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Mix Design Properties of Asphalt Concrete Wearing Course Made from Pyrolized Polyethene as Partial Replacement for Bitumen

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ABSTRACT: The environmental health hazard caused by the careless disposal of waste Polyethene/plastic cannot be overemphasized. This material constitutes major cause of drainage system blockages. The blockage causes drainage overflow, which accumulate water on the highway pavements and eventually result in pavement failure. Polyethene possesses water proofing quality hence could be used to modify bitumen for asphalt concrete production. This study was conducted to investigate the properties of asphalt concrete made from Pyrolized polythene as partial replacement for bitumen. Tests were carried out on a set of asphalt concrete specimens prepared using bitumen partially replaced (PR) with pyrolized Polyethene and another set prepared using bitumen Directly Added (DA) with pyrolized Polyethene. Mixed design parameters such as stability, flow, density, air void, voids in mineral aggregates, retained marshal stability and swelling index of the specimen were determined. Result showed that using waste sachet Polyethene as partial replacement for bitumen modified and improved the mixed design properties of asphalt which resulted in cost saving of ₦627,412.26 per kilometer road asphalt concrete pavement at 15% optimum modifier content. The study was validated by comparing the result of the study with the minimum requirements and result showed that the mix design properties of asphalt concrete made from pyrolized waste sachet Polyethene as partial replacement for bitumen met minimum requirement. It was concluded that asphalt concrete made using waste Polyethene as partial replacement for bitumen is economical and improved the mix design properties of the concrete, and recommended the use of the partial replacement procedure in order to save cost and also reduce the environmental hazard caused by careless disposal of waste sachet bags in the environment.

KEYWORDS: Asphalt Concrete, Pyrolized Polyethne, Partial Replacement, Bitumen

I. INTRODUCTION

Asphalt is a composite material (Aggregate, binder and filler) commonly used in the construction of flexible pavement. Asphalt pavement suffers from four main factors viz: moisture, oxidation, temperature variation and traffic loading. Moisture damage is a result of accumulation of moisture on the asphalt concrete pavement which causes adhesion between the binder and aggregates (aggregate stripping), which eventually leads to pavement distress or failure. Also, moisture is the primary cause of pavement deterioration as it reduces the serviceability or service life of the asphalt pavement. Polyethene like bitumen has water proofing quality and is emerging as one of the most common materials for improving the quality of asphalt concrete due to the similarity in property with bitumen. Bituminous pavement referred to as flexible or asphalt pavement, consist of Hot Mix Asphalt (HMA) concrete that is overlaid on a base, sub-base, and the underlying soil. Flexible or asphalt pavement are made up of various layers that range from the sub-grade, sub-base, base and surface (wearing course). For the purpose of this study, emphasis shall be made on the modification of the bitumen using pyrolized polythene for asphalt pavement wearing course (surface course). Pyrolysis is the breaking down of polyethene with the absent of oxygen and using heat at a high temperature in an instrument called Reactor**.**

Pyrolysis is a common technique used to convert plastic waste into energy in the form of solid, liquid and gaseous fuels. Pyrolysis is mostly used in the chemical industry for production, such as: production of ethylene, production of carbon, production of coal, production of wood, production of coke from coal and production of oil from waste plastic[1], [2].

Study have revealed that flexible pavement when under moisture continuously loses blind-ability between the aggregate and asphalt cement therefore result in stripping of the pavement under repeated traffic loads due to reduction in stiffness (dynamic modulus) the presence of moisture and can lead to cracking under applied loading due to tensile stresses[3]. Studies have also shown that the use of waste polyethene in bituminous concrete mixes for highways is eco-friendly, economical, in addition polyethene gives strength in the sub base course of the pavement[4]. Research on recycle polyethene resulting from the processing of plastic product show that the material meet the standard requirements and indicated also an increase in viscosity, cohesive strength and heat resistance of bitumen[5]. Research further showed that grinded high density polyethylene (HDPE) modifier provides better engineering properties. In addition, modification of asphalt in hot asphalt mixture increases the stability, reduce the density and slightly increase air voids and the void of mineral aggregate[6].

Most researches in the modification of bitumen binder involve direct addition/ combination of certain percentages of modifier and bitumen at the optimum content. Not much consideration has been given to use of the modifier as partial replacement for the bitumen. Also no consideration has been given to a comparison of the result of Direct Addition (DA) and Partial Replacement (PR) procedures. This study investigated the characteristics of asphalt concrete wearing course made from Pyrolized polythene-modified bitumen as partial replacement for bitumen.

II. MATERIALS AND METHODS

2.1 Sample collection and Classification Test

The materials used in the preparation of the asphalt concrete samples for both partial and direct addition methods awere: fine aggregate (sand), coarse aggregate (granite), bitumen, and pyrolized waste sachet polyethen. The aggregates (Fine and coarse aggregates), material were obtained from Mile 3 market in Port Harcourt, Rivers State, Nigeria., the bitumen was obtained from ASCAS Limited in Port Harcourt, Rivers state, Nigeria while the waste sachet polythene were obtained from the Rivers State University, Port Harcourt, Nigeria. The waste Polyethene obtained was pyrolized at the Petroleum Engineering Laboratory of the Rivers State University[7].

Classification tests such specific gravity, viscosity, softening point and penetration were carried out for aggregates and bitumen(asphalt) to ascertain the properties and quality of the materials. Presented in Table1 is the classification test of the materials.

2.2 Specimen Preparation

The samples preparation in this study were carried out in accordance with Marshall Mix Design guideline, aggregates were sieved using stipulated guideline. Blending/combination of aggregate using straight line methods was adopted in the study [8], [9], [10].

To determine optimum bitumen content, samples were prepared at varying asphalt content ranging from 4.0% ,4.5% up to 6.0% at increments of 0.5%, of asphalt content. Aggregate were first heated for about five (5) minutes before a percentage of asphalt was added to the preheated aggregate to allow for absorption into the aggregates. The specimens where allowed to heat for about 160°C, after which the mix was poured into a mound and compacted on both faces with a Rammer of 6.5kg at 75blows on both faces (for heavy traffic) at free falling on a height of 450mm. The prepared samples were allowed to cool for about 24hours then were fully immersed in a water bath at 60°C for five (5) minutes (which represents the destructive temperature at worst condition for damage). Three samples were prepared for each percentage of bitumen and the average was obtained.

The prepared samples were tested using the Marshall apparatus and the Marshall Stability and Flow were recorded. The specimen Density, Air void and Void in Mineral Aggregates (VMA) were also determined. The results obtained were used to plot a graph of asphalt content against Stability, asphalt content against Density and asphalt content against Air Voids to determine the optimum binder content using equation (1):

$$O.B.C = \frac{1}{3}\left(X + Y + Z\right) \qquad (1)$$

Where,
O.B.C = Optimum Bitumen Content
X = Asphalt content corresponding to maximum Stability
Y = Asphalt content corresponding to maximum Density
Z = Asphalt content corresponding to median limit of Air Voids (4% Air voids)

The O.B.C) was thus determined as 5.5%. This value was used in preparation of the unmodified (control specimens) and modified asphalt concrete specimens. The same procedures were adopted for the modified samples but at varying Pyrolized

Polyethene content (5%, 10%, 15%, 20% and 25%). The modified samples were prepared in two ways; Direct Addition (DA) and Partial Replacement (PR) of the pyrolized polyethene. The direct addition method involves adding the pyrolized polyethene content directly to the prepared asphalt concrete mix while partial replacement method involves removing some percentage of bitumen and replacing it with pyrolized ployethene. The samples were soaked in water in curing tank for 24 hours and subjected to the Stability and Flow test, Air Void, Void in Mineral Aggregate and Density analysis.

2.3 Marshall Stability

Marshall Stability is defined as the maximum load carried by a compacted specimen at a standard test temperature of 60^0C. Stability of asphalt concrete regulates the performance of flexible pavements and is a measure of the resistance to moisture damage of asphalt concrete mixes. It was obtained using the Marshall Test apparatus

2.4 Flow

Flow is derived from the recurring loading and unloading of HMA specimen in which permanent deformation is recorded as a function of load cycles. This was obtained using Marshall Test Apparatus.

2.5 Density

Density of compacted asphalt concrete mix is the unit weight of a mixture, it is calculated as follows:

$$Density = \left[G_{mb} = \frac{W_2}{W_2 - W_w} \right] x1000kg/m^3$$

(2) (2)

Where,

G_{mb} = bulk modulus of mix

W_2 = weight of mix in air

W_w = weight of mix in water.

2.6 Air voids

Air Voids are small airspaces that occupy between the coated aggregate particles in the compacted asphalt concrete mix. It is determined as follows:

$$P_a = 100\left[\frac{G_{mm} - G_b}{G_{mm}} \right] \quad (3)$$

Where;

P_a = percent air voids in HMA concrete

G_{mm}= maximum specific gravity of HMA concrete

G_{mb}= bulk modulus of HMA concrete

2.7 Voids in Mineral Aggregate (VMA)

Voids in Mineral Aggregate (VMA) is the volume of voids in the aggregates, it is the sum of air voids and volume of bitumen. VMA is determined using equation 4:

$$VMA = 100 - \left(\frac{G_{mb}}{G_{sb}} \right) P_s \quad (4)$$

Where,

VMA = Voids in mineral aggregates

G_{mb} = bulk modulus of asphalt concrete mixture

G_{sb} = bulk specific gravity of aggregates

P_s = percent of aggregates in mixture

III. RESULTS AND DISCUSSIONS

The results of the physical properties of the materials and aggregate gradation (sieve analysis) are presented in Tables 1 and 2 while the results of the mix design properties of asphalt concrete made from pyrolized polyethene as partial replacement for bitumen are presented in Tables 3, 4, 5, 6, and 7.

3.1Marshaly Stability

Presented in Figure 1 is the variation of Marshall Stability of asphalt concrete with Pyrolized Polyethene (PP) for Direct Addition (DA) and Partial Replacement (PR) methods. From the result, the Marshall Stability for DA method increased between 0-15% PP content to a value of 14680N, after which, the value of Marshall Stability began to decline until 25% PP content. For PR method, the Marshall Stability increased as the PP content increased and attained an optimum value of 14546N at 15% PP content, after which, the Marshall Stability began to decline until 25% PP content. The study observed the threshold Marshall Stability at 15% PP content, an indication of reduction in loss of Stability, improved resistance to moisture damage and durability. The study also noted that the Marshall Stability for the DA method was higher than that of the PR method.

3.2 Flow

Figure 2 presents the effect of Pyrolized Polyethene (PP) on the Flow of asphalt concrete for Direct Addition (DA) and Partial Replacement (PR) methods. The result showed that for both mixes, the flow decreases with increasing PP content to a minimum value of 8.30mm at 15% PP content and 8.36mm at 15% PP content for DA and PR methods respectively. Further increment in PP content up to 25% resulted in an increase in flow.. The decrease in flow recorded between 0-

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15% PP content is an indication that polyethene improved the resistance to permanent deformation of the asphalt concrete mixes. The decrease in flow may be attributed to the non-plastic nature of polyethene.

3.3 Air Voids

Figure 3 shows the air void against the PP content for DA and PR mixes. It can be seen that air voids reduced from 0% to 15% and further increment in PP content caused an in crease in air voids for both DA and PR mixes. The decrease in voids is a result of improved bonding achieved as a result of asphalt surface modification and sinewing effect. The result also showed that the air voids in PR mix is higher than that found in the DA mix.

Table 1: Physical Properties of Materials

Material	Asphalt	Sand	Gravel
Specific gravity	1.03	2.41	2.81
Grade of Bitumen	60/70	-	-
Mix proportion (%)		35	65
Viscosity of binder	1.27Mm/s^2	-	-
Softening point	51.^{0}C	-	-
Penetration value	57mm	-	-

RIVERS STATE UNIVERSITY
Port Harcourt

PROJECT: PSD FOR COMBINE AGGREGATE
LOCATION: Soil Laboratory
CLIENT: Research work

PARTICLE SIZE DISTRIBUTION (SIEVING)

Weight of sample taken for dry/wet grading	1502.00
Weight retained on No. 75 micromillimetre B.S sieve	3.00
Weight passing No 75 micromillimetre B.S sieve	0.00

Sieve Size	Retained		Cumulative		Total Percentage Passing	Specification Limit	
	Retained Weight	Retained Percent	Cumulative Weight	Cumulative Percent			
(mm)	g	%	g	%	%	%	%
19.10	100			100	100	100	100
12.700	34.00	2.26	34.00	2	97.74	86	100
9.520	223.00	14.85	257.00	17	82.89	70	90
6.350	263.00	17.51	520.00	35	65.38	45	70
4.750	198.00	13.18	718.00	48	52.20	40.00	60.00
2.360	122.00	8.12	840.00	56	44.07	30.00	52.00
1.180	165.00	10.99	1005.00	67	33.09	22.00	40.00
0.600	124.00	8.26	1129.00	75	24.83	16.00	30.00
0.300	208.00	13.85	1337.00	89	10.99	9.00	19.00
0.150	120.00	7.99	1457.00	97	3.00	3.00	7.00
0.075	45.00	3.00	1502.00	100	0.00	0.00	0
		0.00	1502.00	100	0.00		
		0.00	1502.00	100	0.00		

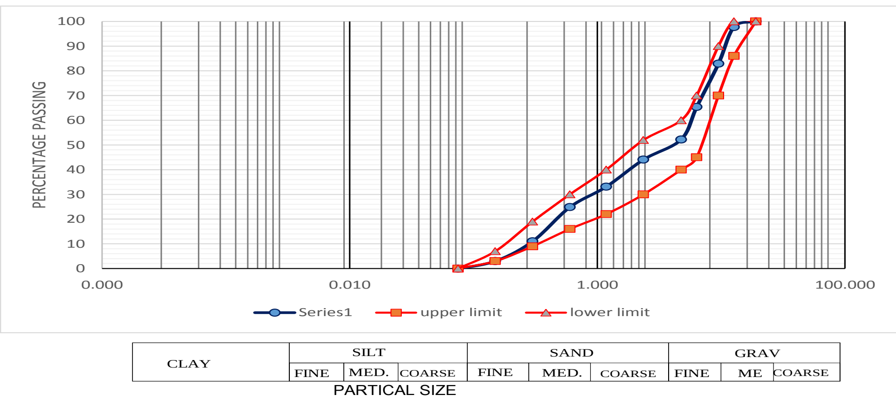

Table 2: Schedule of Aggregate Used for Mix Proportion in Accordance with ASTM 1951:C136

Table 3: Marshal Stability (KN) of Asphalt Concrete Made from Pyrolized Polyethene

PP CONTENT (%)	Stability (KN) Direct Addition (DA)	Stability (KN) Partial Replacement (PR)
0	13090	13090
5	13256	13100
10	13565	13446
15	14680	14546
20	12656	12515
25	12474	12342

Table 4: Flow (0.25mm) of Asphalt Concrete Made from Pyrolized Polyethene

PP CONTENT (%)	Flow (0.25mm) Direct Addition(DA)	Flow (0.25mm) Partial Replacement (PR)
0	8.48	8.48
5	8.39	8.46
10	8.34	8.41
15	8.30	8.36
20	9.84	10.42
25	10.24	11.23

Table 5: Percent Air Void (%) for Asphalt Concrete Made from Pyrolized Polyethene

PP content (%)	Air Void (%) Direct Addition(DA)	Air Void (%) Partial Replacement (PR)
0	5.47	5.47
5	5.23	5.31
10	5.19	5.27
15	5.12	5.22
20	5.27	5.38
25	5.47	5.62

Table 6: Void in Mineral Aggregate (VMA) of Asphalt Concrete Made from Pyrolized Polyethene

PP CONTENT (%)	VMA (%) Direct Addition(DA)	VMA (%) Partial Replacement (PR)
0	21.19	21.19
5	20.24	20.53
10	20.13	20.43
15	19.86	20.08
20	20.92	21.72
25	21.42	22.35

Table7: Density (Kg/M^3) of Asphalt Concrete Made from Pyrolized Polyethene

PP CONTENT (%)	Density (kg/m^3) Direct Addition(DA)	Density (kg/m^3) Soaked Partial Replacement (PR)
0	2173	2173
5	2198	2193
10	2213	2204
15	2268	2229
20	2189	2162
25	2165	2145

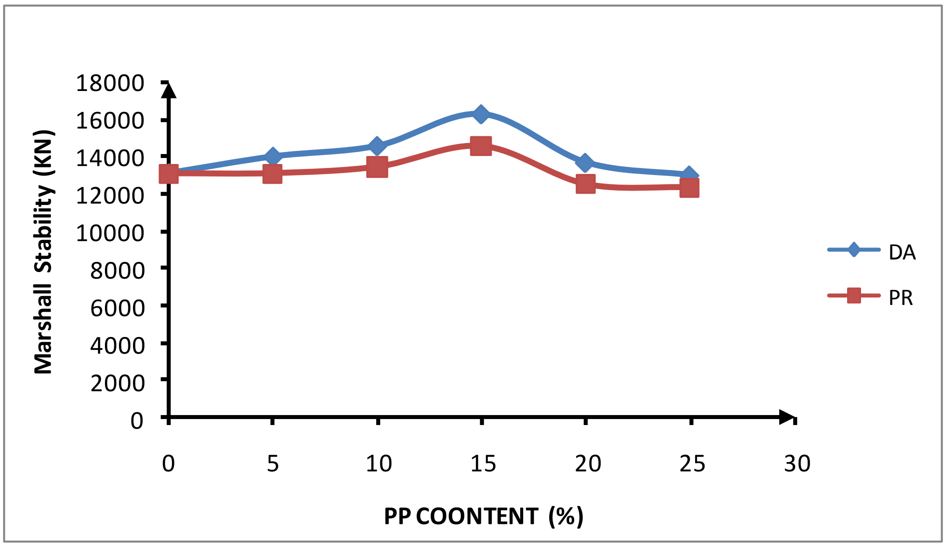

Fig.1: Marshall Stability against Pyrolized Polyethene content

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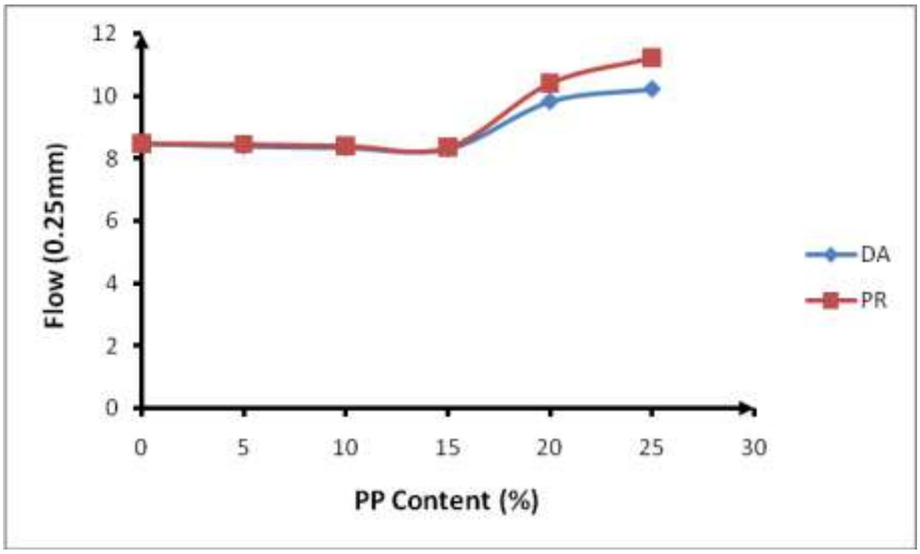

Figure 2: Asphalt Concrete Flow against Pyrolized Polyethene Content

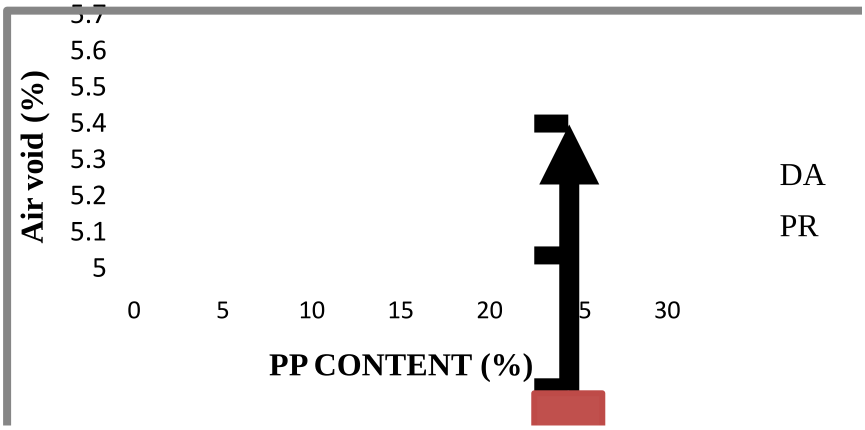

Figure.3: Asphalt Concrete Air Void against Pyrolized Polyethene Content

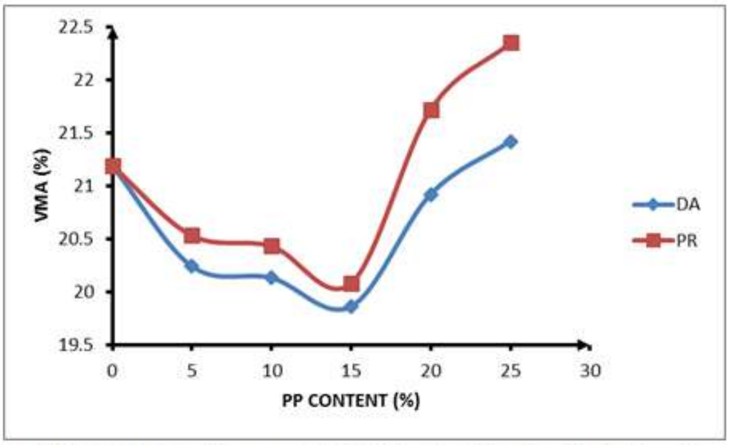

Figure 4: Void in Mineral Aggregate (VMA) Against Pyrolized Polyethene Content

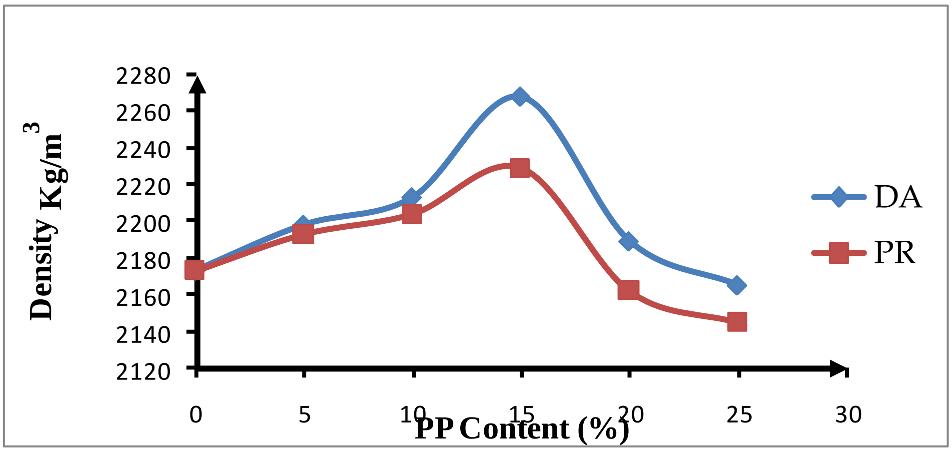

Figure 5: Asphalt Concrete Density Against Pyrolized Polyethene Content

Table 8: Result Validation

Asphalt institute criteria			Research Result			
Asphalt parameter	Required standard					
			PR		DA	
	Min	Max	Min	Max	Min	Max
Stability KN	8.0		12.3	14.5	12.4	14.7
Flow 0.25mm(0.01in)	8	14	8.4	11.2	8.4	10.2
Air void (%)	3	5	5.2	5.6	5.1	5.4
VMA (%)	18		20.1	22.4	19.7	21.2
VFA (%)	65	75	67.0	75.3	66.0	74.0

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Table 9: Cost Benefit Analysis for 1km Asphalt Concrete (A.C) Pavement

Modifier Content (%)	**Weight of modified Bitumen Specimen (kg)**	**Weight of bitumen for 1km A.C. Pavement (kg)**	**Cost of Bitumen for 1km A.C Pavement (₦)**	**Cost Saved (Cost Difference)** (₦)	**Weight of Pyrolized Polyethene** (%)	**Benefit-Cost Ratio**
0	0.060	40,374.00	4,182,746.40	0	0	1.0
5	0.057	38,355.30	3,973,609.08	209,138.32	5	1.05
10	0.054	36,336.60	3,764,471.76	418,274.64	10	1.11
15	0.051	34,317.90	3,555,334.14	627,412.26	15	1.18
20	0.048	32,299.20	3,346,197.12	836,549.28	20	1.25
25	0.045	30,280.50	3,137,059.80	1,046,686.60	25	1.33

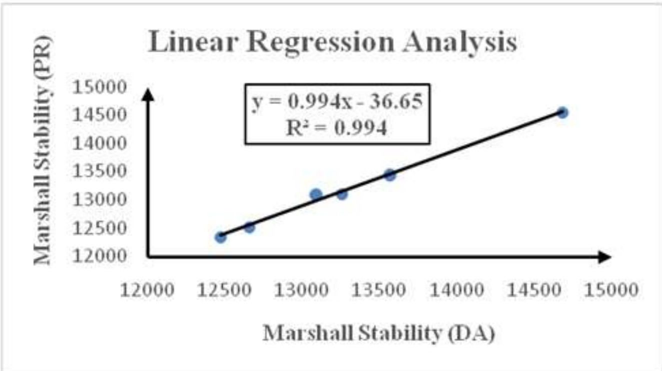

Fig. 6: Linear Regression Analysis of Marshall Stability for PR and DA

3.4 Voids in Mineral Aggregates

Figure 4 showed the voids in mineral aggregates against PP content. It can seen that for both mixes, the voids in mineral aggregates decreases with increasing PP content up to an optimum value at 15% PP content. Beyond the optimum, further increment in PP content increased the voids in mineral aggregates. The result also showed that the DA mixes had less voids in mineral aggregates than the PR mixes.

3.5 Bulk Density

Figure 5 showed that the bulk density increased with increase in PP content for both mixes between 0-15% PP content for DA and PR mixes. Optimum bulk density of 2282kgm^3 and 2288kg/m^3 were achieved at 15% PP content for DA and PR mixes respectively, after which the bulk density began to decline;

3.6 Result Validation of Result

The study was validated by comparing result in two ways:

i) Comparing result with Asphalt Institute Minimum Criteria [11].
ii) Comparing result of Marshall Stability for Partial Replacement (PR) and Direct Addition (DA) methods using linear Regression analysis

The result of the study was compared with the minimum criteria for mix design properties as stipulated by Asphalt Institute [11] as presented in Table 8. The result showed that the mix design properties of asphalt concrete wearing course made from Pyrolized Polyethene as partial replacement for bitumen met the minimum requirement as stipulated by Asphalt Institute.

The result of Marshall Stability for Partial Replacement (PR) and Direct Addition (DA) methods were also compared using linear Regression analysis as shown in Figure 6 and it can be seen that PR and DA methods compared favourably with coefficient of Regression as R^2 = 0.994.

3.7 Cost Benefit Analysis

The cost benefit analysis of asphalt concrete made from Pyrolized Polyethene is as shown in Table 9. The result of the study showed that for one kilometer (1kM) pavement with dimension of 7.2m (width) and 50mm asphalt concrete weaeing course, and for optimum pyrolized waste polyethene content of 15%, cost savings of ₦627,412.26 was achieved resulting in a cost benefit cost ratio of 1.18.

IV. CONCLUSION

The research presented the result of laboratory investigation of the characteristic of asphalt concrete wearing course made from Pyrolized Polyethene as partial replacement for bitumen. The major findings and conclusion obtained from the study are as follows:

i. The study shows that asphalt concrete made from Pyrolized polythene as partial replacement of bitumen improves the mix design properties of asphalt concrete
ii. The Stability of asphalt concrete made from polythene modified bitumen increased with increase in modifier content up to an optimum, hence improved the moisture resistance and durability of the material.
iii. The optimum result for asphalt concrete made from Pyrolized polythene as partial replacement of bitumen was obtained at 15% modifier content.
vi. The mix design properties of asphalt concrete made from Pyrolized polythene as partial replacement of bitumen meet minimum requirement.
vii. The mix design properties of asphalt made from Pyrolized polythene as partial replacement of bitumen compare favorably with the result of direct addition procedure with coefficient of regression (R^2) of about 0.991.
viii. The research showed that asphalt concrete made from Pyrolized polythene as partial replacement for bitumen is cost effective with an optimum cost savings of 15% (N627,412.26) resulting in a cost benefit cost ratio of 1.18.

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