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Case study

Use of waste plastic materials for road construction in Ghana

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ABSTRACT

This paper forms part of research to solve two main problems in Ghana: firstly, the management of municipal solid waste (MSW), particularly with regards to used plastics which have overwhelmed major cities and towns; secondly, the formation of potholes onroads due to excessive traffic and axle weight. This study examines the effect of blending waste thermoplastic polymers, namely High density polyethylene (HDPE) and Polypropylene (PP) in Conventional AC-20 graded bitumen, at various plastic compositions. The plastics were shredded and blended with the bitumen 'in-situ', with a shear mixer at a temperature range of 160 °C–170 °C. Basic rheological parameters such as penetration, ring & ball softening point and viscosity tests were employed to determine the resulting changes from base bitumen.FTIR spectroscopy was also employed to study the chemical functionalities present in the bitumen composite. The properties of the unmodified bitumen were found to be enhanced with the changes recorded in the rheological properties of the polymer modified bitumen (PMB). It was observed that polypropylene polymer, showed profound effect on homogeneity and compatibility with slight linear increment in the viscosity, softening and penetration values as against relatively high changes for HDPE modified bitumen.The viscosity of unmodified bitumen was enhanced with the addition of the polymers and thixotropic effect was observed for both HDPE and PP at 60 °C. For all modified binders prepared, the penetration values decrease as polymer-bitumen ratio increases whiles softening temperature generally increases as polymer ratio increases. The most compatible and incompatible blends for HDPE were respectively observed at 2% and 3% polymer loading. The most enhanced, homogenous blend is achieved with PP at 3% polymer loading. Three prominent peaks were identified in the spectrum of the unmodified bitumen, occurring at the 3000–2850 cm^{-1} IR frequency range, typical of aliphatic —C—H symmetrical and asymmetrical stretches in alkanes. CH_2 and CH_3 bends were also observed at the characteristic frequencies of 1465 cm^{-1} and 1375 cm^{-1} respectively. A low intensity peak was observed within the 2400 cm^{-1}–2100 cm^{-1} range, indicating the presence of a very weak –C≡C- or –C≡N group with an absorbance of precisely 0.12.The use of waste commodity plastics in binder modification carries the advantage of a cheap and effective means of enhancing conventional bitumen binder performance characteristics and is an alternative way to utilise plastic waste.

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1. Introduction

In the year 2000, one of the millennium development goals (MDGs), which Ghana appended to was the promotion of environmental protection and sustainability; However, for well over a decade which has seen the transformation of the MDGs in to Sustainable Development Goals (SDGs), the country is still grappling with the proper disposal and management of its Municipal solid Waste (MSW), especially plastic waste.Currently, the common waste disposal methods employed are land filling, incineration and haphazard littering in the cities, municipalities and the countryside. These disposal methods have a negative impact on human health and the environment; consequently, rivers, gutters and roadsides are choked and filled with waste plastics.

Polyethylene Terepthalate (PET) and High density Polyethylene (HDPE) are used in most bottling applications of water, yoghurt and soft drinks, but in terms of littering, however, one of the worst culprits is polyethylene (or "polythene") bags, for food packaging and sachet water bags. Every day, a multitude of items that are either partly or completely made of plastic are used and these plastics eventually end up in the landfills. Depending on the quality of the plastic, it may take anywhere from a few days to several years to break down in landfills, but it never breaks down completely into particles that can be used in nature. As such, plastic is one of the worst offenders when it comes to environmental pollution [1].

On the other hand, the volume of road traffic is increasing and demands a corresponding increment in the load bearing capacities of the road and its service life span. It has been proven possible to improve the performance of bituminous mixes used in the surfacing course of road pavements, with the help of various types of additives or modifiers to bitumen such as polymers, rubber latex, crumb rubber, etc.

The choice of modifier for a particular project can depend on many factors including construction ability, availability, cost, and expected performance. Modification is achieved by two main procedures; Dry process involves direct incorporation of waste plastic, which is blended with aggregate before adding in bitumen, to prepare a plastic modified bituminous concrete mix and the Wet process which involves, simultaneous blending of bitumen and waste plastic.The use of polymer modified bitumen to achieve

better asphalt pavement performance has been observed for a long time [2,3]. Zoorab&Suparma [4] reported the use of recycled plastics composed predominantly of polypropylene and low density polyethylene in plain bituminous concrete mixtures with increased durability and improved fatigue life. Resistance to deformation of asphaltic concrete modified with low density polythene was improved in comparison with unmodified mixes. The thrust of this study is to generate scientific data which will form basis for using plastic modified bitumen in the construction and repair of roads in Ghana, as well as provide scientific data on the alternative recycling options for managing plastic waste.

2. Materials and methods

2.1. Materials

2.1.1. Bitumen

The bitumen used, AC-20 grade, was obtained from a local road contractor in Kumasi.

Physical properties of this bitumen are presented in Table 2. After the experimental procedures, the modified properties were compared with the Ghana Highway Authority (G.H.A) bitumen specifications (Table 1).

2.1.2. Plastic

The plastic used was waste plastic bottles, bags, wrappers, etc collected from the Department of Chemistry, KNUST and from residential areas on the campus.

2.2. Method

2.2.1. Modified bitumen preparation

The wet process was employed; Samples were prepared, using melt-blending technique. Bitumen (400 g) was heated in oven till fluid condition and polymer was slowly added. The speed of the mixer was kept above 120 rpm and temperature, between 160 °C and 170 °C. The concentration of PP and HDPE, ranged from 0.5% −3% by weight of blend with an increment of 0.5%. Mixing was continued for 30mins-1hr to produce homogenous mixtures. The polymer modified bitumen (PMB) was

Table 1
Ghana Highway Authority Specifications for unmodified bitumen (AC-20 Grade).

Penetration (dmm) at 25 °C, 100 g,5 s	–
Softening Point,°C	48–56
Kinematic Viscosity at 135 °C, cSt.	300
Viscosity at 60 °C, cP	2000 ± 400
Specific Gravity	1.01–1.06

Table 2
Physical Properties of Unmodified bitumen.

Penetration (dmm) at 25 °C, 100 g,5 s	140
Softening Point,°C	53
Kinematic Viscosity at 135 °C, Cst.	360
Viscosity at 60 °C, centipoise	2300
Specific Gravity	1.01

then sealed in containers and stored for further testing. Empirical test such as penetration, softening point and viscosity were then conducted on the prepared samples.

2.3. Laboratory testing

2.3.1. Penetration (ASTM D-5)

The standard 100 g, 25 °C, 5 s penetration test was performed on an Analis Penetrometer P734, on base bitumen and PMB with the concentration of polymer varying between 0.5%-3% by weight of the bitumen.

The results of the test are shown in Fig. 1.

2.3.2. Softening point (ASTM D-36)

Ring and ball softening test, is the standard test to determine the consistency of the bitumen, which represent the temperature at which a change of phase from solid to liquid occurs. It is the temperature at which standard 3/8 inch steel ball weighing 3.55 g falls and touches the base plate which is 2.5 mm away. The results are shown in Fig. 2.

2.3.3. Viscosity (ASTM D-4402)

Viscosity test was conducted using a DV-III Ultra Programmable BrookField viscometer, on unmodified and polymer modified bitumen. The absolute and kinematic viscosity measurements were made at 60 °C and 135 °C respectively. The test was carried out on all polymers up to the concentration of 3%.

The results are shown in Fig. 3a and b.

2.3.4. Fourier transform infra-Red (FTIR) test

FTIR analysis was conducted on the base bitumen and bitumen-plastic composites (PMB) in order to determine if a chemical change occurred during the dispersion of the waste plastics within the asphalt binder. Fourier transform infrared spectroscopy (FT-IR) spectra were measured by using an Interspec 200-X Fourier Transform Infrared Spectrometer. The scanning frequency of each spectrum was 32 times per minute.

The results are shown in Fig. 4a and b.

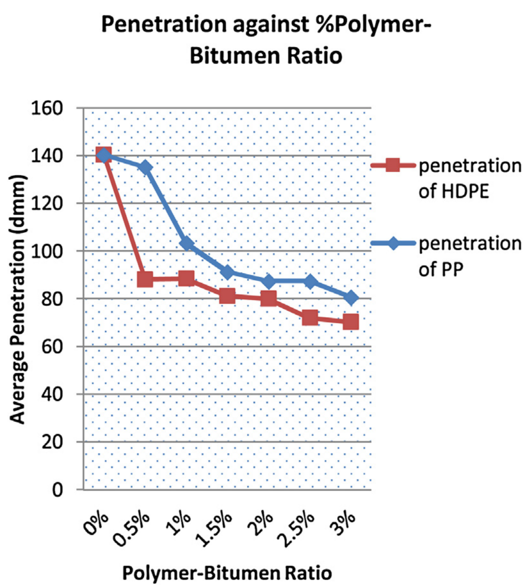

Fig. 1. Penetration Graph of HDPE vs. PP.

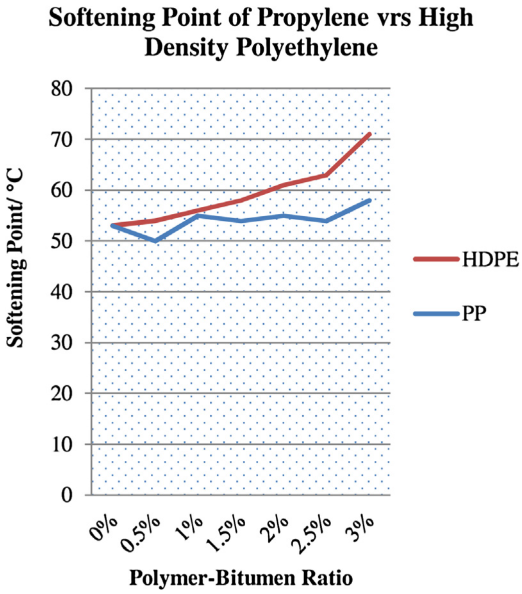

Fig. 2. Softening point of Propylene vs. High density Polyethylene.

3. Results and discussion

3.1. Penetration

From the result shown in Fig. 1 for unmodified bitumen, PP and HDPE modified bitumen, the sharp decrease in the penetration value of 104.3dmm for base bitumen to 88.03dmm for HDPE and 135.2dmm for PP at 0.5% concentration of polymer shows the increase in the hardness of the PMB. This is because of the use of the high molecular weight polymer, HDPE. The melting temperature of HDPE and PP is 135 °C and 165 °C respectively, Polyethylene at temperature above 160 °C is in melt state; it absorb some oil and release low molecular weight fraction into the bitumen which increases the viscosity of the PMB [5]. Thus it increases the viscosity by the end of mixing process, and by the time it cools harden mixture was formed. The hardening of the bitumen can be beneficial as it increases the stiffness of the material, thus the load spreading capabilities of the structure but also can lead to fretting or cracking [6]. 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 PMB/neat bitumen can be established.

3.2. Softening point

The results obtained from Fig. 2, shows that there is a linear increase in the softening temperature for HDPE PMBs up to 3% concentration of polymer in bitumen as compared to base bitumen. Thermoplastic modification does not significantly affect the softening point as compared to the penetration [5]. This is attributable to the internal structure formed by the polymer, which seems to be thermodynamically stable and does not significantly affect the softening point of the PMB. HDPE shows rapid increase in softening point in comparison to PP. This confirms that the PMBs with an increase softening point have been found to show enhancement in pavement performance characteristics in terms of rutting, fatigue and temperature susceptibility [7]. Again, it can also be observed that, PP offers lesser variation in softening point, which may be due to homogeneity achieved during blending of PP with base bitumen as a result of its low molecular weight and also being more polar. Thus PMB with PP may offer better rutting resistance at higher temperature.

3.3. Viscosity

When bitumen is blended with polymer, a multiphase system is formed; one such phase is rich in asphaltenes not absorbed by the polymer which enhances the viscosity by the formation of more complex internal structure [8,9]. The flow behaviour of a bituminous material described in terms of viscosity, exhibits Newtonian and non-Newtonian characteristics depending on the composition and source of the crude. Temperature and loading also affect the behaviour describing the viscoelastic properties of the material; the internal structure of the base bitumen also plays a key role [10].

From Fig. 3a, base Bitumen with viscosity of 360 CSt at 135 °C shows increase in viscosity with the increase in polymer concentration and shear rate. However, Non-Newtonian behaviour is observed with the decrease in viscosity as shear rate

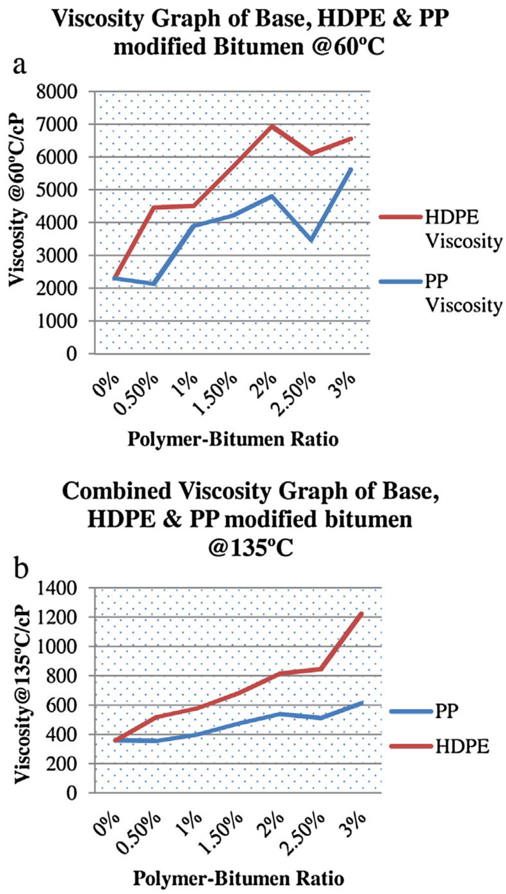

Fig. 3. (a) Combined Viscosity graph of base, HDPE & PP modified bitumen @60 °C. (b) Combined Viscosity graph of base, HDPE & PP modified bitumen @135 °C.

increases for both polymers at 2.5% concentration. This non-Newtonian phenomenon is dependent on the shear rate and is also influenced by the internal structure of the PMB [10]. The fluctuation of viscosity observed, was more for HDPE till 2.5% concentration of polymer. The mixed behaviour with the decrease in viscosity as shear rate increases and increase again in viscosity, is a result of thixotropic effect (property exhibited by certain gels by becoming fluid when stirred or shaken and returning to the semi-solid state upon standing). The thixotropic behaviour of modified bitumen may be due to reversible breakdown of structure which is commonly found in the multiphase system of polymer modified bitumen [7]. Also, pseudo-plastic behaviour of PMB may be attributed to breakdown of structure, or polymer particles existing in equilibrium state, being more aligned. This offers lesser resistance to flow but with the increase in shear rate, these offer higher resistance due to agglomeration, aggregation or flocculation of particles in multiphase system as the interparticle forces like Brownian, van der Walls forces become prominent. HDPE is not fully dispersed in bitumen because of higher molecular weight and as such exhibit both thixotropy and viscoelasticity at all concentrations of polymer in the blend [11]. PP offers less fluctuation as can be observed for all concentrations of the polymer in the various blends shown in Fig. 3a.

3.4. Fourier transform infra-Red (FTIR) test

High density polyethylene is primarily aliphatic, composed of only hydrocarbons. The spectrum shown in Fig. 4a reveals that 0.5% HDPE modification of the unmodified binder yields more than 20% increment in the aliphatic —C—H- group intensity in the binder, the absorbance in the unmodified binder changes from 1.0 to 1.24. The CH_2 and CH_3 bends at 1465 cm^{-1} and 1375 cm^{-1}, are also observed to increase in intensity. A fourfold increment can also be observed in the weak $-C{\equiv}C$- or $-C{\equiv}N$ group as its absorbance becomes 0.5 precisely. Spectra for 1% HDPE and 2% HDPE respectively show profound intensities in the peaks for aliphatic —C—H groups, the CH_2 and CH_3 bends, as well as the triple bond $-C{\equiv}C$- or $-C{\equiv}N$ group. This suggests an active cohesion between the polymer strands and the bitumen fractions. Since no new distinct functional groups are formed, it can be further deduced that the enhanced intensities in the peaks of the original functionalities is the result of a successful blending of the polymer into the binder matrix. Nonetheless, in the spectra for 1.5% HDPE and 2.5% HDPE modified bitumen; it can be observed that, the intensities of three prominent peaks are only enhanced

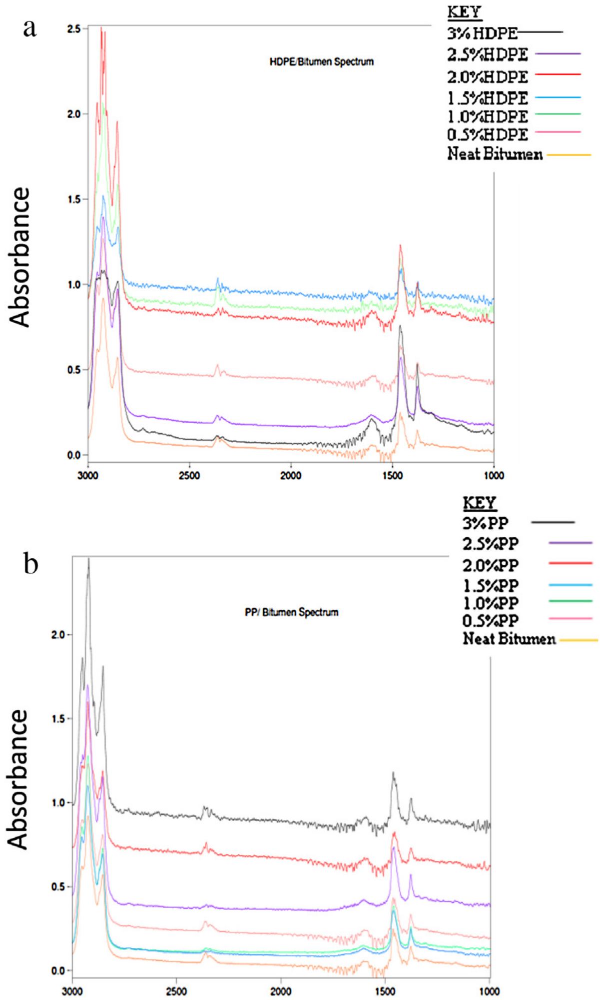

Fig. 4. (a) Combined FTIR Spectra of unmodified and various% loadings of HDPE modified Bitumen. (b) Combined FTIR Spectra of unmodified and various% loadings of PP modified Bitumen.

slightly as compared to those exhibited by the spectra for 1% and 2% HDPE modified bitumen. This suggests a low shearing of the plastic into the binder.

From the spectrum of 3% HDPE plastic modified bitumen, it can be clearly seen that there is very low influence of this plastic composition on the functional properties of the bitumen. At this maximum polymer ratio, the effect of the high molecular weight plastic becomes very prominent, as the aggregation of unblended polymer strands greatly enhances the peak intensity of the bending CH_2 and CH_3 groups with very little influence on the functional structure of the binder. The above observation explains the susceptibility of this polymer-bitumen mix to undergo gross phase- separation under undisturbed conditions. HDPE at 3% polymer loading is observed to have the least intense peak. This suggests a poor interaction between the plastic and the bitumen at that percentage of blending.

Polypropylene plastics can be observed (see Fig. 4b) to have a comparatively reduced influence on the microstructure of the binder at low polymer ratios as compared to HDPE (Fig. 4b). There is very little increment in the intensity of the prominent peaks as polymer ratio is increased from 0.5% to 1.5%. Between 2% and 3% PP modification, the intensity of the groups absorbing in the aliphatic —C—H IR region become more pronounced. This is indicative of the functional influence the polymer begins to display as its percentage ratio increases. The most intense peak for PP also occurs between 3000 and 2850 cm^{-1} at 3% PP content. The corresponding trend of increase in peak intensity as polymer ratio increases of the different spectra suggests that the polymer ratio could have been increased beyond 3% for PP modified bitumen.

4. Conclusion

The addition of thermoplastic modifiers to conventional bitumen is known to improve the viscoelastic behaviour of the bitumen and change its rheological properties. Two types of modifiers were used, High density polyethylene (HDPE) and

Polypropylene (PP); they were observed to display different amount of influence i.e. increasing the softening point, decreasing penetration value whilst enhancing the overall dynamic and absolute viscosities of the binder.

Spectroscopic analysis carried out by FTIR spectrophotometry did not show new functionalities distinct from the spectrum of the base binder for all the modified bitumen samples. However, the original prominent peaks occurring at the $3000\,cm^{-1}$–$2850\,cm^{-1}$ for aliphatic —C—H stretching, $2400\,cm^{-1}$–$2100\,cm^{-1}$ for triple bond C≡C- or –C≡N group and $1465\,cm^{-1}$ and $1375\,cm^{-1}$ for CH_2 and CH_3 bends are observed to increase in intensity depending on the polymer type and blending ratio. This suggests a successful 'blending-in' of the polymer strands into the bitumen matrix. Best results obtained within the limitations of the study, for stable PMB suitable for road making purposes were obtained with Polypropylene (PP).

This study has also shown that waste plastic modified bitumen carries great promise as an alternative recycling method for plastic waste management in Ghana, as well as a non-traditional, modified binder for road construction. Further studies should be done to investigate long term performance of field test sections with PMB so as to evaluate the effect on storage, rutting, cracking resistance under various traffic conditions.

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References

[1] United Nations Environment Programme, Converting Waste Plastics into A Resource: Assessment Guidelines, (2009) pp 1.
[2] G.N. King, H.W. King, Polymer modified asphalts, an overview, Am. Soc. Civ. Eng. (1986) 240–254.
[3] U. Isacsson, X. Lu, Testing and appraisal of polymer modified road bitumen, Mater. Struc. 28 (1995) 139–159.
[4] S.E. Zorrob, L.B. Suparama, Laboratory design and investigation of proportion of bituminous composite containing waste recycled plastics aggregate replacement (Plastiphalt), CIB Symposium on Construction and Environment Theory into Practice (2004).
[5] A.A. Yousefi, A.A.I.T. Kadi, Composite asphalt binders: effects of modified RPE on asphalt, J. Mater. Civ. Eng. (May) (2000) 113–123.
[6] C.D. Whiteoak, The Shell Bitumen Hand Book, (2003) Surrey, UK.
[7] N.Z. Habib, I. Kamaruddin, M. Napiah, I.M. Tan, Rheological properties of polyethylene and polypropylene modified bitumen, Int. J. Civ. Environ. Eng. 3 (2) (2011).
[8] A.I. Al-Hadidy, Tan. QuiYi, Effect of Polyethylene on life of flexible pavements, Constr. Build. Mater. 23 (2009) 1456–1466.
[9] J. Stastna, et al., Viscosity functions in polymer modified asphalts, J. Colloid Interface Sci. 59 (2002) 200–209.
[10] D. Sybilsk, New simplified equation for the computation of absolute viscosity of polymer-bitumens, Mater. Struc. 30 (1997) pp. 182187.
[11] N. Bhattacharya Sati, Chapter 1, Rheology Fundamentals and Measurement, Royal Melbourne Institute of Technology, Australia, 1997.

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