Asare et al., *Cogent Environmental Science* (2019), 5: 1576373
https://doi.org/10.1080/23311843.2019.1576373

cogent environmental science

ENVIRONMENTAL CHEMISTRY, POLLUTION & WASTE MANAGEMENT | RESEARCH ARTICLE

Evaluation of incorporating plastic wastes into asphalt materials for road construction in Ghana

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Received: 30 November 2018
Accepted: 25 January 2019
First Published: 30 January 2019

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Abstract: In improving the aesthetics of the environment, the management of plastic wastes cannot be left out of the picture. Among the numerous ways that plastic wastes are managed, incorporating them into plastic roads is another viable option. This study quantified plastic wastes generation in Sunyani Municipality in Ghana and investigated the optimum percentage of asphaltic materials that could be made of plastic wastes for road construction in Ghana. Plastic Wastes were obtained from social gatherings, residential areas and restaurants, there was dialogue with key persons in the plastic industry and various experiments were also conducted for plastic wastes utilization in road construction. It was found that only one entrepreneur recycles the plastic wastes to make bags, dustbins, ropes and many more in the Municipality. It was also estimated that plastic wastes generation in the municipality per capita was 49.7 g/person/day whiles the total plastic wastes generated in the Municipality was 6,725.64 kg/day. In addition, numerous experimentations proved that it is possible to substitute about 10% of asphaltic road materials with plastic wastes as plastic coated aggregates (PCA) to meet the Ghana Highways Authority (GHA) standards for road construction. The novelty finding in this research is that substitution of about 10% or more of asphaltic road materials in Ghana with plastic wastes could bring economy and cost savings in both road construction and plastic wastes management in Ghana.

Subjects: Environmental Issues; Environment & Resources; Environment & Health; Clean Technologies; Environmental; Novel Technologies; Civil, Environmental and GeotechnicalEngineering

ABOUT THE AUTHORS

Our group's research activities have centred on resource recovery of all abandoned and waste resources that could have a secondary value for other activities. We have been working on resource recovery potentials of mine wastes and other municipal solid wastes.

This work on plastic wastes recycling into road construction in Ghana is an aspect of a broader research focus on resource recovery through various technologies to enhance circular economy. Our focus has been the applications of these technologies into low income countries where these technologies are almost non existent which is coupled with scarcity of resources through rapid consumption of virgin materials.

PUBLIC INTEREST STATEMENT

Handling of plastic wastes in Ghana has some crucial environmental, technical and economic challenges for waste management authorities.

This perspective article describes how plastic wastes could be incorporated in asphaltic materials for road construction in Ghana to meet all quality standard requirements through laboratory experiments.

It was found that asphaltic materials could compose of more than 10% plastic wastes to still give superior qualities to even exceed standard requirements and bring about economy in both plastic waste management and road construction in Ghana.

Keywords: plastic roads; asphaltic roads; asphaltic materials; bitumen dense macadam

1. Introduction

Just as advancing technology has its dark side; plastics too have become both a convenience and an inconvenience to the society. Plastics, as used in everyday life, have made packaging simple. Such can be seen in the form of water bottles, "take away" products such as cups, bowls, plates, cutlery and so on. Plastics have become a major concern because they are the fourth largest volume of waste generated worldwide where most of its types are not biodegradable (Hoornweg & Bhada-Tata, 2012). Mudgal et al. (2011) revealed that 1.5 million tonnes of plastics were produced worldwide in 1950 and this figure escalated to 245 million tonnes in 2008. The increasing volumes of plastics over the years create havoc on the environment, especially the non-biodegradable ones which can stay in the environment for up to 1000 years without decomposing (Stevens, 2002).

Ramaswamy and Sharma (2011) have revealed that indiscriminate disposal of plastics by the roadside, riverside and public places has resulted in the choking of gutters. Also, cattle consume plastic wastes that is exposed to them mostly at refuse dump sites. This leads to some cattle suffocating and dying and for those that do not die, have low milk production. When the wind blows, it carries along with it anything it can lift up such as plastics. Plastic waste is usually handled using the three R's, namely re-use, recycle and recovery (or disposal). There are other types of plastic waste management options that have been extensively investigated Bassi (2017). These include incineration, landfill and biotechnology. Hoornweg and Bhada-Tata (2012) report agree with Bassi (2017) that although recycling is a good option, very little recycling is done of MSW produced worldwide.

Biotechnology looks at producing biodegradable plastics and finding microbes or other components that can degrade the already existing plastic wastes. According to Bassi (2017), some plastics are still difficult to degrade. He mentioned that the negative effects of incineration and landfill waste management are overwhelming. Ghana is not an exception when it comes to the menace associated with plastic waste and its management. This work, therefore, seeks to determine the optimum percentage of asphaltic materials that could be incorporated with plastic wastes for road construction. The consequences of not properly managing plastic wastes are far reaching from health-related issues to increasing future financial burdens. One major intervention that is becoming quite popular is the incorporation of plastic wastes into bituminous roads. Many researchers are currently evaluating the potential of using plastic wastes in bituminous roads as part of its management Vasudevan, Sekar, Sundarakannan, and Velkennedy (2012). There is the need to do a similar analysis in Ghana in order to ascertain its potency in adopting this in Ghana. Plastic roads or roads made from plastic have been tried and proven to be the best way by which plastic wastes can be managed. This is because such roads are more durable, leaves no potholes, can withstand extreme climate changes even with temperatures above 50°C and can last up to 10 years compared with conventional roads that can last up to 5 years Verma (2008). Vasudevan et al. (2012) identify the types of plastic wastes used for plastic roads as those from polyethylene (PE), polypropylene (PP) and polystyrene (PS). These plastic types and bitumen both have hydrocarbon chains that are extensive made up of both asphaltenes and maltenes. Although the plastic is highly bonded with the aggregate, part of the bitumen is able to find its way to fuse with the aggregate also. Such interlocking between the plastic and the bitumen results in a strong bond. According to Vasudevan et al. (2012), 10–15% mix of plastic can be used as a coating of aggregates before mixing with bitumen. He made practical analysis explaining that using plastic wastes in plastic roads helps to avoid burning of plastics along with municipal solid waste. This releases toxic gaseous emissions that form a part of the greenhouse gases and hence contributing to global warming and above all, climate change. According to Vasudevan et al. (2012), a tonne of plastic waste is used for every 1 km of road laid. This is supposed to reduce carbon dioxide emission by 3 tonnes. The number of roads built with plastic wastes in India is over 2500 km and this led to a reduction of about 7500 tonnes of carbon dioxide from the environment. Also, plastic wastes burnt along with municipal solid waste contributed to the release 250,000 tonnes of carbon dioxide.

The results from Vasudevan R. et al (2012)'s experiment proved that plastic roads will be of a higher quality than the normal conventional roads. Assessing the economics, Vasudevan et al. (2012) contradicted that of Verma (2008) saying that the cost is reduced for plastic road construction when compared with that of conventional roads. Part of the amount used for the 10% reduction of bitumen would be used to purchase plastics. This would end up reducing cost.

The two main methods that are needed for the process are the Dry process and Wet process. Sahu and Singh (2016) summarize the two processes as mentioned above. In the dry process, Sahu and Singh (2016) explained that after the separation of plastic wastes from non-plastics, the plastics are washed and shredded to smaller sizes. After the shredding is done, the aggregates are heated up to 170°C and the plastic wastes are added which softens and melts (but does not burn) to form a coating around the aggregates. The bitumen is also heated to 160°C. The plastic-coated aggregates are mixed with the bitumen and used for road construction. The road properties were improved with this practice.

Sahu and Singh (2016) further explained the wet process. After the washing, the plastics are ground into powder. 6–8% of this is directly mixed with the bitumen before adding to the aggregates. The mixing should be done well to ensure even mix of plastic and bitumen and the temperature range for this method is between 155 and 165°C. The bitumen requirement is reduced by 10% if the percentage of plastics is also increased.

Rokade's (2012) work factored both the dry and the wet process of mixing plastic with asphalt. The low-density polyethylene (LDPE) plastic was used for the dry process and crumb rubber was used for the wet process. Different percentages of these were used for the experiment where the Marshall method was employed. Five per cent of the bitumen content of the 60/70 grade was used whereas 3%, 6% and 9% of LDPE and 8%, 10% and 12% of the crumb rubber were used in the experiment.

The results for the LDPE mix showed that increasing the percentage of the plastic also increased the Marshall Stability and bulk density. On the other hand, values for the Marshall stability increased with that of the crumb rubber up to 10% and then decreased but the bulk density increased up to 12%. All other parameters were well within the standard values. The use of plastic that is 5–10% of bitumen improves the Marshall stability, strength, fatigue life and other required properties that go a long way to increase the lifespan of the road whereas some bitumen is saved too, Gawande A. et al., (2012).

Chavan's (2013) comments on the bitumen reduction is no different. She said that the use of plastic waste would help to reduce the bitumen used by 10% while still increasing the value of its properties. There will not be the need for any anti-stripping agent. Rokdey, Naktode, and Nikhar (2015) experiment compared the compressive strength and the bending strength for varying percentages of plastic. These are 10%, 20%, 30% and 40%. The compressive strength and the bending strength had high values that were well within the specification. The present research would study which percentage of asphaltic materials could be made from plastic wastes and how this can work for Ghana when it comes to road construction as road utilization policies for small and heavy duty cars and road maintenance frequencies are limited for case of Ghana compared to other advanced countries. It has been reported that about 61% of Ghanaian roads currently are poor (Amoako-Atta, 2017). Above all, there are frequent generation of potholes on Ghanaian roads as a result of heavy traffic and axle weight (Appiah, Berko-Boateng, & Tagbor, 2017).

2. Methodology

Polystyrene and polyethylene plastic wastes were retrieved from social gatherings, residential areas and restaurants. They were then thoroughly washed, dried and taken to the Accra Compost and Recycling Plant (ACARP) to be shredded to the sizes ranging from 2 mm to 4 mm according to Gawande et al. (2012). The small plastic size will allow for even coating of the aggregates. In order to assess the performance of the plastic waste in the bituminous mix, two different sets of tests were performed on the materials needed for the mix. The materials needed were plastic wastes, aggregates and bitumen. The two sets of tests were; Tests conducted on the aggregate coated with plastic waste and Tests conducted on the asphaltic mix with plastic waste.

2.1. Tests conducted on the aggregate coated with plastic waste

The aggregates of sizes 10–20 mm were heated to around 160–170°C with a hot plate in the laboratory. It was then mixed with melted shredded plastic wastes, which were stirred with a spatula to attain a uniform and thorough coating of plastic 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 tests where records and observations of its properties were made and compared to another aggregate sample that was not mixed with plastic waste to give it a coating. This served as the control sample. Various tests conducted here include;

2.1.1. Apparent density and bulk specific gravity: (ASTM C127)

According to the Ghana Highways Authority (GHA), aggregates are porous by nature. The determination of the porous nature of the aggregates can only be done by the conduction of the Apparent Density and the Bulk Specific Gravity tests. The Apparent density helps to identify the pore spacing that will absorb the asphalt. The Bulk Specific Gravity helps to identify all the pores in the aggregates. The more porous it is, the lesser its workability. Knowing how much of the bitumen will be absorbed, will help determine the exact excess of bitumen to add in order to make up for the loss. The more porous the aggregates are, the more they will absorb the bitumen. When the aggregates are coated, the plastic seals all the voids and does not allow for absorption of the bitumen. When more plastics are introduced percentage voids reduces as molten plastics fills all voids in the asphaltic material. Hence the amount of bitumen used in highway construction is reduced. The use of the pyconometer method is required for this test. Here, the empty pyconometer bottle is first weighed and recorded. It is filled with water to the brim, weighed and recorded. The mass of the water is calculated. The temperature of the water is also taken as well as the density of the water at the test temperature. The bottle is weighed with dry aggregates and recorded. The mass of the aggregates is calculated. The bottle with aggregates is filled with water to the brim and recorded. The mass of the water displaced is calculated. This was done for both the control and the PCA. Calculations were made to determine the apparent density.

2.1.2. Water absorption and bulk specific gravity: (ASTM C127-04 and C29)

It was performed to identify the capacity of aggregate's resistance to water. Aggregates used for road pavements must have low water absorption capacity (<2%). To begin with, both samples (the PCA and the control where the aggregates are not coated) were taken and soaked in water for 24 h so that all air spaces are filled. Afterwards, they were then brought out, quickly dried on the outer surface with a dumb towel. This is to avoid complete drying of the aggregates. This procedure is followed by the use of the Pyconometer method. Prior to removing the aggregates from the water, the empty pyconometer bottle is first weighed and recorded. It is filled water to the brim, weighed and recorded. The mass of the water is calculated. The temperature of the water and the density of the water at the test temperature is recorded. The aggregates that are removed from the water and dumb dried are put into the bottle, weighed and recorded. The mass of the aggregates is calculated. The bottle with aggregates is filled with water to the brim and recorded. The mass of the water displaced is calculated. Aggregates are emptied from the bottle put into a pan and oven dried at a constant temperature of 110°C and allowed to cool. An empty pan is weighed and recorded. The pan is filled with the dry aggregates and weighed to get the dry mass of the aggregates. To enable us to get the value for absorption, the Bulk Specific Gravity and the Bulk Density of stone were first calculated. This experiment was done for both the PCA and the control.

2.1.3. Aggregate impact test: (ASTM D5874)
Test was performed to evaluate the toughness or the resistance of aggregate to fracture and how suitable it is for road construction under repeated impacts. The two samples were taken after passing them through sieves with spacing of 14 mm and 10 mm. Both samples were each weighed separately and recorded. The aggregates were pre-heated under a constant temperature of 110°C for 4 h and cooled. This was to ensure that the aggregates are dry. The cylindrical steel cup of the impact testing machine was filled with the weighed sample. A tamping rod was used to give the sample 25 gentle blows to allow for even distribution and also to avoid any depressions in the cup. They were then sent to the crusher where various samples were subjected to 15 blows of a hanged-tap hammer of weight 14 kg. The interval between each blow was less than a second. There was no adjustment in height of the hammer once the blows were executed. The crushed aggregates were sieved on a 2.36 mm sieve and the retained materials were weighed and recorded. The observed weight difference in each sample represents the impact value which determines their toughness.

2.1.4. Los Angeles abrasion (LAA): (ASTM C131)
The repeated movement of the vehicle will produce some wear and tear over the surface of roads. Thus, the principle of Los Angeles abrasion (LAA) test is to find the percentage wear and tear of aggregate due to relative rubbing action between the aggregate and the steel balls used as abrasive. The Los Angeles test is a measure of degradation of mineral aggregates of standard grading resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres (Habeeb, 2017). That is, a high-quality aggregate must be able to “resist crushing, degradation and disintegration” (Habeeb, 2017).

This test was performed by taking 5000 g of each sample at size 14 mm (i.e. passing through 20 mm and retained at 14 mm) and placed into different LAA wheels each containing 12 steel balls. Rotations were done for 15 mins. During the rotation, the steel balls together with the aggregates were moved up and allowed to fall. The steel balls then crush the aggregates. The weaker aggregates were crushed to dust in the process. Later, the crushed aggregates were sieved with a 1.18 mm sieve. The retained materials were measured. The observed weight loss which represents the abrasion resistance was determined from the difference in weight after abrasion action from the LAA wheel. PCA showed maximum resistance towards abrasive action than control sample.

2.2. Tests conducted on the asphaltic mix with plastic waste
The aggregate of varying sizes ranging from dust to 14 mm was coated with plastic wastes and subsequently mixed with bitumen of AC 10. The temperature was kept at 160°C for the mixing process to attain a plastic-coated aggregate bitumen mix (plastic asphalt). A control was also prepared by mixing the melted bitumen directly with the aggregates. The plastic asphalt and control were then cooled and subjected to the following tests.

2.2.1. Stripping test: (ASTM D4469/AASHTO T182-84)
Test is performed to evaluate asphalt adhesion towards water. Aggregates of size 6.3 mm (i.e. passing through 10 mm and retained at 6.3 mm) were placed in an oven to remove moisture. 100 g of aggregates was mixed with 5 g of bitumen. The control was prepared by mixing the oven dried aggregates with bitumen. The PCA was made and then mixed with bitumen at temperature 160°C. The plastic asphalt was attained and cooled; it was later immersed in distilled water for 24 h. The distilled water totally covered the samples. In a stripping test, the water is able to penetrate into the tiny pores of the aggregates used for the control. Gradually, the water is able to separate the

bitumen from the aggregates. When this happens on a road, pot holes will begin to appear on the roads. It was observed that PCA showed no sign of stripping as compared to control sample. This was due to a good bond between plastic and bitumen which made the mixture hardly to be removed by water. Also, plastic wastes act as a modifier to bitumen which enhances it properties.

2.2.2. Marshall stabillity and flow (ASTM D6927 −15)

Marshall Stability is the measurement of the strength of the road. Aggregates ranging from dust-14 mm (0–14 mm) were taken and sieve analysis was performed to get a mix design. From design, various sizes and quantity was taken and place in an oven to remove moisture. Plastic wastes at varying percentages (i.e. 10%, 30%, 50%), aggregates and varying amounts of bitumen were then mixed at temperature around 160°C to acquire plastic asphalt. They were then put in a moulding container that is cylindrical in shape to give the desired shape. The mixture was compacted by subjecting the plastic asphalt to 75 blows with a rammer at one side and turning the other side and giving the same 75 blows to form various brickets which were subjected to various tests. At the Ghana Highways Authority (GHA), brickets must weigh up to 1200 kg. These tests include the Marshall Stability Value, Air Voids and Flow Value and Specific Bulk Gravity. One of the brickets formed is soaked in water at 60°C for 30 min. After that, it was put into a breaking head on a loading machine. This machine is able to read the Marshall Stability and the flow values. The Marshall Stability must prove the strength of the bricket, but it must flow in order to have a flexible pavement or road. The presence of the voids makes the flow or flexibility possible. Observations made were that; after compaction, bricket appeared firmer and stronger, hence it proves that plastic wastes added strength and also served as a good binder. It may reduce lime and fillers used in asphalt to improve these qualities. Calculations were made to get the values for air voids and Specific Bulk Density. After the bricket were formed, the height and the diameter of the bricket were taken. The bricket was then weighed in the air on a scale as D. It was then put in water for not less than five (5) minutes and quickly removed and put into a density table. The weight was then recorded as E. The weight of the bricket is taken again in the air while it is still moist from soaking in water as F. The bulk volume and the Specific Bulk Density are then calculated. To help us calculate for percentage of air voids, another experiment called the GMM (Theoretical Maximum Specific Gravity) was performed. In this experiment, a pyconometer flask is used. The flask is first weighed empty with its lid. The flask is filled with water to the brim, covered with the lid and weighed. The sample is placed in the flask and weighed. Water was poured up to half of the flask to totally submerge the sample inside it. A vacuum pump was then used to remove all the air inside for 15 min. In the absence of a mechanical agitator, manual agitation was used to agitate the flask to enhance vacuum pump activity. The flask was then filled to the brim and weighed again in a density table. After this, the sample was then emptied from the flask, dried and weighed again. Calculations were made to get the GMM value. The formulas given below are those given by GHA.

Bulk Volume is given as

$$G = F - E, \text{ where}$$

G is the Bulk Volume, E is the density of the bricket and F is the weight in air of the moist bricket.

The Formulae for the Bulk Specific Gravity is given as

$$\text{Bulk S. G} = (D/G)^{*}H, \text{ where}$$

Bulk S. G is the Bulk Specific Gravity, D is the weight of the dry bricket in the air, G is the Bulk Volume and H is the temperature of the water used for soaking the bricket.

The Formulae for percentage Air Void is given as

% AirVoid $= 100(\mathrm{I} - \mathrm{H})/\mathrm{I}$, where

% Air Voids is the percentage air voids, I is the GMM and H is the temperature of water.

The Formulae for the GMM is given as

Sp.Gr $= \{D/(G + E - F)\}^{*}A$, where

Sp. Gr is the Theoretical Maximum Specific Gravity, D is the weight of the sample in air, G is the weight of sample surface dry, E is the weight of flask with water, F is the weight of sample in flask filled with water to the brim with the lid and A is the temperature of water used.

2.2.3. Bitumen extraction test: (ASTM D2172)
The principle of this test is to find out if the amount of bitumen recommended to road contractors was used for the road construction. This experiment is done to verify whether all the bitumen will be removed after extraction for both the control and the plastic asphalt. There are different types of extractors and they are the centrifuge, reflux, vacuum and the extraction kettle. The GHA uses the centrifuge type of extractor for the extraction process. 500 grams of each of the samples was measured and put into the extraction bowl. Trichloroethylene (TCE) was the solvent used for the extraction. The TCE was poured into the extraction bowl to totally cover the sample. A filter paper was weighed (F1) before it was used to cover the extraction apparatus. The cover of the apparatus was put over the filter paper and clamped into place. The TCE was allowed to remain on the sample for 30 min before the centrifuge was run. A jar was placed at the mouth of the drain pipe to collect the extracted solvent. the extractor is run until all TCE was drained from the sample. The TCE was added to submerge the sample in the extractor bowl, and the cycle of extraction was done for two more times. At this stage, the colour of the extracted solvent had become very light coloured. The control and the filter papers were oven dried to 105–110°C and cooled to room temperature. The filter papers collected the grits that would have attached to the cover of the extractor. The plastic asphalt samples were sun dried to avoid the plastic from melting in the oven. Each of the samples and the filter papers (F2) after drying were weighed.

The Formulae for the Percentage of binder in the total mix was calculated as

Percentage of Binder in the total mix $= (W1 - (W2 + W3))/W1)^{*}100$, where

W1 is the weight of the sample taken, W2 is the weight of the sample after extraction, W3 is the increased weight of the filter paper (F2-F1).

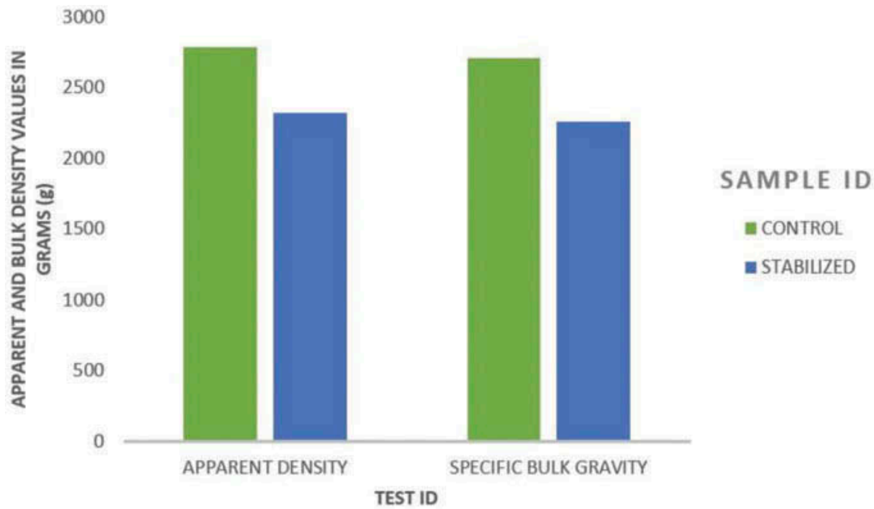
Observations made prove that, plastic wastes had a good bond with bitumen, therefore, making complete extraction of bitumen to be very difficult as compared to asphalt with no plastic waste (control sample) where there was an almost complete bitumen extraction. This disclosed that, an inter binding surface layer of plastic wastes and bitumen exist, which gives strength and improvement in the plastic-bitumen bonding.

3. Results and discussion

3.1. Results of tests conducted on plastic coated aggregates

3.1.1. Apparent density and specific gravity: (ASTM C127)
The only tests in which the performance of the PCA seemed poorer than the control was in the Apparent Density and Specific Gravity tests. The specific gravity and apparent density of an aggregate are the indirect measurements of its strength and weight, with and without voids respectively. In both tests, higher values are indicative of better strength. However, for these two tests, the GHA standard values should be ≥2500 Kg/m^3 but the results from Figure 1 show

Figure 1. Apparent density and specific bulk gravity.



that values for the PCA were lower than standard required apparent density and specific bulk density. The values were 2320 Kg/m^3 and 2255 Kg/m^3 which were 7.2 and 9.8% lower than the standard value of 2500 Kg/m^3 respectively. However, the slight deviation in these values compared to the standard does not necessarily mean that the new PCA is not workable. Results having values less than the standard values implies that the aggregates are light in weight and therefore may be brittle. Nevertheless, the tests conducted on the Aggregate Impact test and LAA show that the aggregates are rather tough and strong. The results can be seen from Figures 3 and 4 respectively.

The observed values not meeting the standard may probably due to the manual mixing of the plastic wastes as a result of lack of a mechanical mixer. It could also be because both the PE and the PS were combined before using it to coat the aggregate. Such a combination has not been found yet in literature. These suggestions may have increased the bubbles and hence reducing density.

3.1.2. Water absorption

Another important consideration in the design of flexible pavements is the water absorption property. According to the GHA, water absorption for materials used in flexible pavement should have an absorption percentage of not more than two. Deducing from Figure 2, the control sample

Figure 2. Water absorption.

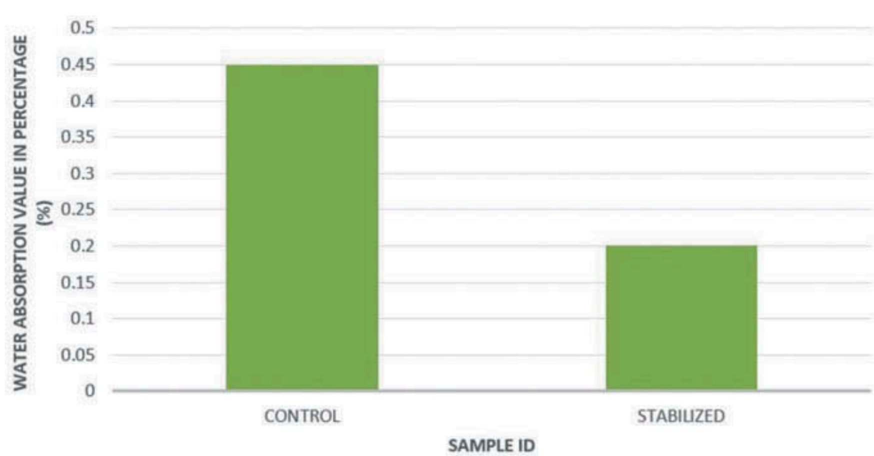


Figure 3. Aggregate impact test.

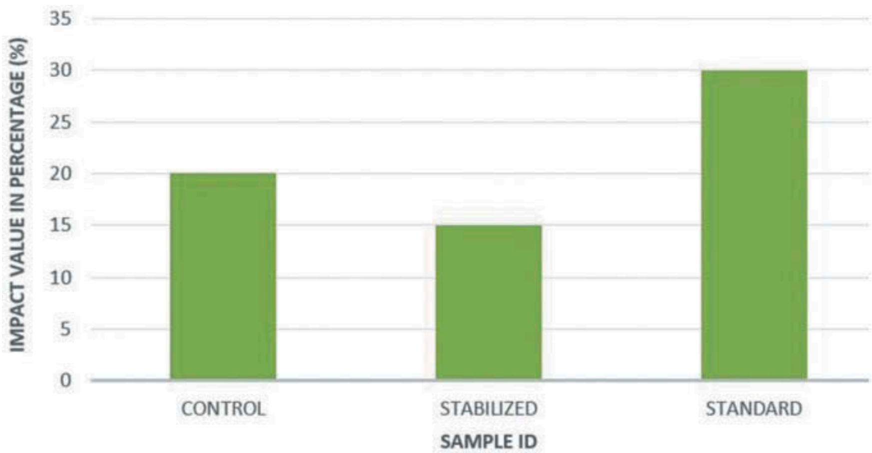
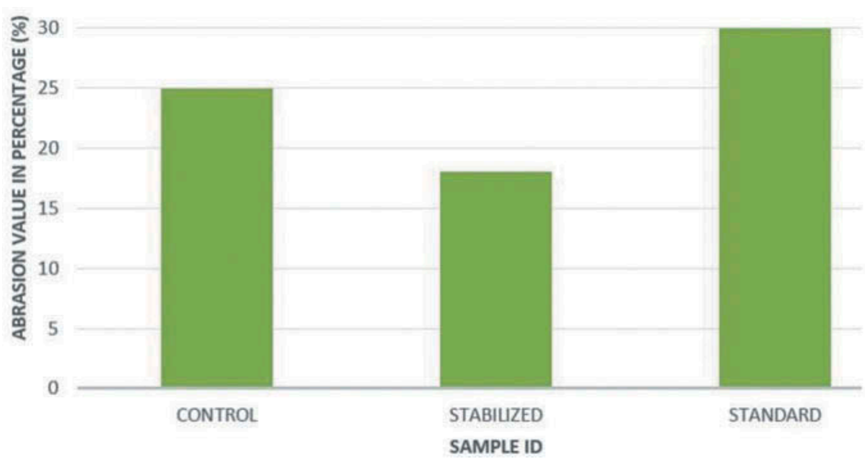


Figure 4. Los Angeles Abrasion.



absorbed 0.45%, whereas the PCA improved upon it by absorbing 0.2% of water. This indicates that the control sample absorbed more water as compared to the PCA which absorbed less water of 0.2%. The water absorption gives an indication of the road's resistance to potholes (Sahu & Singh, 2016). There are areas that are waterlogged and roads constructed in those areas have not seen the light of the day. Large potholes are created in the roads to the extent that, part of the road, begins to peel off. In such areas, there is the need to utilize plastic wastes in the roads constructed since absorption is minimal and such roads can last longer even up to 10 years compared to the conventional roads, which are 5 years as reported by Yerkar, Jagtap, and Borkar (2017).

3.1.3. Aggregate impact test

Comparing PCA to control sample shows that plastic wastes have added value to aggregate by improving its toughness as can be seen from Figure 3.

Aggregates should be tough enough to withstand the impact that it receives as motorists ply the road. Although both the control and the PCA obtained Aggregate Impact values within the standard (<30%), the PCA performed much better than the control sample by reducing the Aggregate Impact Value from 20% to 15%. The 20% indicates that many of the aggregates were broken into smaller particles as compared to the 15%, which represents a few of the aggregates that were broken after the impact was done repetitively. The plastic coating around the aggregate will be deemed as protecting the aggregate from totally breaking down to dust or smaller particles thus, indicating a lower crushed fraction under load. The plastic coating on the aggregate may be acting as impact absorber that reduces the force exerted on the aggregates when subjected to loading or activity. This enhances the properties of the aggregate's performance. This also means that heavy-duty vehicles plying the roads will do little damage to roads made with plastic wastes. It also translates into improved road quality and a longer service life. Also, inferior quality aggregates can be made improved by coating with plastic wastes. According to Vasudevan et al. (2012) the brittleness of the aggregates is a measure of its Impact value. When aggregates are coated with waste polymers, voids and the air cavities present in the aggregates are reduced and this prevents the cracking on load.

3.1.4. Los Angeles Abrasion

The results of the Los Angeles Abrasion (LAA) Test also showed improved performance when comparing the PCA to the control sample as seen from Figure 4. The percentage of the aggregates that underwent wear and tear reduced from 25% to 18%, against the standard of less than 30%. The 18% LAA value for the PCA shows that the plastic used to coat the aggregates has made it tougher than it was and so was able to resist the abrasion from the steel balls.

3.2. Results of tests conducted on plastic asphalt

The results from the stripping test in Table 1 proved that the plastic waste addition improved the adhesion of bitumen to the aggregates. According to the GHA standard, the stripping value should be less than 5%. Fortunately, no stripping occurred within 48 h of the stripping test for the plastic-coated aggregates whereas there was stripping for the non-coated aggregates. This shows that if the control were laid on the road and the PCA were also laid on the road, the control will begin to experience the bitumen peeling off as water penetrates in it and therefore potholes will result from that, but that result will not be the same for the PCA. Bitumen tends to bond well with plastic wastes, making asphalt robust, thereby reducing the affinity of aggregate towards the water to zero. It can also be said that most plastics are hydrophobic which repels water and thus keep water out of reach of aggregates and this reduces the affinity to water and enhances aggregate properties. Also, plastic wastes can reduce anti-stripping agents which would have been added to asphalt to reduce stripping. According to Vasudevan et al. (2012), the molten polymer does not only fill the voids of the aggregate and binds them together but also strongly binds with bitumen which leads to the formation of organic bond. The stripping test results are shown below;

Control-Asphalt without plastic

Stabilized—Asphalt with plastic

Table 1. Results for the stripping test

			Observation made for bitumen stripping	
A	**Weight of bitumen added (g)**	**Weight of plastic added (g)**	**After 24 hours**	**After 48 hours**
ASTM			< 5%	
Control	5	0	No stripping	Stripped < 5%
Stabilized A	3	2	No stripping	No stripping
Stabilized B	2	3	No stripping	No stripping
Stabilized C	1	4	No stripping	No stripping

3.2.1. Marshall stability and flow

With the Marshall Stability test, the higher the value, the better. Gawande et al. (2012) explained that "Marshall stability is related to the resistance of bituminous materials to distortion, displacement, rutting and shearing stresses." This shows how vital it is to perform this test. It was observed that the more plastic was added, the more the Marshall Stability value increased as seen in Figure 5. The plastic was increased from 10% to 30% and then to 50%. The values increased from 21.0 to 23.8 and then to 26.3, respectively. These values were all higher than the control which gave a value of 15.1. Their corresponding flow values were given as 6.6, 8.2, 9.8 and 4.2, respectively. That of the percentage voids also follow as 10.02, 12.33, 14.93 and 5.31, respectively. Aggregates sizes of zero –14 mm, which is recommended by GHA to be used for the wearing course in road construction, was used for the experiment.

From the above discussions, it can be seen that all parameters were better than the standard with the introduction of plastic wastes to the asphaltic materials. The more the plastic wastes the better the quality standards as observed from the marshall stability test. This means that as more plastic wastes are introduced while getting superior qualities of asphaltic materials, it also introduces economy into plastic wastes management and road construction. The funds needed to manage plastic wastes will be reduced due to reduced plastic wastes in the system whiles at the same time serving as an alternative cheaper material for road construction. This constitutes a key novelty in this research.

The standard values of Marshal Stability for wearing course should be 9 −18 whereas the flow and the percentage voids are 2–4 and 3–5, respectively. The standard Marshall Stability values for the Dense Bitumen Macadam (DBM) are 8.2–18, whereas flow and the percentage voids are 2–4 and 4–8, respectively. The values of air voids from the experiment are rather close to that of the DBM. The Marshall Stability values with 10% plastic addition produced results close to the standard values whereas higher percentages of plastic wastes had Marshall Stability values that were not close to the standard. This could be due to the fact that addition of plastic wastes to the aggregates increases the sizes of the aggregates from the original 0–14 mm to about 0–40 mm.

3.2.2. Bitumen extraction test

The last test conducted was the extraction test. This test helps to examine if the amount of bitumen in the asphalt meets the GHA standard value. The control sample had an extraction value of 4.9% whilst the plastic asphalt with 10% and 50% of plastic performed better, with lower extraction values of 3.7% and 2.3%, respectively. Making deductions from Figure 6, it can be seen from the results that, only 0.1% of bitumen remained on the aggregates after three cycles of extraction for the control. 0.3% of the bitumen remained from the plastic asphalt containing 10% plastic wastes whereas 0.7% of the bitumen remained from the plastic asphalt with 50% plastic wastes added. This shows that the more plastic wastes are added, the more the asphalt resists the

Figure 5. Marshall stability.

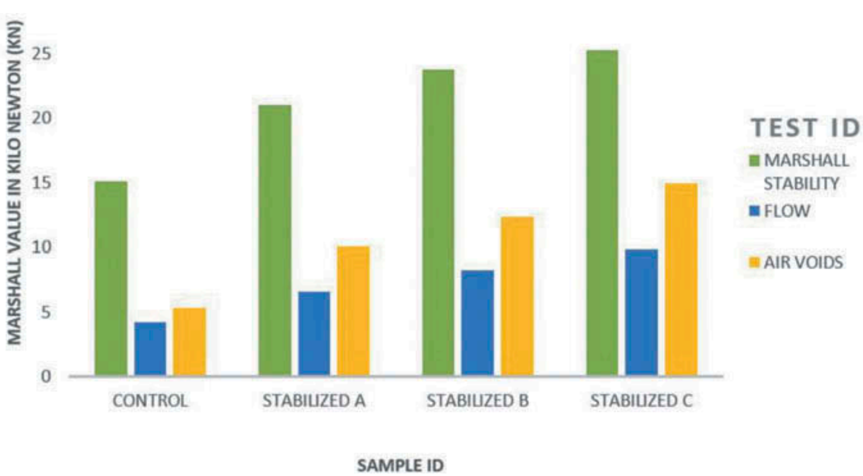
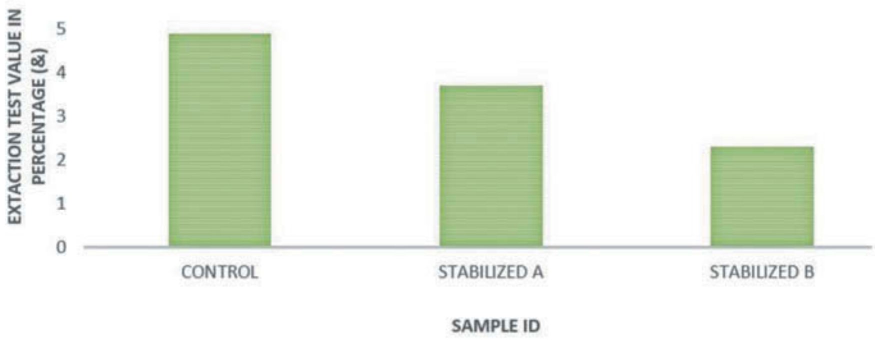


Figure 6. Bitumen extraction.



extraction. Vasudevan et al. (2012) as mentioned earlier talked of how easy it was to extract bitumen from the control with TCE (trichloroethylene) but had it tough with the plastic asphalt until he added decaline. It was then that he was able to completely remove the bitumen from the aggregates. He continues to explain this phenomenon as happening because of the bond created between the PCA and the bitumen getting stronger with the increasing amount of plastic waste (that is 10%, 20% and 25%). Such solvents are perhaps spilt on the roads during a car accident. With road accidents occurring every now and then, it will be appropriate to protect the roads by incorporating plastic wastes into the road construction.

4. Conclusion

Various tests were conducted on the plastic-coated aggregate (PCA) and the plastic asphalt to determine their quality standards for roads in Ghana. Each test was compared to a control (aggregates not coated with plastic waste) and Ghana Highway Authority Standards for roads. Different percentages of plastic wastes that were combined with the asphalt were 10, 30 and 50. After conducting the experiments, it was realized that the stripping test result proved to be very good because even after 48 h there was no stripping for the plastic asphalt compared to the control. The PCA absorbed a - very minute quantity of water compared to the control. Both the Los Angeles Abrasion test and the Aggregate Impact Value test produced better results than the control. The density and specific gravity had values that decreased compared to the control tests. The same anomaly was seen for the Voids in the Mineral Aggregates (VMA), which had high values compared to the control. Perhaps the manual mixing of the plastic waste with the aggregates and combining the PS with the PE may have influenced these values. The aggregates might have increased in sizes as they were being coated before bitumen was added. This research has proven that plastic coated aggregates can do better as Dense Bitumen Macadam than conventional asphalt in the construction of Highways. It was also found that more than 10% of asphaltic road materials in Ghana could be made of waste plastics to meet Ghana Highway Authority Standards and even with superior qualities. The novelty finding in this research is that substitution of about 10% or more of asphaltic road materials in Ghana with plastic wastes could bring economy and cost savings in both road construction and plastic wastes management in Ghana.

Funding
The authors received no direct funding for this research.

Competing interests
The authors declare no competing interests.

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Citation information
Cite this article as: Evaluation of incorporating plastic wastes into asphalt materials for road construction in Ghana, Patricia Nana Ama Asare, Francis Atta Kuranchie & Eric Antwi Ofosu, *Cogent Environmental Science* (2019), 5: 1576373.

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