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Moisture Resistance of Asphalt Concrete Modified with Polyethene as Partial Replacement for Bitumen

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Abstract:
Background*: The indiscriminate disposal of waste polyethene/ plastic in some developing countries has become a huge challenge to those environments. Polyethene is a non-bio-degradable materials and when disposed indiscriminately causes drainage blockage, accumulation of moisture on asphalt pavements which eventually result in early pavement failure. Polyethene is a carbon-hydrogen (C-H) compound and possesses water proofing quality hence, could be used to modify bitumen for asphalt concrete production.*
Material and Method*: This study was conducted to investigate the moisture resistance properties of asphalt concrete made from Pyrolized polythene (sachet water polyethene) as partial replacement for bitumen. Tests were carried out on a set of asphalt concrete specimens prepared using bitumen Partially Replaced with pyrolized Polyethene and another set prepared using bitumen Directly Added / combined with pyrolized Polyethene. Resistance to moisture damage parameters such as Stability, Retained Marshal Stability and Swelling index of the specimens were evaluated. The study compared the results obtained from Direct Addition and Partial Replacement methods. The study also evaluated cost savings arising from the use of the Partial Replacement method.*
Results*: Results showed that using waste sachet Polyethene as partial replacement for bitumen improved the moisture resistance properties of asphalt concrete with a cost savings of ₦627,412.26 at 15% optimum modifier content for a one kilometer asphalt concrete road. Comparison of the partial replacement and direct addition (DA) methods using retained Marshall stability showed that the results compare favorably with coefficient of Regression $R^2 = 0.9948$.*
Conclusion*: It was concluded that asphalt concrete made using waste Polyethene as partial replacement for bitumen is economical and improved the moisture resistance properties of asphalt concrete and recommended the use of polyether in partial replacement for bitumen in asphalt concrete production*
Key Wods: *Moisture Resistance, Marshall Stability, Retained Marshall Stability, Swelling Index, Partial Replacement, Direct Addition*

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I. Introduction

Asphalt is a composite material comprising of crushed rock, gavel, sand mineral filler and bitumen binder commonly used in the construction of flexible pavement. Asphalt pavement suffers from four main factors such as: moisture, oxidation rates, temperature variation and traffic loading. Moisture damage is as a result of accumulation of moisture on the asphalt concrete pavement; this causes adhesion between blinders and aggregates which leads to segregations of the materials, known as stripping. The advance form of stripping causes segregation of aggregate which eventually leads to pavement failure and formation of pothole on the flexible pavements. Moisture is also the primary cause of pavement deterioration as it reduces the design properties and serviceability of the asphalt pavement. Flexible pavement when under moisture continuously loses blinding-ability between the aggregate and asphalt cement resulting in stripping of the pavement under repeated traffic loads due to reduction in stiffness (dynamic modulus)[1]. The surface course as top layer is a relatively thin layer and designed to possess as much as possible the desired properties of stability, durability, flexibility and skid resistance [2]. The purpose of designing asphalt concrete wearing course is to provide a stable mixture by means of a good mechanical interlock held together by a binder. Bitumen are black or brown mixture of hydrocarbon gotten naturally from petroleum distillation, used for construction of flexible pavement or roofing due to their binding characteristic, water proofing quality and low cost. Bitumen due to its good cementing ability is a good binder material for asphalt pavement construction[3].

Polyethene (a hydrocarbon C-H compound) has waterproofing quality and can provide resistance against moisture damage on hot mix asphalt concrete, Modification of bitumen using polyethene is helpful to the construction industry since the polymer is considered as one of the most common materials for improving the quality of asphalt concrete due to the similarity in property with bitumen as it increases asphalt concrete Marshall Stability, Retained Marshall Stability (RMS) and reduces Swelling Index (SI) of the asphalt concrete. The use of waste polyethene in asphalt concrete production also reduces the environmental hazard caused by its indiscriminate disposal. Several researches have been conducted on the modification of asphalt using low density polyethene (sachet polyethene) and high density (plastic bottle); results showed that modification of asphalt concrete using polyethene improved the moisture resistance characteristics of asphalt pavement and minimized frequent pavement maintenance [4,5,6].

Pyrolysis is a process of breaking down materials in the absence of oxygen and presence of heat. It is defined as the thermal decomposition of materials at elevated temperatures in an inert atmosphere[7]. It involves a change of chemical composition and is irreversible. Pyrolysis is a common technique used to convert plastic waste into liquid and gaseous fuels[8].

This study investigated the moisture resistance of asphalt concrete modified with polyethene as partial replacement for bitumen. The study also evaluated cost saving arising from the use of polyethene as partial replacement for bitumen.

II. Materials And Methods

2.1 Sample collection

The materials used in the preparation of the asphalt concrete samples for both partial and direct addition methods were: fine aggregate (sand), coarse aggregate (granite), bitumen and pyrolized waste sachet polyethen. The aggregates (Fine and coarse aggregates) 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 school Environment in Rivers State University, Port Harcourt, Nigeria. The waste Polyethene obtained was pyrolized at the Petroleum Engineering Laboratory of the Rivers State University using a Reactor at a high temperature of about (300- 3500c)[9].

2.2 Classification Test

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

. 2.3 Sample Preparation

The samples preparations in this study were carried out in accordance with Marshall Mix Design method. Aggregates were sieved using stipulated guideline and blending/combination of aggregate using straight line method was adopted in the study[9,4,11]. To determine the Optimum Binder Content (OBC), the 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 15 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 to about 60°C, after which the mix was poured into a mould 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 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 crushed with the Marshall apparatus to failure 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 Flow, asphalt content against Density, asphalt content against Air Voids and asphalt content against Voids in Mineral Aggregates 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 specimen) and modified asphalt concrete specimens.

The same procedures were adopted for the unmodified and modified samples but at varying Pyrolized Polyethene content (0%, 5%, 10%, 15%, 20% and 25%). The modified samples were prepared in two ways; direct addition and partial replacement of the pyrolized polyether. The direct addition method involved adding the pyrolized polyethene content directly to the prepared asphalt concrete mix while partial replacement method involved removing some percentage of bitumen and replacing it with pyrolized ployethene. The unmodified and modified sample were subjected to Stability and Flow, Density, Air Void, and Void in Mineral Aggregate analysis. The Retained Marshall Stability (RMS) and Swelling of the specimens were also determined.

2.4 Marshall Stability and Retained Marshall Stability

Marshall Stability is defined as the maximum load carried by a compacted specimen at a standard test temperature of 60^0C. Marshall Stability and Retained Marshal Stability are measures of resistance to moisture damage of asphalt concrete. They are therefore measures of durability of asphalt concrete. The lower the RMS, the less durable the asphalt pavement becomes while the higher the RMS, the more durable the pavement becomes. Retained Marshal Stability is determined using the equation below:

$$RMS = \left(\frac{S_1}{S_0} \right) x \ 100 \ \% \qquad (2)$$

Where:

RMS = Retained Marshall Stability (%)

S_0 = Stability before immersion in water (N)

S_1 = Stability after immersion in water(N)

2.5 Swelling Index derivation

Swelling index of asphalt concrete pavement is the percentage increase in the volume of the pavement as a result of absorption of water due to submergence for a period of time. It is determined using equation 3:

$$SI = \left(\frac{V_2 - V_1}{V_1} \right) x \ 100 \ \% \qquad (3)$$

Where,

SI = Swelling Index (%)

V_1 = Volume of the prepared hot mix asphalt concrete samples before soaking (mm^3)

V_2 = Volume of the prepared hot mix asphalt concrete samples after soaking (mm^3)

2.6 Cost Benefit Analysis

Asphalt concrete cost benefit was carried out using the following pavement data:

- Dimension of Roadway - 1kM x 7.2m x 0.05m thickness
- Density of Asphalt = 2243kg/m^3
- Volume of Asphalt Concrete = 360m^3,
- Total mass of asphalt concrete required = 807,480kg
- 1.2kg of A.C specimen required 0.06kg of bitumen in the mold
- Total mass of bitumen = 40,374kg
- At 5% pyrolized polyethene content, Cost savings = N209,138.32
- At 15% pyrolized polyethene content, cost saving = ₦627,412.26
- Cost benefit cost ratio at 15% modifier content = 1.18

III. Results And Discussions

3.1 Results

The results of material classification test and aggregate combination in accordance with[10,12] are presented in Tables 1 and 2 respectively, while the results of Marshal Stability, Retained Marshal Stability, Swelling Index and cost benefit analysis are presented in Tables 3, 4, 5 and 6 respectively.

3.2 Discussions

3.2.1 Marshall Stability

The effect of Pyrolized Polyethene (PP) on the Marshall Stability of asphalt concrete for Partial Replacement (PR) and Direct Addition (DA) methods for un-soaked and soaked conditions are shown in Figures 1a and 1b respectively.

For un-soaked condition, Figure 1a showed that for Partial Replacement (PR) method, the Marshal Stability of asphalt concrete modified with pyrolized bitumen increased from 15638N at 0% Pyrolized Polyethene (PP) content to 16921N at 15% Pyrolized Polyethene (PP) content and decreased to 15230N at 25% PP content. Figure 1a also showed that for Direct Addition (DA) method, the Marshal Stability of asphalt concrete increased from 15638N at 0% Pyrolized Polyethene (PP) content to 16984N at 15% Pyrolized Polyethene (PP) content and decreased to 15230N at 25% PP content.

Similarly, for soaked condition, Figure 1b showed that for PR method, the Marshall Stability increased from 13090N at 0% PP content to 14546N at 15% PP and decreased to 12342N at 25% PP content. Figure 1b also showed that for DA method, the Marshall Stability increased from 13090N at 0% PP content to 14680N at 15% PP content and decreased to 12474N at 25% PP content. This observed increase is a result of improved moisture resistance due to the water proofing property of polyethne

Generally, the result showed that, for asphalt concrete modified using the PR and DA methods for un-soaked and soaked conditions, the Marshall Stability increased to an optimum at 15% PP content indicating improvement in resistance to moistiure damage of the asphalt concrete mix.

3.2.2 Retained Marshall Stability

The effect of Pyrolized Polyethene (PP) on Retained Marshall Stability (RMS) of asphalt concrete for partial replacement and direct additions methods is shown in Figure 2. The result showed that for Partial Replacement method, the Retained Marshall Stability increased from 83.70% at 0% PP content to 85.96 at 15% and decreased from 81.25% at 20% PP content to 81.04 at 25%. For Direct Addition method, the RMS increased from 83.70% at 0% PP content to 86.43 at 15% and decreased to 81.00 at 25% PP content. The result showed that asphalt concrete modified using pyrolized polyethene attained optimum RMS at 15% Modifier content indicating an optimum improvement in durability and resistance to moisture damage.

3.2.3 Swelling Index

The effect of Pyrolized Polyethene (PP) on Swelling Index (SI) of asphalt concrete is shown Figure 3. The result showed that for Partial Replacement (PR) method, the addition of pyrolized polyethene content reduced the Swelling Index from 1.73% at 0% PP content to 1.04% at 15% PP content. The SI however increased from 1.26% at 20% PP content to 1.57% at 25% PP content. Similarly, for the Direct Addition (DA) method, the Swelling Index addition of pyrolized polyethene reduced SI from 1.73% at 0% PP content to 1.03% at 15% PP content and increased from 1.13% at 20% PP content to 1.38% at 25% PP content. This result indicated that addition of pyrolized polyethene to asphalt concrete reduced swell and improved resistance to moisture damage at 15% optimum PP content.

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	-	-

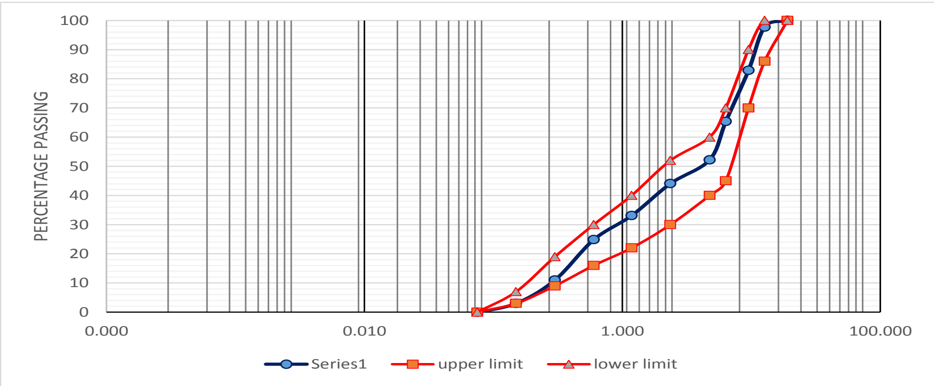
Table 2: Schedule of aggregate used for mix proportion in accordance with ASTM 1951:C136

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		



CLAY	SILT			SAND			GRAV		
	FINE	MED.	COARSE	FINE	MED.	COARSE	FINE	ME	COARSE

PARTICAL SIZE

Table 3: Marshal stability (kn) of asphalt concrete made from pyrolized polyethene

PP CONTENT (%)	Stability (N) Un-soaked condition (PR)	Stability (N) Un-soaked condition (DA)	Stability (N) soaked condition (PR)	Stability (N) soaked condition (DA)
0	15638	15638	13090	13090
5	15710	15810	13100	13256
10	16001	16140	13446	13565
15	16921	16984	14546	14680
20	15406	15520	12515	12656
25	15230	15400	12342	12474

Table 4: Retained Marshall Stability for PR And DA

PP CONTENT (%)	RMS (%) (PR)	RMS (%) (DA)
0	83.70	83.70
5	83.43	83.85
10	84.01	84.05
15	85.96	86.43
20	81.23	81.53
25	81.04	81.0

Table 5: Swelling Index (S.I) for asphalt concrete made from pyrolized polyethene

PP CONTENT (%)	S.I (%) (PR)	S.I (%) (DA)
0	1.73	1.73
5	1.33	1.22
10	1.26	1.15
15	1.04	1.03
20	1.26	1.13
25	1.57	1.38

Table 6: 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

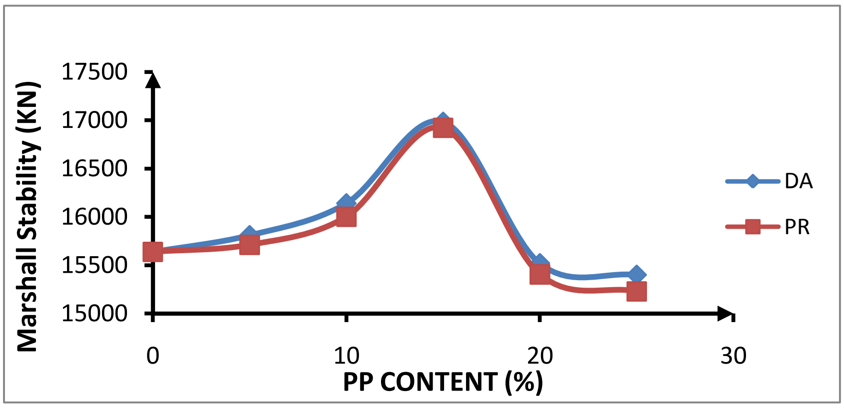


Figure 1a. Marshall stability of pyrolized polyethene for un-soaked ondition

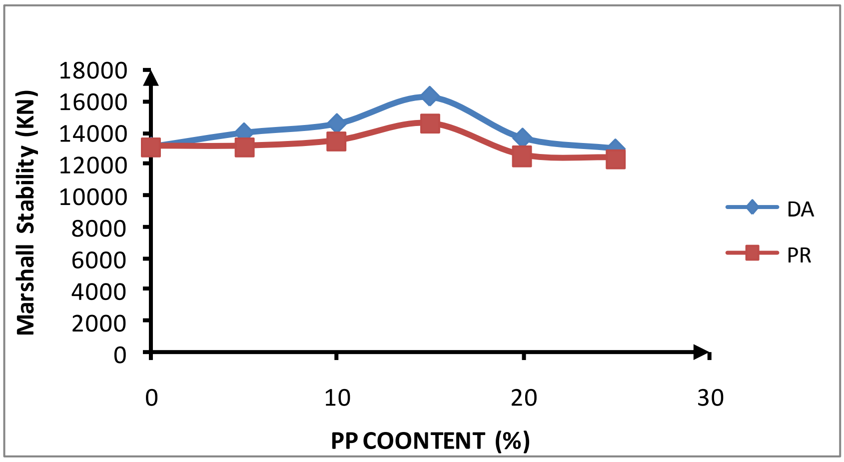


Figure 1b. Marshall Stability of Pyrolized Polyethene for soaked

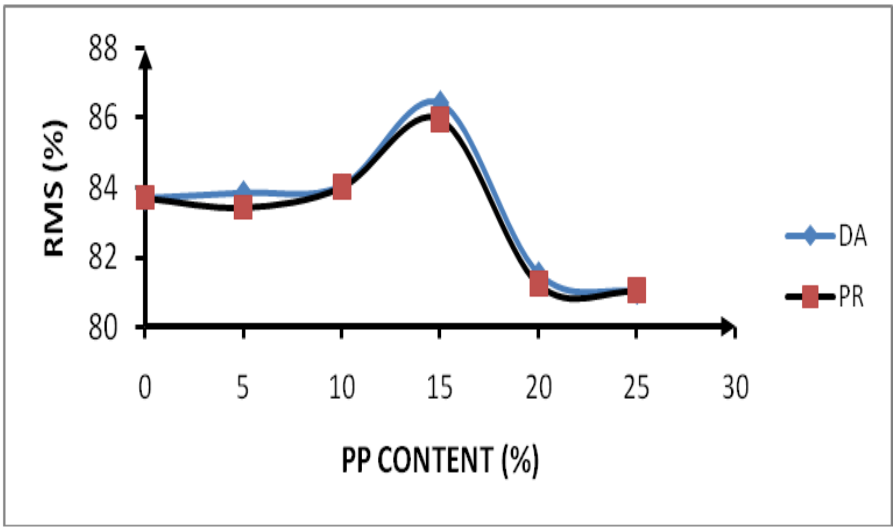


Figure 2. Retained Marshall Stability for Partial Replacement and Direct Addition.

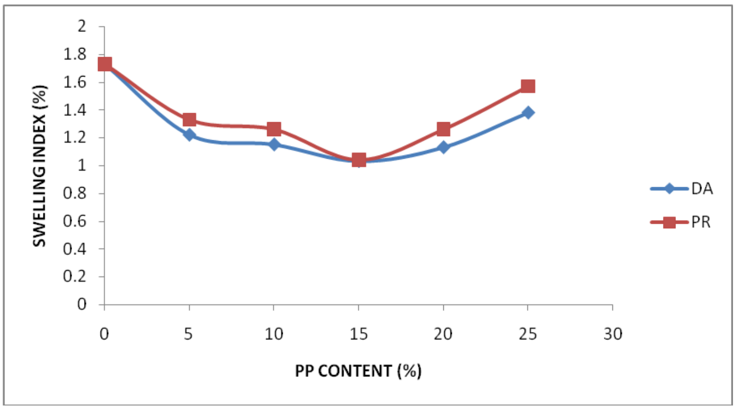


Figure 3. Swelling Index for Partial Replacement and Direct

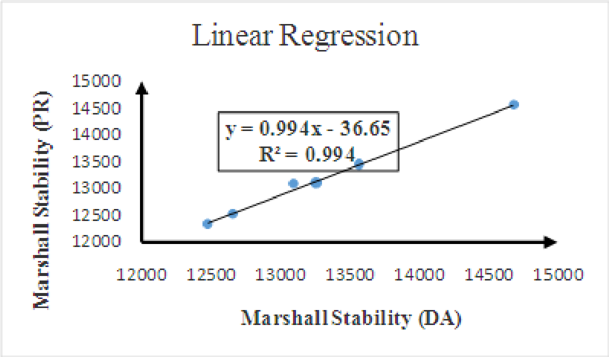


Figure 4*. Linear Regression Analysis of Marshall Stability for PR and DA

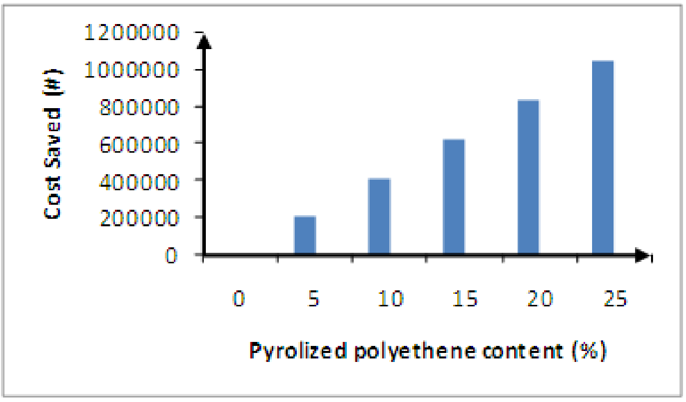


Figure 5. Cost benefit using PP as partial replacement for

3.2.4 Comparing Partial Replacement and Direct Addition Methods

The comparison of Partial Replacement and Direct Addition methods using linear regression analysis is shown in Figure 4. The result indicated that Partial Replacement and the Direct Addition methods compared favorably with coefficient of Regression $R^2 = 0.9948$.

3.2.5. Cost Benefit Analysis

The result of the cost benefit analysis of asphalt concrete made from Pyrolized Polyethene as modifier is as shown in Table 6 and Figure 5. The result of the study showed that for one kilometer (1kM) road with dimension as stated in section 2.6, for the optimum pyrolized waste polyethene content of 15%, cost savings of (N627,412.26) was achieved. This translates to a cost benefit ratio of 1.18 indicating that using pyrolized polyethene as partial replacement for bitumen is economical when compared with the direct addition method.

IV. Conclusion

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

i. The Stability of asphalt concrete made from polythene-modified bitumen increased to an optimum as the modifier content increased.
ii. The Retained Marshal Stability (RMS) of asphalt concrete made from Pyrolized polythene as partial replacement of bitumen increased to an optimum as the modifier content increased.
iii. The Swelling Index (SI) of asphalt concrete made from polythene modified bitumen decreased to a minimum as the Pyrolized polythene contret increased.
iv. The optimum result for asphalt concrete made from Pyrolized polythene as partial replacement of bitumen was obtained at 15% modifier content.
v. The research showed that asphalt concrete made from Pyrolized polythene as partial replacement for bitumen is cost effective with an optimum cost savings of N627,412.26 at 15% modifier content resulting in a cost benefit cost ratio of 1.18
vi. The partial replacement method should be adopted for modification of asphalt concrete.

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