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Assessing Plastic Waste Usage as Additives in Flexible Asphalt Mix for Road Construction

Freshnel Adou[1] Boateng Ampadu[1*] Nana Kwesi Agyepong[2] Olivia Naa-Afi Soli[2]
1.University for Development Studies, Department of Environmental Science, P. O. Box 24, Navrongo, Upper East Region, Ghana
2.Ghana Highway Authority, Central Laboratory, P. O. Box 1541, Accra, Ghana

Abstract
Disposal of waste materials including plastic wastes has become a serious problem in Ghana and plastic wastes burnt for apparent disposal cause environmental pollution. These wastes are non-biodegradable in nature causing environmental pollution and hygiene problems. Research conducted at various institutions across the world indicates that plastic wastes can be used in asphalting of roads. In this research, Plastic waste was coated around aggregate and subsequently mixed with bitumen to produce asphalt with plastic wastes and the samples obtained were subjected to various tests in the laboratory to determine its properties. The results show that, plastic waste improved the quality of aggregates, enhancing its properties. The use of this innovative technology will increase the strength and life span of roads; and more importantly, will help improve the quality of the environment by reducing and removing plastic waste, which comes at a lower cost. Roads made with plastic waste in an asphalt mix will therefore be of great solution to Ghana's environmental problems by serving as an alternative solution to disposal of plastic waste and minimizing flood cases due to choked drains by plastic waste. It is recommended that, roads should be constructed and paved with plastic waste in an asphalt mix to study its behaviour, benefits and interaction with the environment.
Keywords: Plastic waste, Bitumen, Aggregates, Plastic Asphalt mix

1. Introduction

Plastic has been a very useful material in mankind's daily life resulting in an enormous production of plastic waste. Plastic materials are mostly in the form of carry bags, wrap, foams, films, bottles, cups etc. The world's annual consumption of plastic materials has increased from around 5 million tons in the 1950s to nearly 100 million tons thus; 20 times more plastic is produced today than 50 years ago (UNEP, 2004). In Ghana, the use of plastics in recent years have been enormous due to industrial and population growth which has led to increase demand of various types of plastic products in the country (Owusu et al., 2013). Fobil (2001) reported that there are about 40 plastic manufacturing companies producing over 26,000 metric tons of assorted plastic products annually in Ghana, with 90% of these companies sited in Kumasi and Accra-Tema Metropolitan Areas. Additionally, over 10,000 metric tons of finished plastic products are imported annually into the country (Fobil, 2001).

Plastic waste disposal has been a problem for authorities in Ghana, thus causing environmental and socio-economic problems. Landfills and incineration as disposal systems for plastic wastes are not the best since they tend to have detrimental effects on the environment and its inhabitants. These environmental problems and danger includes air, soil and water pollution, outbreak of diseases such as cholera, choking of drainage systems leading to flooding in most urban centers of the country to such an extent that, it takes only a slight rainfall to generate floods in major cities like Accra and Kumasi (Fobil and Hogarh, 2006). Therefore, finding an eco-friendly way of disposing plastic waste is of great interest in today's research, particularly in Ghana and Africa as a whole.

Weather conditions and significant increase in the volume of road traffics which includes heavier loads, high traffic volume and higher tire pressure is becoming more extreme, resulting in constant increasing demand for higher performance roads (Toth and Soos, 2015). Performance of roads depends highly on the quality of its components, especially the type and quality of the bitumen and aggregate properties since it determines the most important properties of the asphalt mix (Toth and Soos, 2015). Methods used to attain a higher performance road are duly by improving the quality of bitumen which is done by modifying the rheological properties of bitumen by blending it with various products such as plastics and rubber (Vasudevan et al., 2010). In Ghana, Aforla et al. (2015) assessed the suitability of plastic waste in bituminous pavement construction where Low Density Polyethylene (LDPE) was used to modify bitumen of grade aggregate cement (AC) 10 to improve it properties. The use of plastic waste, poly-ethylene terephthalate (PET) in asphalt concrete mixture as aggregate replacement in Iran has also been reported by Hassani et al. (2005). Therefore, the use of plastic waste as an additive in asphalt mix to improve the properties and performance of roads offers us a very promising alternative.

Over the years, various ways of management, treatment, and disposal method such as primary, secondary, tertiary and quaternary recycling of plastic wastes has come into existence to offer viable solutions to these problems. However, in Ghana, recycling companies have been established which include the plastic recycling

programme established at Pokuase but yet still the impact of the programme at mobilizing plastics from the environment has hardly been felt (Fobil and Hogarh, 2006). Though, these recycling process is helpful, it is not viable, due to the absence of local sustainable mechanisms for retrieving the plastic wastes from the environment (Fobil and Hogarh, 2006) and very expensive to operate. Thus, when plastic wastes are introduced in road construction, it will encourage more plastic waste collectors and rag pickers to adequately retrieve plastic wastes from the environment. Again, since most recycling machines are expensive in both purchasing and maintenance, this will reduce the cost of recycling and also there is no need for any advanced technology and facilities, therefore, very cheap to operate. Consequently, to provide a less costly and eco-friendly way of managing and removing plastic wastes in Ghana, there is the need to assess the use of plastic waste as raw material for road construction to be able to establish an effective way of managing and removing plastic waste with no consequences in the country (Ghana).

The main aim of the study is to investigate the viability of plastic wastes usage in asphalt mix for road asphalting in the Ghanaian environment, thus establishing an alternative way for plastic wastes disposal in order to reduce its existence in the environment. This is effective and eco-friendly way for managing, reducing and removing plastic wastes from the environment of Ghana. Specifically, the research seeks to perform the following:

- To coat aggregates with plastic waste and compare with normal aggregate for road construction.
- To mix plastic wastes with aggregate and bitumen to make asphalt (Plastic asphalt) and compare with normal asphalt for flexible road pavement.
- To mix plastic with bitumen and test its viscosity.
- To improve qualities of both aggregate and asphalt mixture (asphalt).

2. Materials and Method

2.1 Materials

2.1.1 Plastic Wastes

Shredded plastic wastes consisting of Polyethylene terephthalate (PET) were procured from Blow recycling company (Blow Chemical Industry Limited, Kpone Police Barrier, Tema, Ghana). PET was mostly used in this study because it is readily available in the Ghanaian environment and the most largely used in all aspect of life in Ghana.

2.1.2 Bitumen

The Bitumen used was aggregate cement (AC) 20. This type of grade was chosen because it is affordable, easily acquired in Ghana and mostly used for road construction in the country as approved by Ghana Highway Authority (GHA). It was obtained from Vivo Energy, Accra, Ghana.

2.1.3 Aggregates

Aggregates used in this study were obtained from PW quarry, Shia Hills, Accra, Ghana. It was carefully chosen based on criteria of strength, moisture absorption, durability, toughness, hardness, soundness, shape and size.

2.2 Methods

There are two ways of adding plastic wastes into asphalt; they are, as described by Verma (2011), as wet and dry process. However, this study was more focused on the direct addition of plastic wastes into the asphalt mix thus; dry process.

2.2.1 Wet Process

This method is used for the formation of polymer modified bitumen (PMB), in which the polymer is directly added to bitumen and kept around temperature of 160°C-170°C to prevent thermal degradation of plastic waste. Mixing is done to form a blend with proper dispersion of waste polymer in the bitumen. However, this process has limitations which include storage temperatures, addition percentage and bonding of plastic with bitumen to give a uniform mixture.

2.2.2 Dry Process

This process involves the direct introduction of plastic wastes into asphalt mixture. Temperature is kept around 160°C-170°C to prevent thermal degradation of the plastic waste. This process is easier to attain, has a wider range of addition percentage, increases the thickness of asphalt and also plastic wastes tends to coat with aggregate given it a first phase bind due to binding properties of the plastic, before bitumen comes into play, resulting in the formation of a stronger bond between the components of the asphalt mix.

2.2.3 Preparation of Plastic Coated Aggregate (PCA)

Shredded plastic wastes were sieved through a 4.75 mm sieve and retained at 2 mm. Aggregate of size 10-20 mm was heated to around 160°C - 170°C. The hot aggregate was then mixed with the melted plastic waste which was stirred to attain a uniform and thorough coating of plastic wastes over aggregates. The plastic wastes formed an oil surface around the aggregates and crystallized upon cooling. The Plastic Coated Aggregate (PCA) was then subjected to various test like Impact, Los Angeles Abrasion, Moisture Absorption and Soundness where records

and observations of it properties were made and compared to a control sample that is, aggregate with no plastic coatings.

2.2.4 Preparation of Plastic Coated Aggregate Bituminous Mix (PLASTIC ASPHALT MIX)

Plastic coated aggregate was subsequently mixed with bitumen of AC20. The temperature was kept around 160°C-170°C for the mixing process to attain a plastic coated aggregate bitumen mix (plastic asphalt). The plastic asphalt was then cooled and was subjected to tests like moisture sensitivity, marshal stability and flow, and stripping. Note: Asphalt tested mix was chosen to be AC20 wearing course.

2.2.5 Preparation of Plastic Modified Bitumen (PMB)

Plastic wastes of varying percentage (i.e. 2, 4, 6, and 8 %) were added to bitumen of AC20 at temperature around 160°C-170°C and mechanically stirred thoroughly to attain a uniform blend. It was then cooled and subjected to viscosity test. Though this study is focused on adding plastic waste to asphalt mix, PMB was made and tested to know the type of bitumen it modified into upon addition of plastic waste specifically PET.

3. Results and Discussion

On the basis of the above methods, various aspects regarding the Plastic coated aggregates and Plastic asphalt are discussed below. Table1, Table 2 and Table 3 show the summary of test results on plastic modified bitumen (PMB), summary of test results of PCA and test results of Marshall Stability and flow, respectively.

3.1 Characteristics of PCA

3.1.1 Water Absorption: (ASTM C127-04)

Water absorption and specific gravity test were performed to know the capacity of aggregate's resistance to water. Aggregates used for road pavements must have low water absorption capacity to help extend the life span of the road (Mathew and Rao, 2007). Using the pyrometer method (according to ASTM standards), test and calculations were made to determine the water absorbed by the aggregate. The aggregate when coated with plastics improved its quality with respect to moisture absorption. The coating of plastic decreases the moisture absorption and helps to improve the quality of the aggregate and its performance in the flexible pavement. Table 2 shows that, the moisture absorbed by PCA was less as compared to the control sample, hence will give good performance if it is used for road construction, in terms of resistance to pot holes which are formed due to the presence of water. Also, an observation made was that, the more plastic coating, the less water it absorbs, since plastic coat serve as a protective medium for aggregate. Hence, coated aggregate improved its quality with respect to moisture absorption. The coating of plastic decreases the pore space in the aggregate and helps to improve its quality in respect to water absorption.

3.1.2 Aggregate Impact Test: (ASTM D5874)

This test was done to evaluate the toughness of stone or the resistance of the aggregate to fracture under repeated impacts. Both samples of size 10 mm were subjected to 15blows of a hanged-tap hammer of weight 14kg. The crushed aggregates were sieved using a 2.36 mm sieve and the retained materials were weighed and recorded. The observed weight difference in each sample represents the impact value and the percentages obtained for each sample determines their toughness. Impacts from the hammer had less effect on PCA as compared to the control sample (Table 2). This is because the plastic serve as a protective coat around the aggregates and subsequently improves the quality, hence reducing fracture of the aggregate. The coating of the aggregate with plastic improved Aggregate Impact Value, thus indicating a lower crushed fraction under load and would give a longer service life to the road and also improves the quality of the aggregate. Moreover, a poor quality aggregate can be made useful by coating with plastic. It will help to improve the quality of roads since plastic, upon coating with aggregate enhance toughness of the aggregate to face impacts actions as compared to control sample.

3.1.3 Los Angeles Abrasion (LAA): (ASTM C131)

The repeated movement of the vehicle will produce some wear and tear over the surface of pavement or roads. Thus, the principle of Los Angeles Abrasion (LAA) test is to find the percentage wear due to relative rubbing action between the aggregate and the steel balls used as abrasives. PCA showed maximum resistance towards abrasive action as compared to the control (Table 2), due to protection received by aggregates from plastic thus enhancing aggregate resistance to wearing. Under this study the percentage of wear and tear values of plastic coated aggregate (PCA) was found to decrease. PCA showed more resistance to abrasion action meaning, it will have good resistance to wearing and tearing when used in our roads hence improving its quality and life span. Also it was observed that, the more plastic coating, the more protection against abrasion actions, since plastic coat serve as a protective medium for aggregate.

3.1.4 Soundness Test: (ASTM 88-13)

Soundness test is intended to study the resistance of aggregates to actions of weather; this is evaluated by performing an accelerated weathering test cycle. Accelerated weathering test was done by immersing samples into sodium sulphate solution for 24hrs repeatedly for 5 cycles. Soundness value of aggregate was determined by

the calculated weight difference between the initial weight of aggregate before test was performed and the final weight after test was performed. The weight loss is attributed to the effect of sodium sulphate on aggregate. However, PCA had a smaller weight loss as compared to aggregate without plastic wastes (control sample), thus ensuring the improvement in the quality of the aggregate. Also, observation made was that, plastic coating served as a protective medium for aggregate against weathering actions.

3.2 Characteristics of Plastic Asphalt (PA)

3.2.1 Stripping Test: (ASTM D4469)

This test intends to evaluate asphalt adhesion towards water. Stripping value gives the effects of moisture upon the adhesion of bituminous film to the surface particles of the aggregate. Observations made shows that, the control specimen is although good but coating of the aggregate with plastic reduces the affinity of the aggregate towards water to zero. It was observed after 48hrs that plastic asphalt (PA) showed no sign of stripping as compared to control sample. This was due to a good bond between plastic, aggregate and bitumen which made the mixture hardly to be removed by water. This indicates that the PA tends to be more suitable for flexible road construction than plain aggregates. In addition, the plastic acts as a modifier to bitumen which enhances its properties. Also the plastic replaced anti-stripping agents which would have been added to asphalt to reduce stripping therefore, reducing cost of construction.

3.2.2 Marshall Stability and Flow (ASTM D6927 -15)

Marshall Stability is the measurement of the strength of the road, that is, its resistance to shearing stress, distortion, rutting and displacement. Marshall Stability values for PCA and control sample were determined. Figure1 shows that, PA mix had higher load withstanding strength and flow value as compared to control bituminous mix representing good resistance to shearing, distortion, displacement, stress and rutting. Some observations made when plastic was added to asphalt includes, increased sizes of aggregate, leading to increase in thickness of brickets. Plastic binds with coarse aggregate and fines resulting in fewer fines in mixture giving it a brittle-like look. But after compaction, the bricket appeared more firm and strong; hence proving that plastic wastes add strength and also served as a good binder, because it binds first with aggregate before bitumen comes in. It also replaces lime used in asphalt to improve these qualities. Therefore, plastic wastes when added to our road will improve its quality and strength to withstand heavy roads and rutting which comes at a low cost.

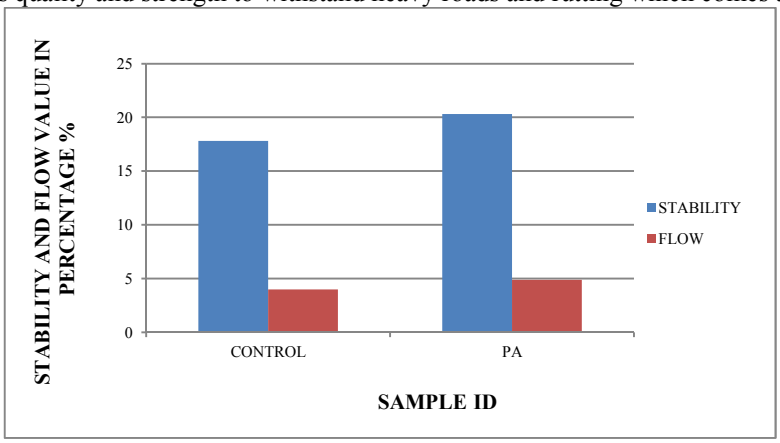

Fig 1 Comparison of Marshall Test Results
*Control (aggregate without plastic waste) and PA (plastic asphalt)

3.3 Characteristics of Plastic Modified Bitumen (PMB)

3.3.1 Viscosity (ASTM D 2170)

This test method is used for the determination of viscosity of bitumen at 60°C (140°F) and of asphalt cement at 135°C (275°F) which helps to determine the type of bitumen and its quality. It was performed to know the type of bitumen modified when plastic waste is introduce in the asphalt mix since the plastic waste does not only coat around aggregate and fines but also modifies the bitumen. As shown in (Table 1) plastic waste tends to modify bitumen into different grade depending on the percentage added. The results obtained shows that, plastic waste modified bitumen of grade AC 20 (aggregate cement) to performance grade (PG) of various types depending on the percentage of plastic wastes added. The various viscosity values of plastic modified bitumen (PMB) indicate that, plastic help to upgrade properties of bitumen, therefore high quality roads can be achieved at a lower cost.

Table 1: Summarized results of Viscosity Test

Sample ID	Plastic waste added (%)	Weight of bitumen (g)	Temperature (°c)	Torgue value (%)	Viscosity (cp)
Control (AC 20)	0	250	60°C	12.9	2030
PMB	2	250	135°C	10.9	545
PMB	4	250	135°C	11.8	590
PMB	6	250	135°C	12.3	615
PMB	8	250	135°C	12.7	640

Table 2: Summarized results of various test Performed on PCA

Sample ID	Plastic waste added (g)	Weight of aggregate (kg)	Various tests performed			
			Water absorption (%)	Impact Test (%)	Los Angeles Abrasion (%)	Soundness (%)
Control	0	2	1.22	33	24	0.15
PCA	400	2	1.05	20	19	0.08

Table 3: Test results of Marshall Stability and Flow

Sample ID	Bitumen Added (%)	Plastic Waste Added (%)	Specimen Diameter (mm)	Specimen Height (mm)	Air Void (%)	Flow Value (mm)	Specific Bulk Gravity (g/cm^3)	Marshall Stability Value (KN)
Control	5	0	101.45	62.43	5.75	4.0	2.56	17.8
PA	5	8	101.50	70.98	9.52	4.9	2.27	20.3

4. Conclusions and Recommendation

4.1 Conclusions

The use of plastic waste for road construction can save the environment, increase the service life of roads, reduce the use of petroleum products including road paving materials and serve the society with extra income for those associated with it. The coating of plastics on aggregate also improves the quality of the aggregate in terms of impact and abrasion action, water absorption, soundness and others. PCA and Asphalt with Plastic formation helps us to use higher percentage of plastic waste, reducing the need of bitumen and aggregate, increase the strength and performance of the road, reduces the cost and provides employment for plastic wastes collectors. In plastic asphalt mix, plastic waste was added to aggregate and mixed with bitumen. Plastic waste thereby increased the performance of bitumen and quality of aggregate in asphalt making. It retains its flexibility during Marshall Test, resulting in good stability and flow of road. The use of shredded plastic waste acts as a strong "binding agent" making the asphalt stronger. In summary, the process thus helps to achieve the following:

- Plastic waste improves aggregates by enhancing it qualities; it can therefore be used to modify poor quality aggregates.
- Reduce the amount of bitumen, aggregate and also may replace the use of lime and fillers in asphalt mix.
- Increase the strength and performance of roads per the Marshall Stability value obtained.
- Protects roads from increasing damaged caused by water.
- Avoids the use of anti-stripping agents in asphalt mix and therefore, reducing the cost of roads construction.

We can conclude that, using plastic waste in asphalt mix will help serve the nation a great deal in all areas concerning the environment, social, and the economy due to the numerous advantages it provides. Weather conditions such as heavy rainfall, increased traffic and flooding are reducing the life span of roads and causing problems to livelihoods, therefore plastic waste roads from the study are a means of protection and prevention and will ultimately be the solution to such problems. The use of plastic waste in asphalt mix to pave roads will save the country a fortune which may be used for plastic wastes clean-up from the environment. It will also reduce the amount of resources used for road construction leading to the reduction of the cost.

4.2 Recommendation

We recommend that, roads with plastic waste should be laid to study it behaviour, properties, benefits and interaction with the environment. Furthermore, Accra Metropolitan Authority (AMA), Waste Management Agencies and Companies in Ghana must encourage citizens to separate wastes at the source of production by providing more wastes bins to collect different type of wastes materials which will facilitate the process and the ease of getting plastic waste and also reduce cost in waste management.

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