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Effect of Coconut Shell Ash as Void Filler on Durability and Elastic Modulus of Asphalt Concrete

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Abstract:
Background: The cost and availability of asphalt concrete filler materials have made pertinent the need for research into possible alternatives to conventional fillers for asphalt concrete production. Researchers have shown that the inclusion of mineral fillers in hot-mix asphalt concrete improved its mix design properties considerably. This research investigated the effect of Coconut shell ash on the durability and Elastic modulus of asphalt concrete,
Materials and Method: An experimental approach was adopted to investigate the durability and elastic properties of asphalt concrete. Tests were carried out on a set of asphalt concrete specimens prepared using bitumen at the optimum bitumen content and under severe moisture condition. First and second durability, and elastic modulus of the briquette specimens were evaluated.
Results: Results showed that using coconut shell ash as void filler under severe moisture condition improved durability (reduced moisture damage) and elastic modulus of asphalt concrete at 15% optimum modifier content.
Conclusion: The study concluded that coconut shell ash is a good void filler and should be incorporated in asphalt concrete production.
Keywords: Durability, Elastic Modulus, Asphalt Concrete, Coconut Shell Ash, Void Filler

I. INTRODUCTION

The rapid growth in traffic and axle repetition on our roads have brought about the need for improvement of highway pavement materials. The design, construction and maintenance of highways have been geared towards the development and provision of safe and cost-effective pavements that have the capacity to carry expected traffic load on the highways. As a result of the economic situation of most developing countries, the cost of embarking on road projects has become a serious challenge. The high cost of construction materials has necessitated studies to identify suitable pavement materials that will be cost effective to substitute or completely replace most of the traditional materials presently in use. The quest and curiosity in the search for good pavement materials have been the concern of many researchers in pavement engineering. Pavement design objective is to produce an economical mix that meet up with specifications, and must not fail during use. One major step in the improvement of the existing performance of asphalt roads starts with the modification of the material during the mix design process. The focus is to discover other alternative and locally available materials that can substitute conventional mineral filler in Hot Mix Asphaltic (HMA) concrete. The mix design should be proportioned such that when aggregates and binder are combined, adequate results of durable pavements such as; sufficient voids, workability, strength, and density are achieved. One major area identified and considered is the use of environmental waste materials. Environmental waste material can be classified as waste materials generated by industrial by-product such as coal ash, various slag from metal industries, industrial sludge, and waste from industries like pulp and paper mills, and ceramic waste. The second category are wastes generated from food and agricultural products, plastic and rubber waste[1]. Municipal solid waste (MSW) has been of very serious concern due to environmental pollution and environmental pollution caused by agricultural produced has increased in recent times. Agro-waste like coconut shell (CS), oil palm shells, rice husk, corncob and groundnut husk have constituted an environmental challenge, hence the need to convert them into useful materials to minimize their negative effect on the environment. It has been reported that close to 60 million tons of coconut are produced across the world, principally in Indonesia, Philippines, and India[2]. The shells that cannot be used find their way in municipal solid waste (MSW). Coconut shell is bio waste and other bio wastes such as bamboo, jute, hemp, oil palm shell and rice husk have great potential as reinforcement in thermoplastics. Studies have shown that Coconut shell has high strength, modulus properties, good thermal properties, high toughness, good resistance to abrasion and lignin content which renders it more weather resistant. These advantages can make coconut shell become a very important agricultural product around the world as the new source of energy-bio fuel rather than burnt to produces CO_2, methane emissions and can be considered as a good construction material.

One of the challenges in the production of asphalt paving mixture is the cost of production of fillers like cement or stone dust from crushing of stone aggregates. Various conventional materials such as cement, lime, granite powder are normally used as filler in asphalt concrete mixtures. Conventionally, cement, lime and granite powder are expensive and are used for other purposes more effectively. It has been established from previous studies that the performance of flexible or asphalt pavements can be improved using coconut shell ash. Studies have shown that coconut shell either in ash as cementitious material or other forms can improve the performance of asphalt pavements. As organic filler, research on the assessment of suitability of Coconut Shell Ash as a filler in Stone Mastic Asphalt (SMA) in comparison with other mineral fillers such as fly ash and Portland cement were carried out, it was reported that the maximum stability value obtained for coconut shell charcoal is above 8.0 KN which is the recommended standard as presented by Asphalt Institute and it can be used as filler in SMA mix for highway pavements. Also, Flow increased with increase in bitumen content in the case of all fillers used in the sample and air voids decreased with increase in bitumen content for all the fillers used in the research. The studies concluded that coconut shell charcoal can be used as a substitute for mineral filler as it satisfies all the criteria[4]. Studies on the assessment of the suitability of coconut shell charcoal as filler in stone matrix asphalt showed that coconut shell charcoal possesses high strength property than other fillers due to its hardness, low specific weight, high modulus Property and high lignin content. Its high resistance to different weather condition, durability, abrasion resistance characteristics and low cellulose content makes it suitable material for construction of road[4]. Coconut shell ash is resistant to crushing, absorption, surface moisture, grading, freezing and heat. It is light weight and possesses synthetic resin glues which could act as binder for flexible pavement. This study investigated the effect of Coconut Shell Ash (CSA) as void filler on durability and elastic modulus of characteristics of asphalt concrete.

II. MATERIALS AND METHODS

2.1 Sample Collection

The materials used in this study includes fine and coarse aggregates, bitumen and filler. The fine aggregate used was sharp sand while the coarse aggregates were all-in graded gravel (passing through 19mm sieve and retained in 4.75 mm sieve) and coconut shell ash. The sharp sand and gravel were obtained from the local building materials market within South-South geo-political zone in Nigeria. Laboratory tests carried out on the aggregates included the following:

i. Gradation analysis - Sieve Analysis
ii. Specific Gravity Test

Within the scope of this study, the tests carried out on binder included;

i. Specific gravity Test
ii. Penetration Test
iii. Viscosity Test
iv. Softening Point Test

The binder used was grade 60/70 penetration bitumen as recommended by ASTM D5[5] for Highway Pavements.

2.2 Coconut Shell Ash Preparation

Coconut shells were sun-dried to ease the removal of the coconut fiber. The shells were ripped out and washed from any unwanted substances and sun-dried again to remove moisture. The coconut shells were burnt in the kiln within Civil Engineering laboratory in Rivers State University, Nigeria for about 4 hours to change its properties to charcoal. Coconut shell charcoal was then left to cool in room temperature before being crushed manually to ash with a grinding machine. The coconut shell ash (CSA) was sieved and materials of passing BS sieve 0.425 - 0.075mm were collected. CSA was then batched at 1%, 2%, 3%, 4% and 5% of weight of total mix for preparation of test specimens.

2.3 Sample Preparation

Asphalt Concrete Mix design is basically the selection and proportioning of an economic blend of aggregates and asphalt to produce a mix having:

i. Sufficient asphalt to ensure a durable pavement
ii. Sufficient mix stability to satisfy traffic demands.
iii. Sufficient voids in the total compacted mix to allow for compaction under traffic loading.
iv. Sufficient workability to permit efficient placement of the mix without segregation.

Based on these requirements, samples were prepared using the Marshall Design procedures for asphalt concrete mixes[5,6,7,8,9,10]. The procedure involved the preparation of a series of test specimens for a range of asphalt contents such that test data curves showed well defined optimum values. Each specimen required approximately 1200g of the total weight of the mixture. To determine the Optimum Binder Content (OBC) of 5.0%, 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. In order to provide adequate data, three test specimens were prepared for each of the binder content used; each specimen having 63.5mm thick by 101mm diameter size. Two classes of hot mix asphalt (HMA) concrete were prepared using the optimum binder content; unmodified HMA concrete and modified HMA concrete. All samples were prepared for heavy traffic.

2.4 Presentation of the Models used

This section highlights the models used in the determination of the First Durability Index, Second Durability Index and Elastic Modulus of the modified CSA asphalt concrete.

2.4.1 First Durability Index (FDI)

First Durability Index (FDI) is defined as the sum of the slopes of the consecutive sections of the durability curves[11]. Durability index is a measure of the loss in strength or stability of asphalt concrete pavement. A high value of durability index indicates a pavement with high loss of strength and stability which shows low durability. Mathematically, FDI is expressed as;

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

Where,
S_{i+1} = percent retained strength at time t_{i+1}
Si = percent retained strength at time t_i,
t_{i+1} and t_i = immersion times

2.4.2 Second Durability Index (SDI)

This is defined as the average strength loss area enclosed between the durability curves. It can be calculated using equation (2):

$$SDI = \frac{1}{t_n} \sum_{i=0}^{n-1} A_i = \frac{i}{2t_n} \sum_{t=0}^{n-1} \left(s_i - s_{i+1}\right) x \left[2t_n - \left(t_{i+1} - t\right)\right] \qquad (2)$$

Where,
S_{i+1} = percent retained strength at time t_{i+1}
Si = percent retained strength at time t_i,
ti and t_{i+1} = immersion times (calculated from the beginning of the test)

2.4.3 Elastic Modulus

Elastic modulus was determined as follows[12]

$$E = 40\left(\frac{Stability}{Flow}\right) \qquad (3)$$

Where;
E= Elastic Modulus in pounds per square inch (lb/in^2)
Stability = Maximum load at failure in pounds (lb)
Flow = Flow in inches.

III. RESULTS AND DISCUSSIONS

3.1 Results

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 First Durability Index (FDI). Second Durability Index (SDI) and Elastic modulus of asphalt concrete made from Coconut Shell Ash (CSA) are presented in Tables 3, 4 and 5 respectively. Figures 1, 2 and 3 shows the effect of CSA on First Durability Index, Second Durability Index and Elastic modulus of asphalt concrete respectively.

Table 1: Physical Properties of Materials

Material	Asphalt	CSA	Sand	Gravel
Specific gravity	1.02	2.5	2.66	2.673
Grade of Bitumen	60/70			
Mix proportion (%)		7	41	52
Viscosity of binder	1.27Mm/s^2		-	-
Softening point	48.^{0}C		-	-
Penetration value	68mm		-	-

Table 2: Schedule Aggregate Combination (Mix Proportions)

Sieve sizes mm	Limit	% Passing			Mix Proportion
		Aggregate A%	Aggregate B%	Aggregate C%	0.41A+0.52B+0.07C
19.5	100	100	100	100	100
12.5	80 - 100	91	100	100	96.31
9.5	70 - 90	60	100	100	83.6
4.75	50 - 70	20	98	100	66.16
2.36	35 - 50	4	80	100	50.00
0.6	18 - 29	1	40	100	28.21
0.3	13 - 23	0	30	63	20.01
0.15	8 - 16	0	21	37	13.51
0.075µ	4 - 10	0	7	24	5.32

Table 3: First Durability Index (FDI)

CSA Content (%)	First Durability Index (%) Days of Immersion					FDI for 5 days
	1	2	3	4	5	
0	6.1833	6.1114	6.0395	5.9437	5.4404	29.7184
1	6.0228	5.9652	5.8729	5.7575	5.3652	28.9835
2	5.8536	5.7874	5.6621	5.3806	5.0587	27.7424
3	4.9362	4.7380	4.3005	4.1380	4.3038	22.4164
4	5.0011	4.8980	4.8323	4.5863	4.5821	23.8998
5	6.2001	6.1058	6.0265	5.9384	5.4315	29.7022

Table 4: Second Durability Index (SDI)

	Second Durability Index (%) Days of Immersion					SDI for 5 days
CSA Content (%)	1	2	3	4	5	
0	27.8250	21.3901	15.0989	8.9155	2.7202	15.1899
1	27.1028	20.8780	14.6821	8.6362	2.6826	14.7964
2	26.3411	20.2560	14.1553	8.0709	2.5294	14.2705
3	22.2128	16.5830	10.7512	6.2070	2.1519	11.5812
4	22.5051	17.1431	12.0808	6.8794	2.2910	12.1799
5	27.9005	21.3702	15.0663	8.9076	2.7157	15.1921

Table 5: Elastic Modulus (lb/in^2)

CSA Content (%)	Elastic Modulus per soaking day					
	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5
0%	38723.90	31600.40	26139.29	22091.54	17078.38	13964.29
1%	40452.74	34043.89	27992.66	22091.54	18780.14	15484.28
2%	43501.04	36780.11	30350.80	24619.99	20548.29	17897.46
3%	56366.40	49118.71	41139.63	34308.52	29269.39	25881.01
4%	48016.12	43008.21	36711.68	30148.66	25380.71	22453.41
5%	32372.61	27268.19	22726.51	18573.10	14550.11	12912.84

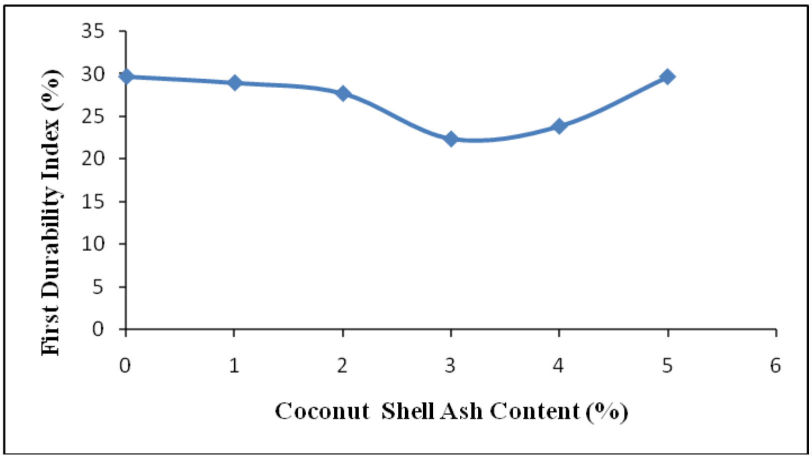

Figure 1: Effect of Coconut Shell Ash on First Durability Index

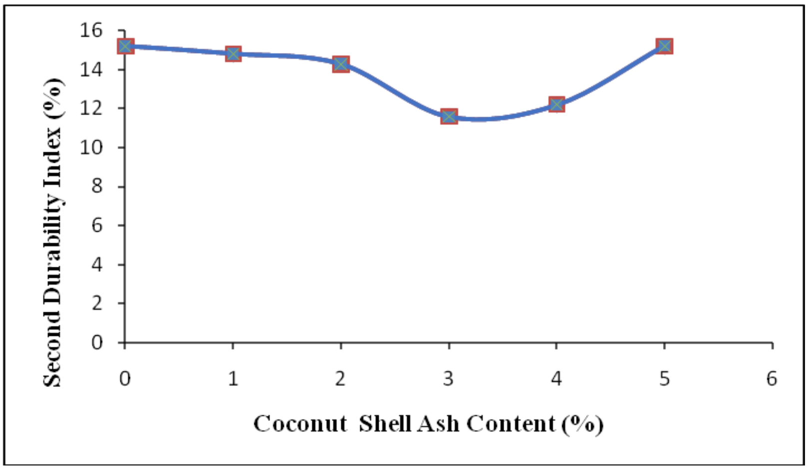

Figure 2: Effect of Coconut Shell Ash on Second Durability Index

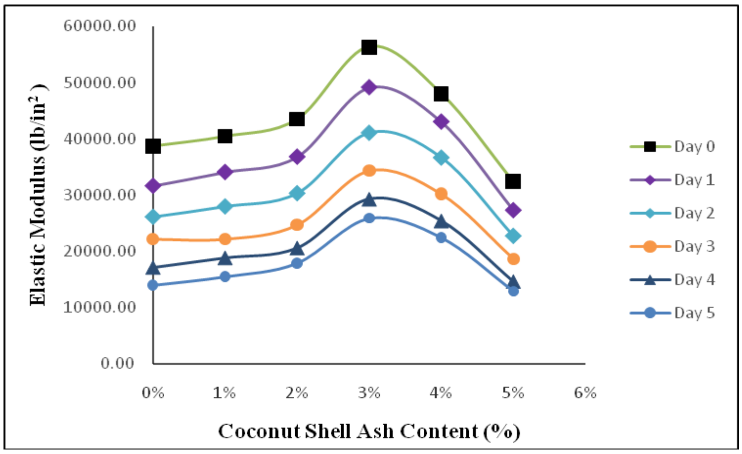

Figure 3: Effect of Coconut Shell Ash on Elastic Modulus

3.2 Discussions

3.2.1 Effect of Coconut Shell Ash on First Durability Index (FDI) of Asphalt Concrete

The effect of Coconut Shell Ash (CSA) on Durability of asphalt concrete using First Durability Index (FDI) for samples modified using 0% - 5% CSA content and immersed in water for 0 – 5 days is shown in Figure 1. The result of the study showed that at immersion Day 5, First Durability Index (FDI) decreased from 29.7184 % at 0% CSA content to a minimum of 22.4164 % at 3% CSA content. Further addition of coconut shell ash increased FDI to 29.7022 % at 5% CSA content. The durability of asphalt concrete pavement is a measure of strength or stability of pavement. Thus, a low value of durability index indicates pavement with reduced loss of strength and stability which implies high durability, hence, the result indicated that addition of CSA as void filler to asphalt concrete increased its durability at 3% optimum CSA content.

3.2.2 Effect of Coconut Shell Ash on Second Durability Index (SDI) of Asphalt Concrete

The effect of Coconut Shell Ash (CSA) on Durability of asphalt concrete using Second Durability Index (SDI) for samples modified using 0% - 5% CSA content and immersed in water for 0 – 5 days is shown in Figure 2. It can be observed that at immersion Day 5, Second Durability Index decreased as CSA content increased. The SDI decreased from 15.1899% at 0% CSA content to a minimum of 11.5812% at 3% CSA content and further addition of CSA decreased SDI to 15.1921% at 5% CSA content. A low value of Second durability Index indicates a pavement with high durability. Therefore, it can be concluded that the addition of CSA can enhance the durability of asphalt pavement subjected to severe moisture condition. It is important to state that positive values of durability index indicate stability or strength lost due to submergence in water or other factors; whereas the negative values of durability index indicates stability or strength gained due to pavement modification[13]. Also, durability actually represents the percentage of stability or strength lost due to deterioration as a result of submergence in water[14]. This result showed that addition of CSA as void filler to asphalt concrete improved durability of asphalt concrete at 3% optimum CSA content.

3.2.3 Effect of Coconut Shell Ash on Elastic Modulus of Asphalt Concrete

The effect of Coconut Shell Ash (CSA) on Elastic Modulus of asphalt concrete for samples modified using 0% - 5% CSA content and immersed in water for 0 – 5 days is shown in Figure 3. The result showed that at immersion Day 1, Elastic Modulus increased from 31600.4lb/in^2 at 0% CSA content to an optimum value of 49118.71lb/in^2 at 3% CSA content. Further addition of CSA decreased the Elastic Modulus to 27268.19 lb/in^2 at 5% CSA content. Similarly, at immersion Day 5, Elastic Modulus increased from 13964.29 lb/in^2 at 0% CSA content to an optimum value of 25881.01lb/in^2 at 3% CSA content and decreased to 12612.84MPa at 5% CSA content. The trend was the same for Days 2, 3 and 4. The result indicated that addition of CSA as void filler to asphalt concrete increased its elastic modulus at 3% optimum CSA content. The increase in elastic modulus could be as result of reduction in air void and increased density of the asphalt concrete mixture caused by addition of CSA. The result also showed that the value of elastic modulus decreased with increase in number of immersion days.

IV. CONCLUSION

The following conclusions can be made based on finding of the research:

i. Coconut Shell Ash (CSA) reduced air void and improved moisture resistance properties of HMA concrete at optimum modifier content.
ii. Under severe moisture condition, CSA improved strength and durability of HMA concrete at optimum modifier content.
iii. Coconut Shell Ash as void filler improved the elastic modulus of the asphalt concrete.
iv. The optimum modifier content for best result is 3% CSA content.
v. Coconut Shell Ash should be used as void filler in asphalt concrete production.

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