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Performance Evaluation of Plastic Modified Asphalt Enhanced with Recycled Glass Powder

Evaluarea performanței asfaltului plastic modificat îmbunătățit cu pulbere de sticlă reciclată

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Abstract. *This study investigates the use of non-biodegradable wastes namely plastic water bottles and recycled glass in the construction of flexible pavements which, conventionally, uses bitumen as the binder and cement or stone dust as the filler. Consequently, the binder and filler were modified using varying percentages of pulverized plastic and recycled glass powder respectively. The modified binder showed improvement in properties when compared to the unmodified bitumen. The asphalt produced thereafter using the modified materials indicated a stability of 3.33kg obtained at an optimum value of 6% plastic replacement which is higher than the 2.017kg obtained without modifying the bitumen.*

Key words: non-biodegradable, bitumen, pulverized, stability, asphalt

1. Introduction

The construction of highways involves a huge outlay of investment. A precise engineering design may save considerable investment but the selection of improved and better mixes will reliably improve the performance of the in-service highway. The quantum of non-biodegradable waste in municipal solid wastes is increasing due to population increase, industrialization and change of life style, which lead to widespread littering of the landscape [1]. Thus, the disposal of these wastes has become a serious problem globally due to their non-biodegradability and unaesthetic sight. Since these wastes can take several years to degrade, it is of urgent need to look for alternative ways to dispose of them. There are three major ways to deal with this kind of wastes namely burying, incineration and recycling [1].

In a bid to be actively involved in the waste to wealth policies through recycling and transformation of non-degradable waste, the re-introduction of these waste as raw materials can be effective in reducing the consumption of natural resources and in managing the environment [2]. Re-introducing these wastes into construction is an important step in reducing the cost of construction, creating stronger asphaltic concrete for road construction, creating other products like asphalt-based roofing tiles as well as managing the quantity of waste especially the non-biodegradable ones from the environment thus, making it multi-advantageous.

Plastics and polythene do not decompose naturally and they have been found to be environmentally unacceptable due to their negative impacts on the environment, thus, alternative methods have to be implemented to recycle these materials. There have been numerous modifiers that can be used to improve the properties of road surfaces, but most of these had been found to be uneconomical [3]. Use of Low Density Polyethene (LDPE) and waste plastic bottles as modifiers in road surfaces can potentially reduce material wastage and improve the performance of road surfaces. Recycling of waste materials serves important purpose of eliminating an expensive and environmentally unacceptable solid waste disposal problem [3]. At present, researchers have been finding ways of incorporating recycled materials into asphalt pavements instead of disposing off in landfill because of the risks associated with land filling using waste materials as well as disposal problem.

Waste glass is one of the least recycled materials globally as it requires relatively large amount of energy to melt the cullet. Over the last 10 years, the quantity of treated waste glass has risen to about 70% due to improved glass collection systems in developed countries [4]. Notwithstanding, the glass waste recycling infrastructure still suffers from unavailability in developing countries thus an alternative solution is required to solve the problems of glass waste. Being an amorphous material and having relatively high silicon and calcium contents, glass is pozzolanic or even cementitious especially when the finesse of the glass powder is much greater than that of the Portland cement [5].

Hence, this study aims at determining the effectiveness of using recycled glass powder as filler replacement in the production of plastic modified asphalt by comparing the properties of the unmodified asphalt with those of the asphalt modified with recycled glass and plastic. This study provides information about the optimum utilization of these wastes (plastic and recycled glass powder) in the production of enhanced bituminous mix, as well as highlights the potential use of these wastes as large scale modifiers and raw materials for the production of asphalt.

2. Background Literature

The poor performance of bituminous mixtures under increased traffic volume and heavier axle loads has led to increased use and development of modified bitumen especially the use of discarded vehicle tires in pavement construction. Modified binders generally exhibit decreased temperature susceptibility and potentially improved mix performance [6].

Relevant studies considered the improvement in physical and chemical alternative materials as they may enhance efficiency and lifetime of asphalt [1]. A great amount of money is spent on rehabilitation and reconstruction of roads and pavements in most countries every year. One of the major disadvantages of using bitumen in road construction is its phase change as a function of temperature. Bitumen is brittle at low temperatures and turns into liquid at high temperatures, which is called temperature susceptibility. Base bitumen should be modified to reduce its temperature susceptibility hence prompting various researches on ways to enhance the material economically.

Asphalt modification can be made at different stages of its usage from binder production to asphalt pavement production and can be made using different modifiers [7]. Glass is a potentially promising modifier to asphalt as it is a non –metallic and inorganic material made by sintering selected raw materials comprising silicate and other minor oxides. The ratio of its main oxides namely, SiO_2, Na_2O, CaO are: 77%, 9.4% and 6.7% respectively. Glass can be recycled without changing its composition and properties. Because of the availability and wide spread application and increased consumption in our daily lives, a large quantity of this waste is generated annually. The best way to deal with these wastes is to recycle and reuse them as raw material or modifiers,

There are two primary approaches of recycling waste glass, one is direct and the other is indirect. The first process is to manufacture tabulate glass products utilizing worked broken glass particles. This can save 1.1 tonnes of raw materials such as (quartzite gravel and limestone) and 140 liters of heavy oil. The second process is to manufacture products with some glass content, such as clay bricks, filling materials, building decorations, soundproof or adiabatic materials [8].

By crushing and sieving, waste glass can be used as fine aggregate in asphalt concrete. This is called glasphalt. Satisfactory performance of upper asphalt pavement layers can be obtained with a dosage of between 10 and 15% by weight of the asphalt. Larger amounts may induce stripping problems and make the pavement sensitive to water damage [8].

Investigation into the effects of the use of waste plastic as strength modifiers in the surface course of flexible and rigid pavements showed that despite the large number of polymeric products, only a few are compactable with asphalt cements and these compactable ones are thermoplastics, plastomers and reactive polymers [3]. The thermoplastics were able to embed good elastic properties on the modified binders while the plastomers and reactive polymers were added to improve the rigidity and reduce deformation under load. Their tests showed a substantial increase in Marshall

Stability values of the Bituminous Concrete (B.C) Mix in the order of 2 to 3 times higher than B.C with untreated/ modified Bitumen.

Recent research carried out on the performance of asphalt modified with used tires through the wet process deduced that the asphalt produced had improved Marshall stability values, higher resistance to deformation and increased resistance to temperature changes [6].

In the study conducted on utilization of waste plastic fibers as partial replacement of bitumen through the dry process, it was discovered that at 6% by weight of binder plastic fiber replacement, an optimum stability was achieved and an increase in Marshall Stability of the mix was obtained to a tune of 50-60% above that of the unmodified sample [2].

In the process of improving asphalt by modifying it with plastic, it was discovered that the bitumen modified with crumb rubber (CR) and recycled glass powder (RGP) was more flexible than the unmodified material and that the rutting parameters of the samples modified with CR and RGP were about 180% higher than the control sample and about 40% higher than samples modified with CR alone. It was also observed that the mixtures modified with RGP had higher stiffness than the control mixture and the pavement constructed showed less strain at lower temperatures [1].

Similar studies showed that some of the benefits associated with incorporating glass into asphalt include: reduction of cost through utilizing of waste as raw materials, improved asphalt characteristics, pavement surface appears to dry faster than conventional asphalt because glass does not absorb water. The surface showed reflective characteristics which improve night travels, the mix is highly workable when paving and compacting as it retains heat more than conventional asphalt and above all, it helps reduce the volume of waste glass littering the environment [4].

2.1 Asphalt Concrete

This is a composite material commonly used in construction projects such as road surfaces, airports and parking lots. It consists of bitumen (used as a binder) and mineral aggregates which are mixed together, laid down in layers and compacted. Mixing of asphalt and aggregate is accomplished in one of several ways namely hot mix asphalt concrete (considered in this study), warm mix asphalt concrete, cut-back asphalt concrete and cold mix asphalt concrete.

Hot mix asphalt as the name implies is mixed at high temperatures and possesses the following properties: resistance to permanent deformation, resistance to fatigue and reflective cracking, resistance to low temperature (thermal) cracking, durability, resistance to moisture damage (stripping), workability and skid resistance.

3. Methodology and Materials

The materials used for this study are coarse aggregates comprised of crushed rock that cannot pass through sieve No. 4 with an aperture of 4.76mm, fine aggregates comprised of crushed rock aggregates which pass through a 9.51mm (3/8-in.) sieve, pass almost entirely through a 4.76-mm (No. 4) sieve and is predominantly retained on a 74-μm (No. 200) sieve and filler (in this case, stone dust which was selected because of its high use as mineral filler in asphalt production plants in Nigeria) which fills the pore spaces and aids and comprise of any of Portland cement, charcoal, palm kernel ash, kieselguhr (the silicon remains of mollusk shells) and sieved fine crushed rock aggregates with particles passing through sieve No. 200.

Other materials used are:

Bitumen, which is a crude oil derivative having black to dark brown color. It is a semi-solid hydrocarbon product produced by removing the lighter fractions (such as liquid petroleum gas, petrol and diesel) from heavy crude oil during the refining process. As such, it is correctly known as refined bitumen. At ambient temperatures bitumen is a stable, semi-solid substance. By increasing the temperature of bitumen, it turns into plastic and liquid material. In North America, bitumen is commonly known as “asphalt cement” or “asphalt” while elsewhere, “asphalt” is the term used for a mixture of small stones, sand, filler and bitumen, which is used as road paving material.

Glass Powder which was obtained as a result of grinding waste glass bottles obtained from refuse dumps into smaller particles with size 0.075mm which pass through sieve No 200. Plate 1 shows a sample of the recycled glass powder used in this study.

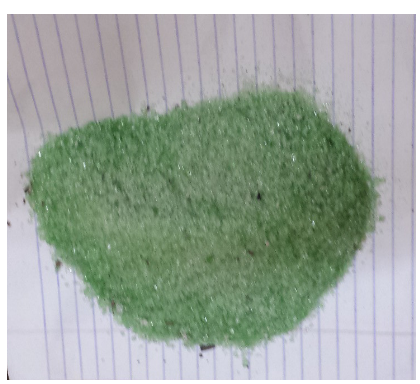

Plate 1. Sample of the recycled glass powder used in the study

Plastic, which is typically a synthetic polymer, most commonly derived from petrochemicals. They can be molded into shape while soft, and then set into a rigid or slightly elastic form. Due to their adhesive properties, they can be utilized in the production of asphalt by shredding or blending them. In this study, pulverized Polyethylene Terephthalate (PET) plastic, as shown in plate 2, was used as plastic modifier.

Plate 2. Sample of the pulverized PET plastic

The selected aggregates were air dried to remove moisture from them, the air drying was preferred to the oven drying because loss of material quality was avoided. The mix design method used for producing the asphalt is the recipe method and it was found to be in compliance with standard requirements [9]. The plastic additive can be introduced into the mix using two methods namely the dry process and the wet process. The wet process was adopted in this study in which the plastic was first shredded and further ground into granular form and introduced directly into the binder at the temperature of 25ºC. The pulverized plastic quantities used can be measured as a fraction of total weight of sample of asphalt or as a fraction of the measured weight of binder. The pulverized PET was added in proportions of 2%, 4%, 6%, 8%, 10% by weight of the binder used.

The temperature of the mixing tray was increased to 50ºC in preparation for the asphalt production. The accurately weighed aggregates and filler types were poured into the tray and heated to a temperature of 130ºC by the heat source. During the heating, the aggregates were mixed thoroughly using the stirrer for 20 minutes. After the mixing, the bitumen which had already been measured, pre-heated to 45ºC and modified with the plastic was poured on the heated aggregate and filler. The mixture was stirred thoroughly for 7 minutes so as to get an even distribution of binder. During the mixing, care was taken not to exceed the 160ºC temperature so that the binding characteristic of plastic as well as the bitumen did not evaporate.

In carrying out the asphalt compaction, the base plate, the Marshall molds, as well as the full assembly for the compaction were cleaned thoroughly and then all movable joints screwed in properly. The base plate and the asphalt mold were conditioned to 20ºC temperature in order to prepare it for the hot asphalt which was compacted. The hot mix asphalt was placed into the assembled mold using the spatula and care was taken not to spill any quantity during this operation. After the placing in the mold, a 7.5kg Marshall Hammer was used to compact the sample by applying 50 blows falling from a height of 45cm freely to each sides of the asphalt sample. At the end of the compaction, the samples were taken to the asphalt extruder so as to remove the samples from the Marshall molds. After the removal, the height and weight of each sample was recorded and the samples were left to cure in air for 24 hours as shown in plate 3.

Plate 3. Air curing of the asphalt samples

The water bath was heated to a constant temperature of 60ºC, then the air cured samples were placed into the water bath for 45 minutes thus raising the temperature of the already compacted and cured asphalt. During the heating up process, the Marshall stability testing machine was set up for the tests. It was ensured that the time of removal of samples from the water bath to the period of which the sample failed on the Marshall Stability testing machine did not exceed 30 seconds.

The Marshall stability of the asphalt concrete was determined next according to standard specifications [10]. Before testing of the asphalt samples, they were conditioned in the water bath having a temperature of 60ºC for half an hour. The specimen was brought to the desired temperature by immersing them in the water bath. The specimens were removed from the water bath, dried and carefully placed in the lower testing head. The complete assembly was placed in position on the testing machine. The dial micrometer was placed in position over one of the guide rods and the flow meter reading was adjusted to zero. The flow meter was firmly held against the upper segment of the breaking head. The load was applied on the specimen by means of constant rate of movement of the load jack or testing machine head at 50cm per minute until the maximum was reached and the load decreased as indicated by the dial. The indicated flow value was recorded in terms of 0.25mm (one hundredth of an inch) of the micrometer dial used. The elapsed time for the test from removal of the specimen from the water bath to the maximum load determination did not exceed 30 seconds. The average stability which is the resistance to flow was then determined using equation 1.

$$\text{Average Stability} = \frac{stability(a) + stability(b) + stability(c)}{3} \qquad (1)$$

4. Discussion of Results

The Marshall stability test was conducted to measure the resistance to plastic flow of cylindrical specimens of bituminous paving mixtures when tested in a Marshal loading frame. The specimens were tested at a speed of 50.8mm/min. The maximum load (stability) and deformation (flow) of the specimens were recorded. Table 1 shows the stability values for the unmodified asphalt and the stone dust asphalt containing varying percentages of plastic.

Table 1

Stability values for the unmodified asphalt and the stone dust-asphalt containing varying percentages of plastic

	Flow	Sample A (KN)	Sample B (KN)	Sample C (KN)	Average Stability
0% P+S. D	2.5	47	38	50	
	5.0	61	42	63	
	7.5	63	50	62	58.33
2% P+S. D	2.5	78	75	65	
	5.0	83	78	70	77.0
	7.5	73	70	68	
4%P+S D	2.5	79	81	71	
	5.0	89	90	74	84.3
	7.5	82	69	79	
6%P+S.D	2.5	89	86	84	
	5.0	110	96	99	101.6
	7.5	82	69	79	
8%P+S D	2.5	59	76	61	
	5.0	71	90	77	79.3
	7.5	62	80	69	
10%P+S. D	2.5				
	5.0	72	66	72	70
	7.5	68	53	64	

Table 2 shows the stability values for the unmodified asphalt and the recycled glass powder-asphalt containing varying percentages of plastic.

Table 2

Stability values for the unmodified asphalt and the recycled glass powder-asphalt containing varying percentages of plastic

	Flow	Sample A (KN)	Sample B (KN)	Sample C (KN)	Average Stability
0%P+RGP	2.5	63	68	60	
	5.0	71	74	70	71.667
	7.5	68	67	74	
2%P+RGP	2.5	79	81	83	
	5.0	87	89	89	88.33
	7.5	90	86	81	
	10	84			
4%P+RGP	2.5	86	80	86	
	5.0	92	94	90	92
	7.5	88	86	82	
6%P+RGP	2.5	94	90	89	
	5.0	100	102	100	100.67
	7.5	88	86	82	
8%P+RGP	2.5	90	94	88	
	5.0	96	100	96	
	7.5	104	107	101	104
	10	98	100	9 2	
10%P+RGP	2.5	96	99	100	
	5.0	100	104	108	
	7.5	107	110	114	110.3
	10	88	86	82	

The stability values of the asphalt were then multiplied with the proving ring factor of 0.03272 to give the final stability values as shown in tables 3 and 4.

Table 3

Stability values for stone dust-asphalt containing varying percentages of plastic (after being multiplied by the proving ring factor)

	FLOW	SAMPLE A	SAMPLE B	SAMPLE C	AVERAGE STABILITY
0% P +S.D	7.5	2.061	1.636	2.356	2.0176
2% P +S.D	5.0	2.7158	2.5522	2.2904	2.5196
4% P +S.D	5.0	2.9121	2.9448	2.4213	2.7594
6% P +S.D	5.0	3.5992	3.1411	3.2393	3.3265
8% P +S.D	5.0	2.3231	2.9448	2.8698	2.7126
10% P +S.D	5.0	2.3558	2.1595	2.3558	2.2904

Table 4

Stability values for recycled glass powder-asphalt containing varying percentages plastic (after being multiplied by the proving ring factor)

	FLOW	SAMPLE A	SAMPLE B	SAMPLE C	AVERAGE STABILITY
0% P +RGP	5.0	2.323	2.4213	2.2904	2.345
2% P +RGP	5.0	2.847	2.912	2.912	2.890
4% P +RGP	7.5	3.010	3.076	2.945	3.010
6% P +RGP	7.5	3.272	3.337	3.305	3.304
8% P +RGP	7.5	3.4028	3.501	3.305	3.403
10% P +RGP	7.5	3.501	3.599	3.730	3.610

Figure 1 shows the graph comparing the stability values of the unmodified asphalt with those of the stone dust-asphalt modified with varying percentages of plastic while figure 2 shows the graph comparing the stability values for the unmodified asphalt with those of the recycled glass powder-asphalt modified with varying percentages of plastic.

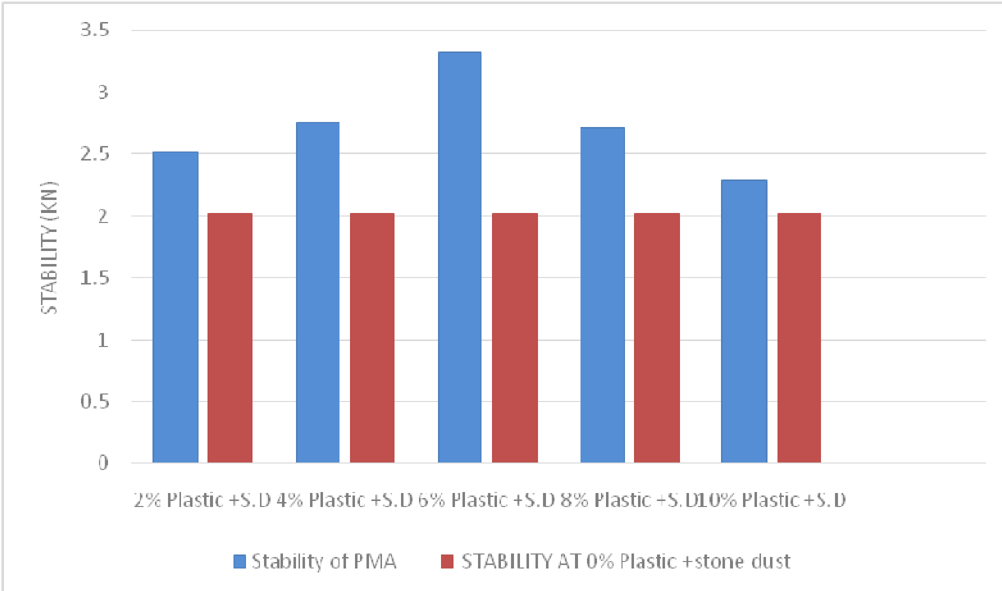

Fig. 1. Graph showing comparison between the stability values for the unmodified asphalt and stone dust-asphalt containing varying percentages of plastic.

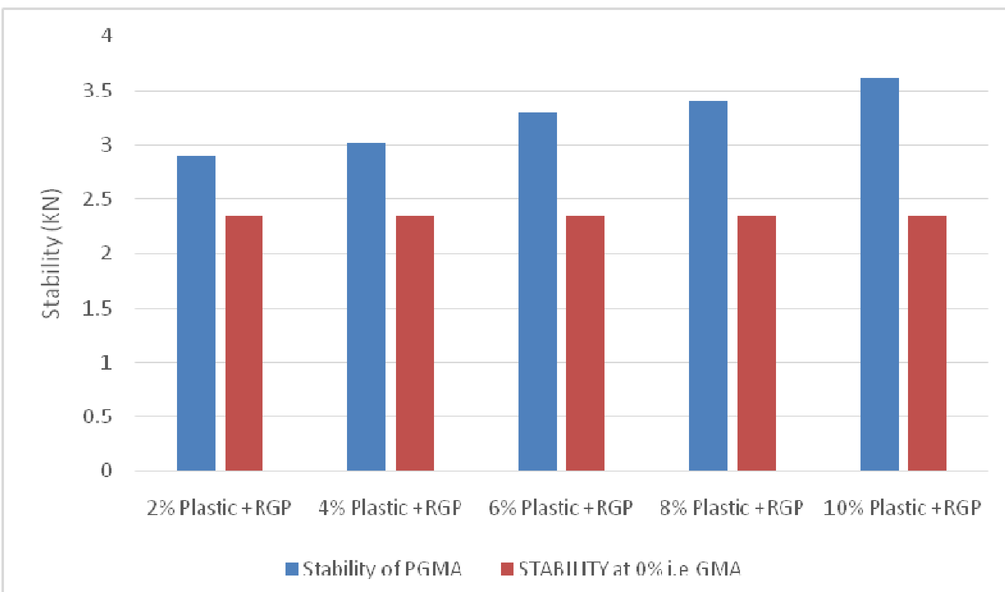

Fig. 2. Graph showing comparison between the stability values for the unmodified asphalt and recycled glass powder-asphalt containing varying percentages of plastic.

Figure 3 shows the graph comparing the plastic modified stone dust-asphalt (PMSDA) and plastic modified recycled glass powder-asphalt (PMRGPA)

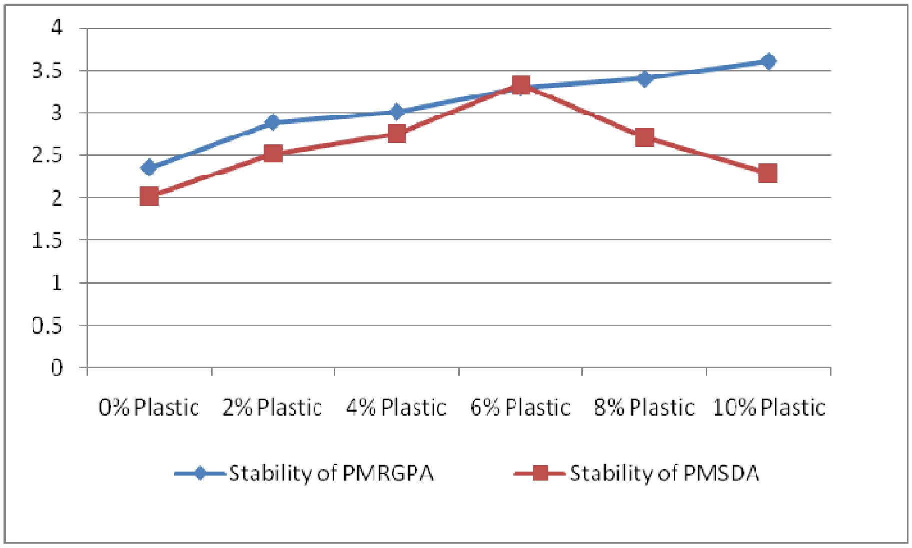

Fig.3. Graph showing comparison between the stone dust-asphalt and recycled glass powder-asphalt with varying percentages of plastic

Tables 1, 2, 3 and 4 show that the introduction of pulverized PET plastic into the stone dust-asphalt and recycled glass powder-asphalt mixes enhanced the adhesive characteristic of the mixes as well as their overall strength in comparison with the unmodified asphalt. The inclusion of recycled glass powder filler also produced an increase in the Marshall stability properties of the asphalt as shown in figure 2 thus, re-emphasizing the effect of the cementitious nature of glass powder when blended to ultra-fine sizes. The optimum strength for plastic modified stone dust-asphalt (PMSDA) was reached at the inclusion of 6% PET plastic whereas further addition of plastic i.e. 8% and 10% led to a decline in strength because the bituminous mix showed more plastic characteristics. On the other hand, the plastic modified recycled glass powdered asphalt continued to show increasing strength up to 10% plastic inclusion.

6. Conclusion and Recommendations

Based on the results of the study, it was concluded that modification process of asphalt using the wastes identified are very effective in controlling the menace of non-biodegradable wastes which pollute the environment. The stone dust-asphalt mix into which plastic is introduced in powder form at 2%, 4%, 6%, 8% and 10% by weight of bitumen showed improved stability compared to the unmodified asphalt. The optimum stability for the plastic modified stone dust-asphalt (PMSDA) was achieved at 6% plastic content and the addition of more plastic fibers thereafter led to a sharp decline in stability due to the asphalt being plasticized. Lastly, the optimum stability for the plastic modified recycled glass powder-asphalt (PMRGPA) was not reached even at 10% plastic content addition thus showing the wider possibilities of increase in the Marshall stability of the mix on the addition of higher plastic content into the mix. Hence the following are recommended:

- The use of pulverized PET plastic waste in asphalt concrete mixture is recommended to the general construction industry because it helps in improving the strength / stability of the asphaltic concrete as shown in this study.
- The use of pulverized waste plastics and recycled Glass Powder in asphaltic concrete should be encouraged to help to tackle the menace of improper disposal of these non-bio degradable municipal solid wastes in the environment.
- Proper sensitization on how to dispose waste and proper collection of non-biodegradable wastes should be set up by the government as well as individuals so that these wastes will be easily sorted out and made accessible for use by asphalt manufacturing companies and other companies which draw value from waste.

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