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Increasing Durability of Bituminous Pavements using Hydro Carbon Void Fillers Produced from Recycled Polyethylene Wastes (RPEW)

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Abstract Current practices in the design of bituminous paving mixtures require a compromise between the properties of asphalt paving mixture. Properties of particular interest to the highway or pavement engineer are stability, flexibility, tensile strength, stiffness, fatigue and skid resistance. All of these properties help to define the overall durability of the pavement which is of paramount interest in design of bituminous mixtures – bituminous pavement. The present study investigated the use of hydro carbon fillers obtained from recycled polyethylene wastes (RPEW) to increase durability of bituminous pavements submerged in water. The study was simulated in the laboratory by submerging bituminous concrete mixtures resembling bituminous pavements in the field and studied the impact of the RPEW on the submerged concretes. Results obtained revealed that addition of RPEW to these concretes increased retained strength of the concretes (RSI). Finally, the addition of RPEW to the concretes reduced the loss of stability/strength in the concretes using both first durability and second durability indexes. In general, the reduction in loss of stability/strength implied increased durability.

Keywords Durability, Recycled Polyethylene Waste, Asphalt Pavement, Hydro-Carbons

Introduction

All forms of bituminous paving material deteriorate with time under the influence of heat, weather and traffic conditions [1]. In the long term the changes resulting from these actions produce distresses which impede the performance of the bituminous paving materials as being both binder material and water proofing agent. Alkawaaz and Qasim [2] revealed that low durability potential of the wearing course layer is one of the major reasons for distresses in asphalt pavement and reduced serviceability of highways.

Durability of bituminous pavement will therefore mean the degree of resistance that the paving material will offer against these militating actions [1]. Other definitions of durability has been offered such as Putri and Suparma [3]; that for asphalt pavements durability can be defined as its resistance to weathering and the abrasive action of traffic. ASTM [4] in their context defines thus; that durability is the capability of maintaining the serviceability of a product, component, assembly or construction over a specified period".

A recent study by Igwe et al [5] further corroborates the definition of durability by investigating moisture effect on stiffness of bituminous wearing course. The results from the study revealed that in un-drained conditions the impact of moisture on bituminous pavements is one of the most damaging factors to durability of pavements. Therefore, durability from his study can be said to be the resistance offered by bituminous pavements against gradual disintegration of the wearing course due to actions of temperature, traffic, moisture and construction practices. Many times the issue of construction practice is ignored which can be quite detrimental to pavement life. For instance in most developing nations', road constructions, especially street roads have poor drainage designs and sometimes none at all. This phenomena leaves in its wake water seating on constructed bituminous pavements longer than necessary without draining and thereby resulting in percolation of moisture into the sub-structure of the pavement and causing disintegration of the wearing course.

Thus current practice in the design of bituminous paving mixture will require a balance among several desirable properties of asphalt paving mixture such as – stability, durability, flexibility, fatigue and skid resistance as well as imperviousness and tensile strength/fracture [1]. Another major factor detrimental to pavement life is bitumen hardening which is almost solely responsible for cracking and disintegration of bituminous paving mixtures. Thus, the degree and rate of bitumen hardening is sometimes used as a measure of checking the durability of the bitumen. Studies have also identified some of the factors that majorly contribute to bitumen hardening which results in cracking and disintegration of bituminous pavement (loss of durability) as – oxidation, polymerization, volatilization, thixotropy, photo oxidation, photo-chemical actions and separation [6-7].

All of these maladies have led to a shift in paradigm in design, production and construction of bituminous paving mixture such that the life expectancy with respect to durability can be enhanced. For instance, there is the use of additives - organic and in-organic in the modification of bituminous paving mixtures or bitumen that can produce a greater durability. Others include the use of recycled aggregates and increased compaction on the paving mixture to provide extra stability.

Ferrira et al [8] investigated the relationship between Marshall Stability and percentage inclusion of RAP; their study concluded that the addition of RAP into the mixture produced concretes having higher stability. In related study in the use of RAP Feipeng et al, (2009) as presented in Alkawaaz and Qasim [2] studied the use of RAP as modifier to asphalt concrete mixtures. Their work evaluated by comparative study the performance of asphalt concretes with certain percentages of recycled asphalt pavement. The study concluded that the addition of RAP increased the performance properties of the asphalt mixtures.

Igwe [9] studied the effects of shredded tire chips as hydro carbon fillers in modification of bituminous concrete with respect to stiffness. The findings of his study revealed that the inclusion of shredded tire chips at optimum bitumen content produced concretes that performed better than the conventional concrete.

The present study seeks to use hydro carbon fillers obtained from recycled polyethylene wastes (pure water sachet) as additive modifier in bituminous wearing course under submerged conditions of moisture. The reason for the choice of modifier is akin to the fact that polyethylene is primarily composed of hydro carbon compounds [10]. Hydrocarbons are a family of organic compounds, composed entirely of carbon and hydrogen. They are the organic compounds of simplest composition and may be considered the parent substances from which all other organic compounds are derived. The hydrocarbons are conveniently classified into two major groups, open-chain and cyclic. In open-chain compounds containing more than one carbon atom, the carbon atoms are attached to each other to form an open chain; the chain may carry one or more side branches. In cyclic compounds the carbon atoms form one or more closed rings. The two major groups are subdivided according to chemical behaviour into saturated and unsaturated compounds [10].

Bitumen on the other hand is a highly viscous almost solid substance at ambient temperature consisting essentially of mineral oil made up of a variety of high molecular weight hydrocarbons and small proportions of oxygen, nitrogen and sulphur [11].

Due to the presence of these hydro carbon compounds predominantly present in both bitumen used as binder material in bituminous concrete and those in polyethylene, it is that there should exist a high level of miscibility and bonding between them. Thus, the present study sought to investigate how this bonding can sustain durability of a submerged bituminous pavement due to inclusion of recycled polyethylene wastes (RPEW).

Sample preparation

Sample preparation was preceded by aggregate gradation and blending. The straight line method of blending which allows for only two aggregates to be blended was adopted. After aggregate gradation and blending Marshal Design Procedures for asphalt concrete mixes as presented in Asphalt Institute [12] and National Asphalt Pavement Association **[**13**]** was adopted for mix design.

The procedures involved the preparation of a series of test specimens for a range of asphalt (bitumen) contents such that test data curves showed well defined optimum values. Tests were scheduled on the bases of 0.5 percent increments of bitumen content with at least 2-bitumen contents above and below the optimum asphalt content. During the preparation of the unmodified bituminous concrete samples, the aggregates were first heated for about 10 minutes before bitumen was added to allow for absorption into the aggregates. After which the mix was poured into a mould and compacted on both faces with 35 blows indicating low traffic volume using a 6.5kg-rammer falling freely from a height of 450mm. Compacted specimens were then subjected to bulk specific gravity test, stability and flow, density and voids analysis at 54^0C. The results obtained were used to determine the optimum asphalt content of the unmodified asphalt concrete. After obtaining the optimum asphalt content the design value of asphalt cement content was used to re-prepare samples that were subjected to varying percentages of RPEW addition between 1-5% by weight of the asphalt cement at optimum. The modified samples were prepared and tested in similar procedure to that of the unmodified asphalt concretes.

Retained Strength Index (RSI) and Durability Index (DI)

Assessment of durability for asphalt pavement wearing course is usually based on loss of strength or stability of the pavement wearing course usually expressed as an index. There are three types of indexes used for assessment of pavement durability namely – Retained Strength Index (RSI), First Durability Index (FDI) and Second Durability Index (SDI) [14]. It is note-worthy that for assessment of pavement durability using Durability Index (DI); the higher the index value, the more the loss of strength/stability of the pavement therefore the less durable the pavement becomes. On the other hand when assessing pavement durability using Retained Strength Index (RSI); the lower the index value the less durable the pavement becomes [14].

(a) Retained strength index (RSI) was considered as presented in equation 1 below according to Ali [14];

$$RSI = \frac{s_i}{S_o} \times 100 \qquad 1$$

Where;

RSI = retained strength index

S_i = stability after immersion at time t_i or stability of conditioned specimen

S_0 = stability before immersion or stability of unconditioned specimen

(b) Durability Index was considered in two parts – first durability index and second durability index.

(i) First Durability Index (FDI) is defined as the sum of the slopes of the consecutive sections of the durability curves [15] and obtained as presented in equation 2 below and the results obtained as presented in Table 5;

$$FDI = \sum_{i=0}^{n-1} \frac{S_i - S_{i+1}}{t_{i+1-}t_i} \qquad 2$$

Where;

S_{i+1} = percent retained strength at time t_{i+1}

S_i = percent retained strength at time t_i

t_{i+1} and t_i = immersion times

(ii) Second Durability Index (SDI) is formulated as follows [16-17]:

$$SDI = \frac{1}{t_n} \sum_{i=o}^{n-1} A_i = \frac{i}{2t_n} \sum_{i=0}^{n-1} (S_i - S_{i+1}) \times \left[2t_n - (t_{i+1} - t)\right] \qquad 3$$

Where

Si+1 = percent retained strength at time ti+1

Si = percent retained strength at time ti

ti, ti+1 = immersion times (calculated from beginning of test)

3.0 Results

Table 1: Classification Test Results of Materials

Material	Asphalt	Sand	RPW	Gravel
Specific gravity	1.06	2.80	0.93	2.56
Grade of binder material -	40/50	-		-

Mix proportion (%)	-	-	42	58
Viscosity of binder (poise)	-	$5.7*(10^{-4})$	-	-
Softening point	-		-	-
Penetration value	-	41.5ºC 51.3mm	-	-

Table 2: Schedule of Aggregates Used For Mix Proportion in Accordance With ASTM 1951: C136

Sieve size (mm)	Specification limit	% passing Aggregate A (Gravel)	% passing Aggregate B (Sand)	Mix proportion (0.58A+0.42B)
19.0	100	100	100	100
12.5	86-100	99.27	100	99.58
9.5	70-90	53.45	100	73.00
6.3	45-70	26.69	100	57.48
4.75	40-60	13.56	98.88	49.18
2.36	30-52	5.90	92.56	42.30
1.18	22-40	3.77	79.12	35.42
0.6	16-30	2.65	43.70	19.89
0.3	9-19	1.85	10.84	5.63
0.15	3-7	0.40	0.02	0.24
0.075	0	0.11	0	0.06
PAN	0	0.01	0	0

Table 3: Retained Stability (N) of Asphalt Concretes measured at varying Candle wax Content after Soaking within 1 – 5 days

Candle wax Content (%)	Day 0	Day 1	Day 2	Day3	Day 4	Day 5
0	12,500	10,600	9,080	7,710	7,000	6,350
1	13,700	11,800	10,280	8,910	8,200	7,550
2	18,360	16,460	14,940	13,570	12,860	12,210
3	21,750	19,850	18,330	16,960	16,250	15,600
4	19,860	17,960	16,440	15,070	14,360	13,710
5	16,200	14,300	12,780	11,410	10,700	10,050

Table 4: Retained Stability Index, RSI (%) of Asphalt Concretes at varying Candle wax Content after Soaking within 1 – 5 days from **Equation 1**

RPEW Content (%)	Immersion Time (Days)				
	1	2	3	4	5
0	84.80	72.64	61.68	56.00	50.80
1	86.13	75.04	65.04	59.85	55.11
2	89.65	81.37	73.91	70.04	66.50
3	91.26	84.28	77.98	74.71	71.72
4	90.43	82.78	75.88	72.31	69.03
5	88.27	78.89	70.43	66.05	62.04

Results in Table 4 were obtained by applying Equation 1 above.

Table 5: Results of Durability Index using FIRST DURABILITY INDEX (FDI) for 1 – 5 Days of Immersion from **Equation 2**

RPEW Content (%)	Retained Strength Lost/Day					Total Retained Strength Lost/Day (%) TRSL	Total Days Immersed - TDI (Days)	FDI (%) = TRSL/TDI
	1	2	3	4	5			
0	15.2	12.16	10.96	5.68	5.2	49.2	5	9.84
1	13.89	11.10	10	5.18	4.74	44.89	5	8.98
2	10.35	8.28	7.46	3.87	3.54	33.50	5	6.7
3	8.74	6.99	6.30	3.26	2.99	28.28	5	5.66
4	9.57	7.65	6.90	3.58	3.27	30.97	5	6.19
5	11.73	9.38	8.46	4.38	4.01	37.96	5	7.59

Results in Table 5 were obtained by applying Equation 2 above.

Table 6: Results of Durability Index using SECOND DURABILITY INDEX (SDI) for 1 – 5 Days of Immersion from **Equation 3**

RPEW Content (%)	Retained Strength Lost/Day					Total Retained Strength Lost/Day (%) TRSL	Total Days Immersed - TDI (Days)	SDI (%) = TRSL/TDI
	1	2	3	4	5			
0	68.40	42.56	27.40	8.52	2.60	149.48	5	29.90
1	62.41	38.83	25.00	7.77	2.37	136.39	5	27.27
2	46.57	28.98	18.65	5.80	1.77	101.77	5	20.35
3	39.31	24.46	15.75	4.90	1.49	85.91	5	17.18
4	43.05	26.79	17.25	5.36	1.64	94.08	5	18.82
5	52.78	32.84	21.14	6.57	2.01	115.34	5	23.07

Results in Table 6 were obtained by applying Equation 3 above.

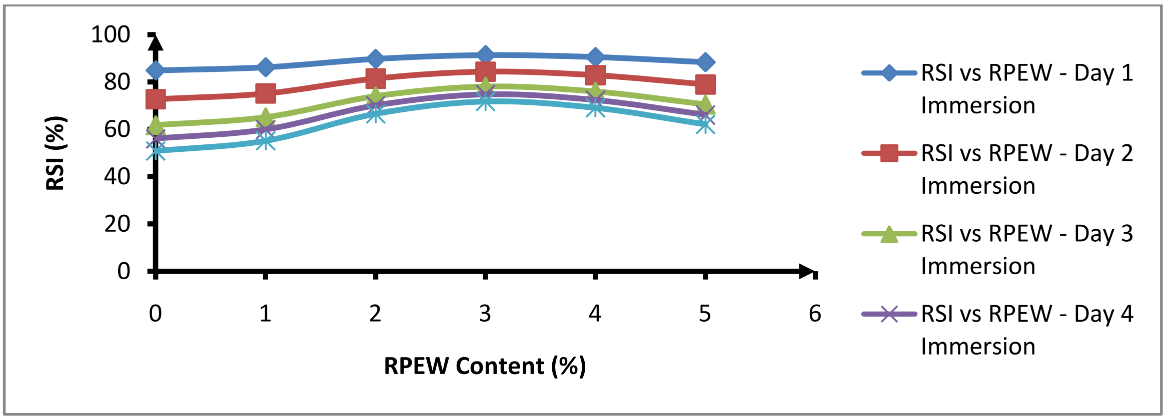

Figure 1: Variation of RSI with RPEW

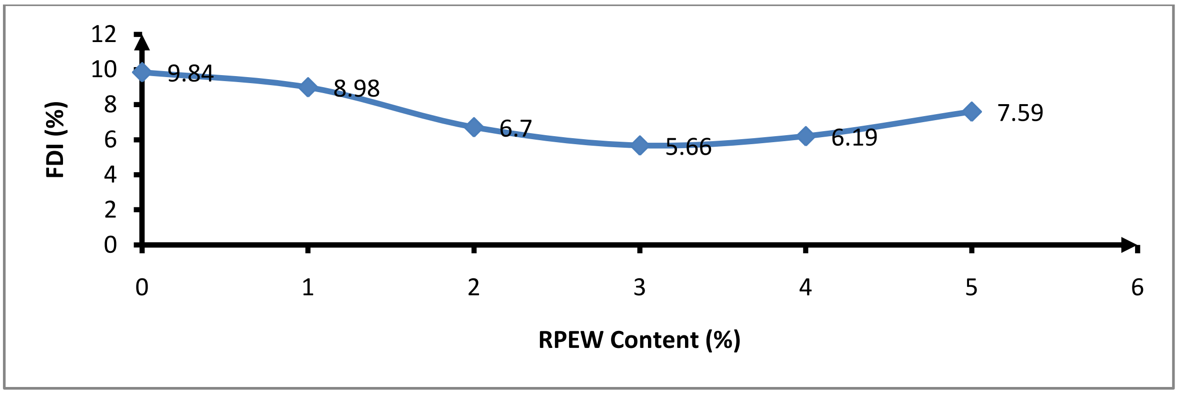

Figure 2: Variation of FDI with RPEW

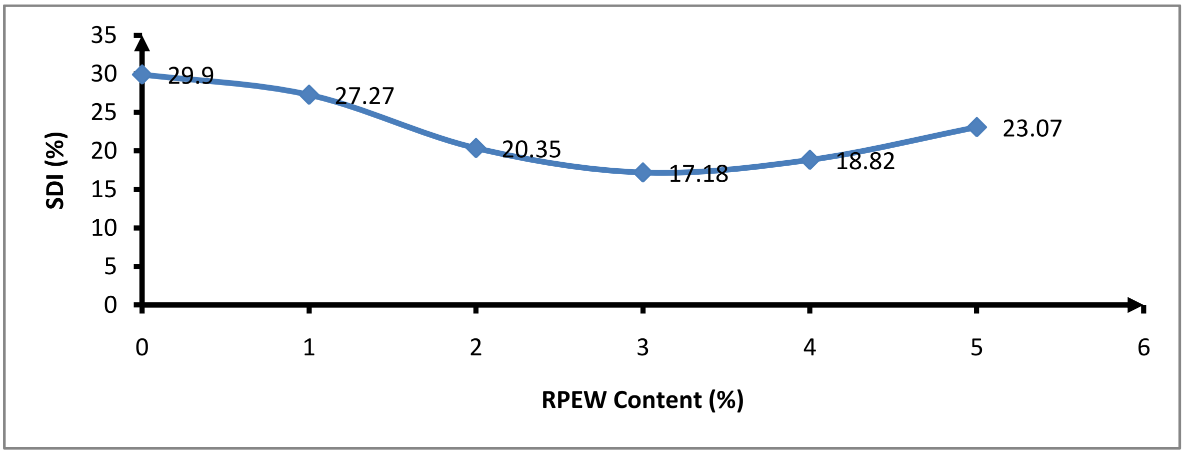

Figure 3: Variation of SDI with RPEW

Result and Discussion

Durability index for bituminous or asphalt pavements is an index used to represent the percentage of stability/strength of the pavement lost due to deterioration from submergence in water or other environmental conditions. When assessing durability of pavements using durability index positive values of the index indicates stability/strength lost due to either submergence or other environmental factors. On the other hand negative values of the index indicate otherwise – that is stability/strength gained due to pavement modification.

Durability Assessment using RSI

From Table 4 and Figure 1, it was observed that values of retained strength index (retained stability index) were increasing linearly with increase in RPEW content up to 3% addition with values of 91.26% after day 1; 84.28% after day 2; 77.98% after day 3; 74.71% after day 4 and 71.72% after day 5 immersion times respectively. These values began to decrease with further addition of RPEW. In durability assessment increase in RSI means a increase in pavement durability; therefore it can be safe to argue that addition of RPEW content up to 3% produced a more durable pavement than that of the conventional bituminous pavement when both are submerged in water. Therefore, it is believed that RPEW content addition can help sustain submerged bituminous pavements.

Durability Assessment using FDI

Using the FDI assessment from Table 5 and Figure 2, it was observed that durability index decreased linearly with increasing RPEW content up to 3% addition after which durability index started increasing with further additions of RPEW. Since durability index defines the loss in stability/strength; it is safe to argue that at 3% RPEW content addition which has the lowest index value of 5.66% we can summarize that is the most durable time of the pavement. Thus, we can conclude that addition of RPEW can sustain durability of bituminous pavement even though submerged in water.

Durability Assessment using SDI

Similarly, using SDI assessment from Table 6 and Figure 3, it was observed that durability index decreased linearly with increasing RPEW content up to 3% addition after which durability index started increasing with further additions of RPEW. Since durability index defines the loss in stability/strength; it is safe to argue that at 3% RPEW content addition which has the lowest index value of 17.18% we can summarize that is the most durable time of the pavement. Thus, we can conclude that addition of RPEW can sustain durability of bituminous pavement even though submerged in water.

Conclusion

From the research findings of the study the following conclusions are made'

- That addition RPEW content up to a maximum of 3% to bituminous pavements submerged in water can reduce loss in the stability/strength of the pavement.
- That addition RPEW content up to a maximum of 3% to bituminous pavements submerged in water can sustain the durability of bituminous pavement.
- That RPEW can be used as a water proofing agent to sustain bituminous pavements when no measures are taken to provide drainage facilities.
- In general all the methods used for assessing durability proved that addition of RPEW up to a maximum of 3% to bituminous pavement can sustain the pavement life in submerged conditions.

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