etc.) are thermoplastic polymers and very common in Ghana. They become plastic wastes after usage of contents. Thermoplastic materials are non-biodegradable; however the deposition of these plastic wastes at a dumping site may not be of any significance but can rather be recycled. However, these thermoplastic materials cannot only be recycled into various plastic products, which can still pose the same disposal problems, but can also be used as a bitumen modifier. Vasudevan and Rajasekan, (2007), stated that polymer bitumen blend is a better binder compared to conventional bitumen. The use of waste plastic as a modifier in bituminous mixtures will not only enhance the properties of mix, but will also, solve the plastic waste disposal problems that have engulfed nations thereby improving the sanitation systems and also create employment for the collectors of it.

2. Literature Review

In recent years, research on the application of modified bitumen binders has reported lots of advantages. These advantages include improved bitumen resistance to rutting due to high viscosity, high softening point and better resilience, improved bitumen resistance to surface initiated cracks, the reduction of fatigue or reflection cracking, the reduction of temperature susceptibility, improved durability as well as the reduction in road pavement maintenance costs. A study on the thermal behaviour of polymers show that on heating at 130-160 ^oC, plastics such as Polyethylene (PE), Polypropylene (PP), and Polystyrene (PS) soften and exhibit good binding properties. As plastics are heated to a maximum temperature of 165 ^oC, there is no evolution of harmful gas. However, when heated above 270 ^oC, plastics get decomposed and above 750 ^oC, they get burnt to produce noxious gases (Amos, 2011). Afroz et al (2012), in their research reveal that polymer modified bitumen shows improved rheological properties for highway construction. In the construction of flexible pavements, bitumen plays the role of binding the aggregates together by coating over the aggregates. The bitumen as a binder also helps to improve the strength and life of road pavements. But its resistance towards water is poor, whereas polymer modified bitumen has better resistance to temperature and water.

(Zoorob & Suparma, 2000) reported the use of recycled plastics composed predominantly of low density polyethylene (LDPE) and polypropylene (PP) in conventional bituminous concrete mixtures with improved durability and fatigue life. Apurva & Chavan, (2013) in their research, showed that polymer-bitumen blend helps to have a better binding of bitumen with plastic coated aggregate due to increased bonding and increased area of contact between polymers and bitumen. The polymer coatings also reduce voids. This prevents the moisture absorption and oxidation of bitumen by entrapped air. This has resulted in reducing rutting, raveling and pothole formation.

Sreedevi & Salini, (2013) investigated pavement performance on roads surfaced using bituminous mixtures with coated aggregates and concluded that, the use of waste plastic for road construction can save the environment, increase the service life of roads, reduce the consumption of petroleum products and serve the society with additional income for those associated with it.

3. Aim and Objectives of the Study

3.1 Aim: To determine the suitability of using waste plastic materials as modifiers in bitumen for bituminous pavement construction.

3.2 Objectives

(1) To investigate the properties of polymer-modified bitumen;
(2) To compare the properties of polymer-modified bitumen with conventional bitumen in order to ascertain its usefulness in bituminous pavement construction in Ghana.

4. Materials and Methods

4.1 Materials

The polymer used for modification was Low Density Polyethylene (LDPE). These polymers are waste plastic sachets that were collected from households in the community for this research. The plastic sachets were shredded into fine pieces (2-3mm size). The processed plastic was used as an additive with heated AC-10 bitumen in different proportions (ranging from 0 to 3%) by weight of bitumen. The raw bitumen was first heated up to temperature of 160-170^{o}C and the shredded pieces of modifier added slowly to the hot bitumen and the mixture stirred manually for about 35 minutes, keeping the temperature constant.

4.2 Methods

Laboratory studies were conducted on both raw bitumen and modified bitumen in their different proportions to determine their properties. The tests that were conducted include Penetration test, Softening Point test, Absolute Viscosity test, and Kinematic Viscosity test.

4.2.1 Penetration test

This test is conducted using the penetrometer according to ASTM D5 [ASTM, 2001]. Penetration test measures the hardness or softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in five seconds. Greater value of penetration indicates softer consistency. A standard needle of a total load of 100 g is applied to the surface of the bitumen sample at a temperature of 25 °C for 5 seconds. The amount of penetration of the needle at the end of 5 seconds is measured in units of 0.1 mm (or penetration unit). Softer bitumen will have a higher penetration, while harder bitumen will have a lower penetration.

4.2.2 Softening Point test

Softening point is used in the classification of bitumen and is indicative of the tendency of the material to flow at elevated temperatures encountered in service. The softening point is determined by the use of the Ring and Ball apparatus according to ASTM D36-95. Generally, higher softening point indicates lower temperature susceptibility and is preferred in warm climates. The softening points were determined for the modified bitumen in their various proportions and the results tabulated.

4.2.3 Viscosity test

Viscosity is defined as the ratio between the applied shear stress and induced shear rate of a fluid. The viscosity test is used to measure the consistency of bitumen at some specified temperatures (60^{o}C and 135^{o}C) and used to designate grades of bitumen. The lower the viscosity of bitumen, the faster the bitumen will flow under the same stress.

(i) *Kinematic viscosity test*: It was used to measure the ability of the modified bitumen to resist flow at a higher temperature. The Kinematic Viscosity was determined for all mix proportions of the modified bitumen at the specified temperature of 135^{o}C according to ASTM 2170 [ASTM, 2006] in units of Stokes.

(ii) *Absolute Viscosity test*: It was used to measure the ability of the modified bitumen to resist flow at a lower temperature of 60°C in accordance with ASTM 2171 [ASTM, 2006] in units of Poise.

4.2.4 Operationalization of Variables

The following variables were operationalized and measured as stated below.

(i) Penetration test: It was used in classifying the grades of both raw and modified bitumen.

(ii) Softening point test: It was used to measure the tendency of the bitumen (raw and modified) to flow at elevated temperatures encountered in service.

(iii) Kinematic viscosity test: It was used to measure the ability of the bitumen (raw and modified) to resist flow at a higher temperature.

(iv) Absolute viscosity test: It was used to measure the ability of the bitumen (raw and modified) to resist flow at a lower temperature

5. Laboratory test results

The results of the laboratory investigations are presented in Tables 1 to 4.

(i) Penetration Test

Table 1: Penetration test results at 25⁰C

Percentage of polymer	Raw(0)	0.5	1.0	1.5	2.0	2.5	3.0
Mass of Polymer (g)	-	2.5	5	7.5	10	12.5	15
Penetration at 25⁰C	123.5	113.3	111.1	100.2	95.1	76.9	57.1

(ii) Softening Point Test

Table 2: Softening point test results (at 4°C)

Percentage of polymer	Raw (0)	0.5	1.0	1.5	2.0	2.5	3.0
Mass of Polymer (g)	-	2.5	5.0	7.5	10.0	12.5	15.0
Softening Point (°C)	49.5	51.6	53.7	54.2	54.8	55.7	56.1

(iii) Kinematic Viscosity Test

Table 3: Kinematic Viscosity Test Results at 135⁰C

Percentage (%)	Raw (0)	0.5	1.0	1.5	2.0	2.5	3.0
Mass of Polymer (g)	-	2.5	5.0	7.5	10.0	12.5	15.0
Kinematic Viscosity,(cSt)	230.5	287.5	302.5	347.5	368.7	389.7	420.7
Shear stress	97.5	102.9	106.3	118.1	128.6	135.1	248.4
Shear rate	34.0	36.9	38.7	41.6	43.6	46.7	48.1
Shear (%)	11.5	12.8	13.6	15.7	17.9	18.7	20.4

(iv) Absolute Viscosity Test

Table 4: Absolute Viscosity test results at 60⁰C

Percentage of polymer	Raw (0)	0.5	1.0	1.5	2.0	2.5	3.0
Mass of Polymer (g)	-	2.5	5.0	7.5	10.0	12.5	15.0
Absolute Viscosity (P)	1180	1370	1430	1610	2240	2309	2369
Shear (%)	13.8	15.1	17.4	19.6	22.6	24.6	26.9

Table 5: Standard Specifications for Viscosity-Graded Asphalt Cement for Use in Pavement Construction (ASTM D3381 – 09)

TESTS	VISCOSITY GRADE	
	AC - 10	AC - 20
Penetration at 25°C, 100g, 5s, mm	120 - 140	100 - 120
Softening Point temperature, °C	45 - 52	48 - 56
Kinematic Viscosity at 135°C, min, cSt,	150 - 250	200 - 300
Absolute Viscosity at 60°C, P	800 – 1200	1600 – 2400
Specific Gravity at 25°C, g/cm^3	1.01 – 1.05	1.01 – 1.06

6. Discussion

The properties of the polymer-modified bitumen were compared with that of raw bitumen. It was observed that, the increase in the percentage of plastic additive from 0.5% to 3% by weight decreased the penetration value (Figure 1). This shows that, the addition of polymer increases the hardness of the bitumen. The decrease in the penetration value may be due to the interlocking of polymer molecules with bitumen.

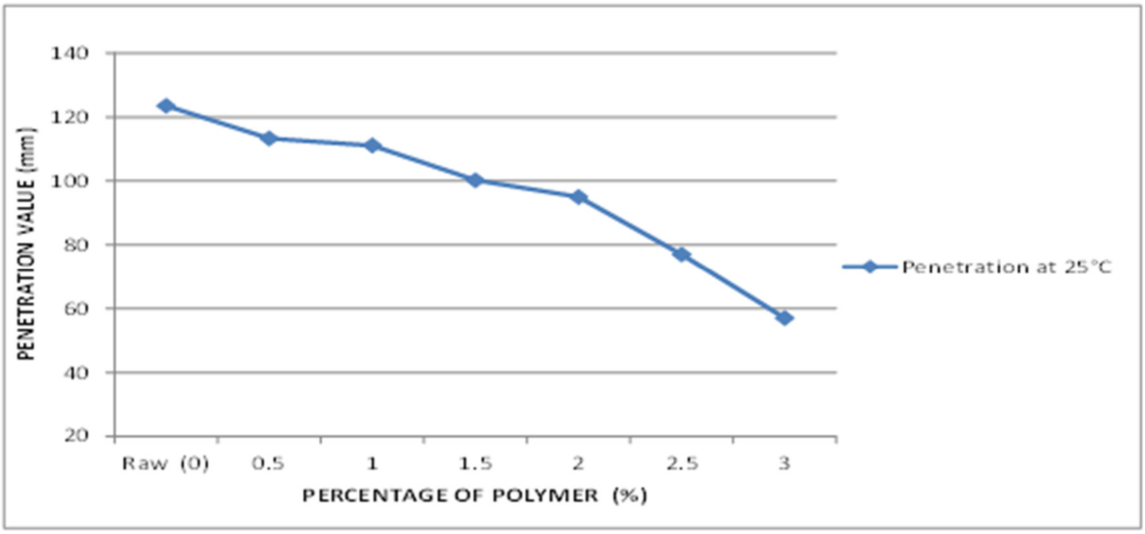

Figure1: A graph of Penetration at 25°C against polymer composition

The softening point increased with the addition of plastic additive to bitumen. The higher the percentage of plastic additive added, the higher the softening point (Figure 2). The influence over the softening point may be due to the chemical composition of polymer added. The increase in the softening point will alleviate the bleeding problems that characterize high tropical climates. Bleeding accounts for the slippery conditions of roads during wet weather. This adverse condition is much reduced by the addition of plastic waste to bitumen.

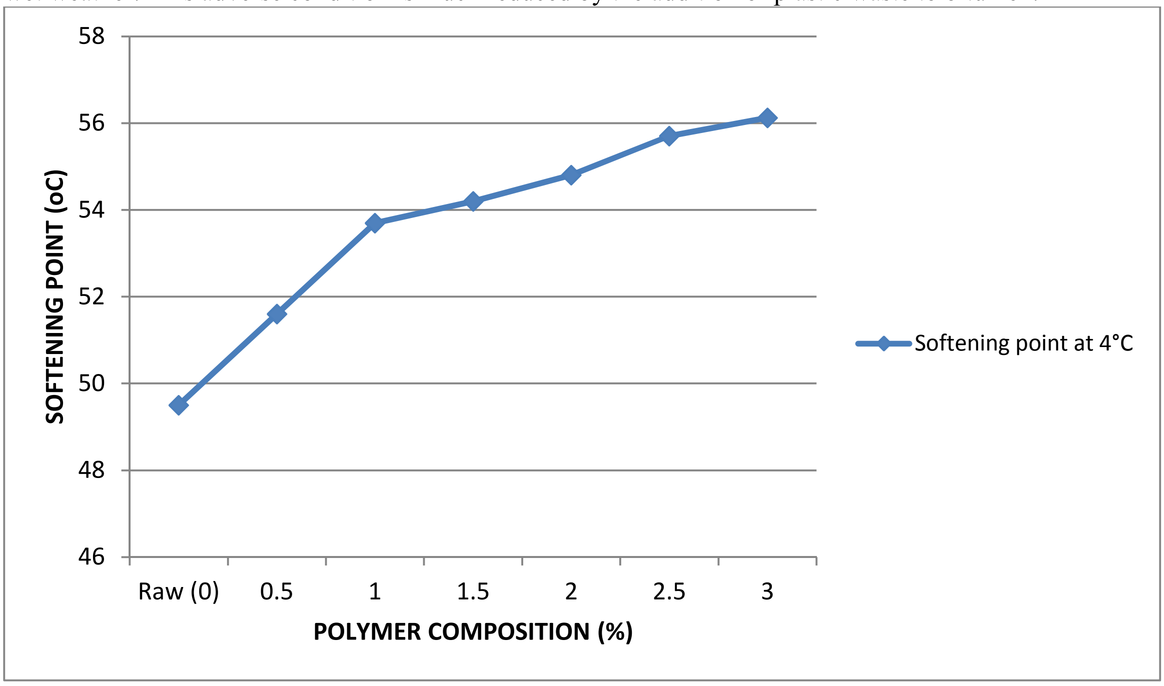

Figure 2: A graph of Softening Point against polymer composition

The results also indicate that, as the percentage of polymer increases, the viscosity also increases. On the absolute and kinematic viscosity tests at 60°C and 135°C respectively, it is also observed that, as the percentage of the polymer additive increases from 0.5% to 3.0% by weight (Figure 3 and 4), the more rapidly the polymer-modified AC-10 bitumen changes from its semi-liquid state to semi-solid state. Analysis of results also indicates that, when the polymer percentage in the mix increases, its hardening properties improve. Comparing the results of viscosity values obtained from the tests to the test specifications of raw AC-20 bitumen (Table 5), it is observed that, modified AC-10 bitumen (with 2% polymer composition by weight) has the same properties as that of raw AC-20 bitumen. This means that Modified Viscosity Graded AC-10 bitumen can be used as Viscosity Graded AC-20 bitumen in asphalt pavement construction with savings in bitumen usage.

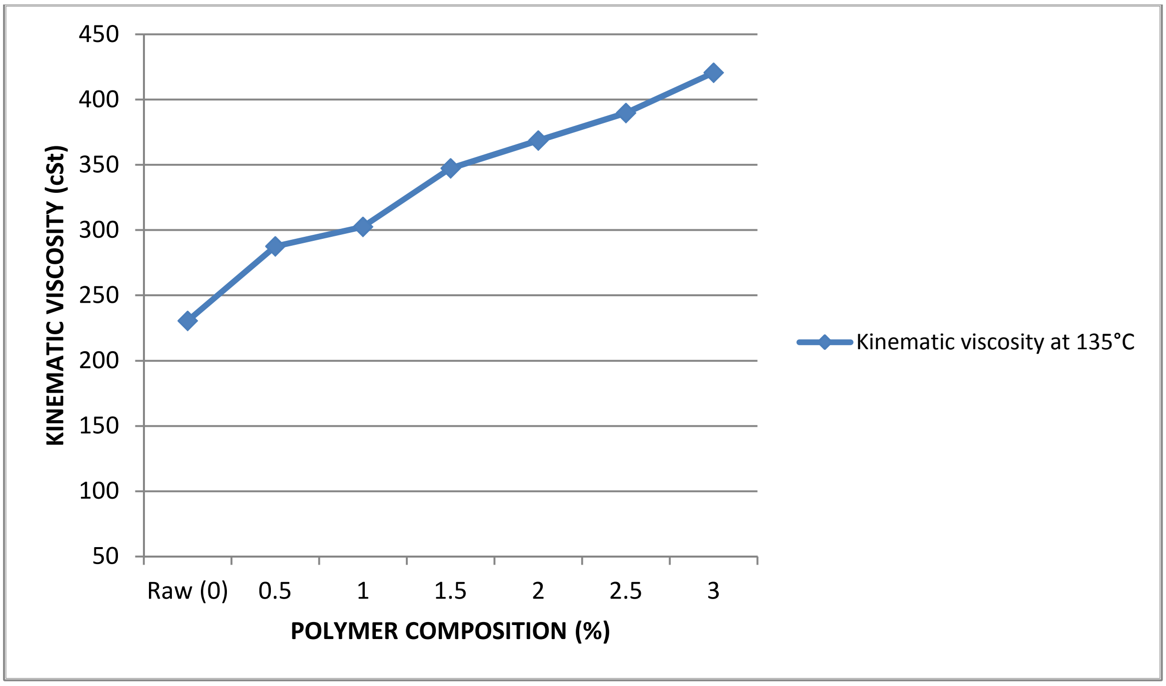

Figure 3: A graph of Kinematic Viscosity against polymer composition

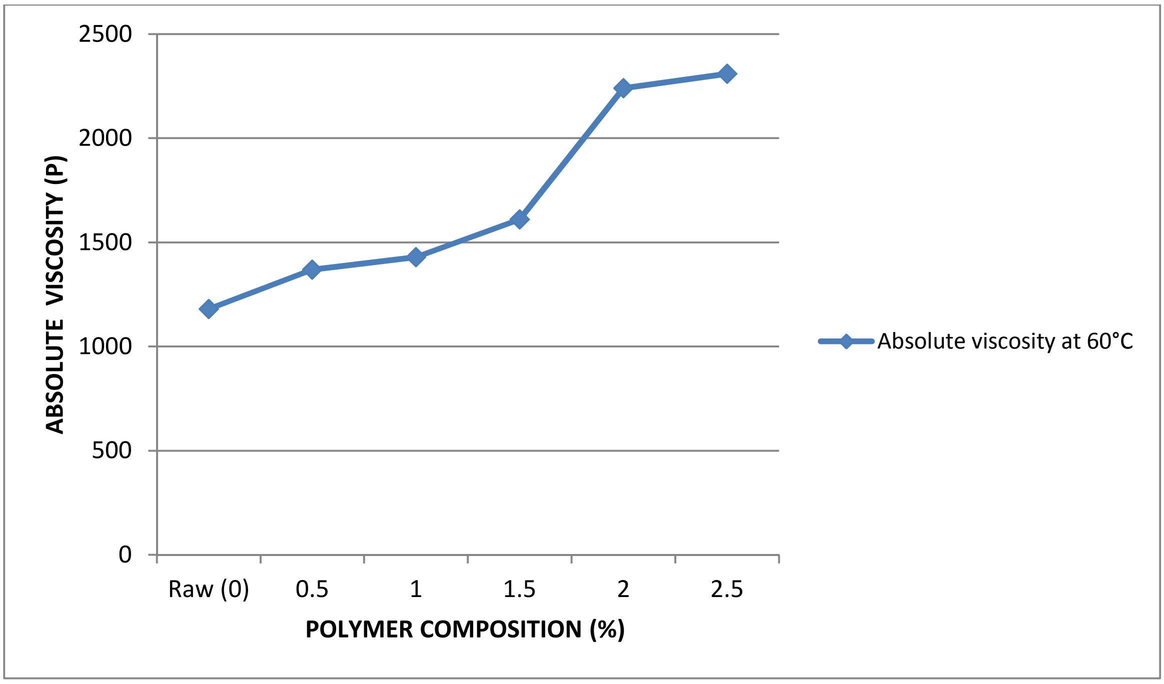

Figure 4: A graph of Absolute Viscosity against polymer composition

The shear values obtained from the absolute and kinematic viscosity tests show an increase as the proportion of plastic additive increases from 0.5 to 3.0% by weight. This desirable improvement in the shear values of the polymer-modified bitumen will offset permanent deformations like ruts which are one of the frequent distress modes of bituminous pavements. Ruts are caused by horizontal and lateral displacements of asphalt in the pavement under shear stress, produced by wheel loads at high pavement service temperatures. Bituminous pavement resistance to permanent deformation depends on the rheological properties of bituminous binder, size and shape of mineral aggregates and additives.

7. Conclusions

The results of this study show that by adding plastic waste to bitumen, the rheological properties have been improved. Therefore, it is apparent that binder performance evaluations should be done with importance on the percentage of polymer in the mix. Two percent polymer composition as a modifier with AC-10 bitumen can give perfect AC-20 bitumen properties that will help improve the Marshall stability, strength, design life and other desirable properties of asphalt concrete pavements with marginal saving in bitumen usage. Plastic is sound absorbent, which will help minimize sound pollution in heavy traffic.

The use of waste plastics in pavement construction will help consume large quantity of waste plastics. Pollution of the environment with used plastic wastes will immensely be reduced and as a result, improve the sanitation problem.

Collection of waste plastics can help create employment for the collectors and reduce the incidence of malaria. The indiscriminate disposal of plastic wastes partially accounts for choked drainage systems in the cities, which serve as breeding grounds for mosquitoes and also contribute to the perennial flooding. The use of plastic wastes in bituminous pavement construction, therefore, will bring a permanent solution to the plastic waste disposal menace and help create a healthy and safe environment for all.

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