EVALUATION OF CARBON POWDER AS MINERAL FILLER IN HOT MIXED ASPHALT

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ABSTRACT

Despite the potential benefits of carbon powder as a waste, there is a need to evaluate the feasibility and effectiveness of carbon powder as mineral filler in hot mixed asphalt. This research therefore seeks to evaluate the replacement of carbon powder with the conventional filler material at a varying percentage range of 0% (control) to 100% at an interval of 20% by producing 15 samples. The result revealed that the constituent materials for the asphalt passed the physical test. The maximum stability was found to be 4.8kN at 5.5% Bitumen content as the control value, the stability increases as the BC increases and begin to drop as more Bitumen were added. The maximum increase in strength was 6% at 50% replacement with carbon powder.

Keyword: ***Bitumen, Carbon powder, filler, Hot Mix Asphalt, Marshal stability***

1.0 Introduction

Road networks worldwide cost billions of dollars. Structural design of roads consists of asphalt layer, base layer; sub base layer on top of the sub grade layer, recently, the constructions of roads have been on the rise (Abdelzaher, 2016). One of the greatest challenges facing road construction industry is focusing on its objectives on the achievement of sustainable development by the use of locally available materials to improve the various materials used in pavement layer construction (Adama and Jimoh, 2011).

A pavement is said to be relatively stable layer or crust constructed over a natural soil. It can also be defined as layers of process and unprocessed materials placed on the natural soil, configured to carry traffic of any kind. The main function of pavement is to support and distribute the heavy wheel loads of vehicles over a wide area of the underlying natural soil called sub grade and permitting the deformation within elastic or allowable range and to provide adequate surface (Ahmed, 2001). The two types of pavements available in Nigeria include flexible and rigid pavements, but for the purpose of this study, flexible pavement would be considered. The materials applicable in it construction processes includes asphalt, laterite, granites and many more.

Asphalt pavements are widely used in modern transportation infrastructure due to their durability and cost-effectiveness. However, asphalt production road contributions contribute significantly to carbon emissions and environmental pollution. The incorporation of sustainable materials and additives in asphalt mixtures has gained significant attention in recent years as a means to mitigate these environmental concerns while maintaining or enhancing pavement performance. Some potential additives includes calcium carbide, rice husk ash, egg shell ash and carbon powder, which has shown promise as mineral filler in hot mixed asphalt. Carbon powder, derived from waste materials such as discarded tires and waste from nail production has the potential to not only improve the mechanical properties of asphalt mixtures but also reduce the environmental impact associated with traditional mineral fillers.

Mineral fillers play a crucial role in asphalt mixtures, contributing to their performance, workability and durability. Traditional mineral fillers, such as limestone and hydrated lime, are commonly used in hot mixed asphalt to improve the characteristics of the mixture (Marasteanu *et al.*, 2013). These fillers enhance the compatibility of the asphalt mixture, promote binder-aggregate adhesion, and improve the resistance to moisture damage and rutting (Chen *et al.*, 2016; Ma *et al.*, 2020). However, the extraction, production and disposal of traditional mineral fillers have associated environmental impacts, including energy consumption and carbon emissions (Sol-Sánchez *et al.*, 2017; Vega-Zamanillo *et al.*, 2019).

Carbon powder derived from waste materials, such as discarded tires, has emerged as potential alternative mineral filler in hot mixed asphalt. Carbon powder exhibits unique properties, including high specific surface area and improved binder-aggregate interaction, which can enhance the mechanical properties of the asphalt mixture (Marasteanu *et al.*, 2011). The use of carbon powder as a mineral filler offers several potential benefits, including reduced environmental impact, improved rutting resistance, and waste material utilization (Shu *et al.*, 2014).

While previous studies have investigated the performance of carbon powder as mineral filler in asphalt mixtures, there is a need for comprehensive evaluations to assess its suitability and effectiveness. The existing research has primarily focused on laboratory-scale experiments, and there is a lack of in-depth analysis on the influence of carbon powder on various aspects of asphalt mixture performance, including rutting resistance, moisture susceptibility, and environmental implications.

2.0 Materials and Method

2.1 Materials Used

The following materials are used for this study;

a) 12.5mm of Coarse aggregate b) 9.5mm of Coarse aggregate c) Mineral Filler (Fine Sand) d) Dust (fine aggregate e) Bitumen Emulsion f) Carbon Waste powder

2.2 Research Method

2.2.1 Determination of physical properties of aggregates

The physical test conducted on the aggregates includes sieve analysis, specific gravity, Bulk densities (compacted and un-compacted), moisture content, Aggregates impact value (AIV) and Aggregate crushing value (ACV) in accordance to BS 812.

2.2.2 Determination of physical properties of bitumen

The physical property conducted on the Bitumen used includes Flash and fire point test, the penetration test, softening point test and specific gravity in accordance to ASTM.

2.2.3 Asphalt mix design

The design for asphalt mix can be defined as the selection of the most suitable materials that is bitumen, coarse aggregate, filler and fine aggregate needed to produce an asphalt mold of desired properties. All mix design methodologies utilize density and voids to assess the fundamental physical characteristics of Hot Mix Asphalt (HMA).

2.2.4 Marshal Test

The Marshall Stability test (in ASTM D1559) is conducted to evaluate the mechanical properties and performance characteristics of bituminous mixtures. Marshall Samples with bitumen contents ranging from 4.5% to 6.5% by weight of the aggregate, increased by 0.5%, were prepared for the tests. For each bitumen content, three samples were made, and the optimal bitumen content (OBC) was found. It is conducted on a prepared cylindrical specimen of asphalt mix to assess its load-carrying capacity and resistance to deformation under specific conditions. A standard dry specimen of 1200g of aggregate and filler was heated at a temperature of 175℃ -

190℃. The dry mix and bitumen was heated in the right proportion according to the mix composition to a temperature of 150℃ - 170℃ and was then placed in an oiled marshal apparatus mold. The mixture is subjected to compaction with a total number of seventy-five blows of a 4.54kg compaction hammer falling through 457mm on the either side of the mold containing the hot mix asphalt. Allow to cool for twenty-four hours, demold and weigh and record the sample separately in air and water. Obtain the values for stability (which represents the maximum load the specimen can withstand before failure) and flow (which is deformation or flow of the specimen.

2.2.5 Filler replacement

The carbon waste powder was sieved through 2.6mm and 0.075mm BS sieve (NO.200), The physical properties like moisture content, bulk density, specific gravity using stated procedure was determined. Using the obtained optimum bitumen content value determined from control specification, hot mix asphalt mould sample was prepared and carbon waste powder was partially replaced for mineral filler in ranges from 20%, 40%, 60%, 80%, 100%. The asphaltic mix sample was subjected to marshal stability test to obtain the value for stability and flow.

3.0 Result and Discussion

3.1 Particle Size Distribution (sieve analysis)

Table 4.1 shows the particle size distribution for the coarse aggregate. It was observes that there was even distributions of particle sizes; hence the aggregate is uniformly graded.

Table 1: Particle size distribution of 12.5mm crushed stone aggregate

Sieve Size	Mass Retained	% Retained	% Passing
20mm	0	0	100
14mm	44.47	3.185	96.815
10mm	456.69	30.47	66.34
6.3mm	496.27	33.11	33.23
2.36mm	165.61	11.05	22.18
1.18mm	72.86	4.861	17.319
600um	56.01	3.74	17.319
300um	54.36	3.63	9.969
150um	80.57	5.375	4.594
75um	23.69	1.58	3.014
Pan	45.28	3.014	0

The grain size distributions for the mineral filler are presented in Table 4.2. The result shows the highest amount was retained on the sieve size 300um.

Table 2: Particle size distribution of mineral filler

Sieve Size	Mass Retained	% Retained	% Passing
20mm	0.00	0.00	100
14mm	0.00	0.00	100
10mm	0.00	0.00	100
6.3mm	0.00	0.00	100
2.36mm	45.02	4.401	95.599
1.18mm	84.08	8.22	87.379
600um	178.34	17.434	69.945
300um	379.76	37.125	32.82
150um	285.34	27.894	4.926
75um	26.46	2.588	2.35
Pan	23.97	2.35	0.00

Table 1 and 2 shows the grain distribution and percentage passing the various sieve sizes for crushed stone and stone dust required for asphalt mixed design and blend proportion determination.

Table 3: Particle size distribution of 9.5mm crushed stone aggregate

Sieve Size	Mass Retained	% Retained	% Passing
20mm	0.00	0.00	100
14mm	0.00	0.00	100
10mm	222.95	21.70	78.3
6.3mm	702.64	68.41	9.89
2.36mm	74.88	7.29	2.6
1.18mm	2.09	0.20	2.4
600um	2.33	0.23	2.17
300um	2.18	0.212	1.958
150um	5.58	0.543	1.415
75um	2.61	0.254	1.14
Pan	11.74	1.14	0.00

Table 4: Particle size distribution of stone dust

Sieve Size	Mass Retained	% Retained	% Passing
20mm	0.00	0.00	100
14mm	0.00	0.00	100
10mm	0.00	0.00	100
6.3mm	0.00	0.00	100
2.36mm	282.89	21.95	78.05
1.18mm	268.72	20.85	57.20

600um	230.64	17.896	39.304
300um	132.98	10.32	28.984
150um	195.49	15.17	13.814
75um	61.72	4.79	9.03
Pan	166.37	9.03	0.00

3.2 Aggregation Gradation and Blending

The percentage passing sieve sizes for the different asphaltic component were put together to determine the percentage composition using trial method. The result shows that to achieve a desired mix, 15% of 12.5mm aggregates, 18% of 9.25mm aggregates, 7% of Filler and 60% of dust were required such that the total blend falls within the range of specification as seen enveloped between the lower and upper specification in Figure 1.

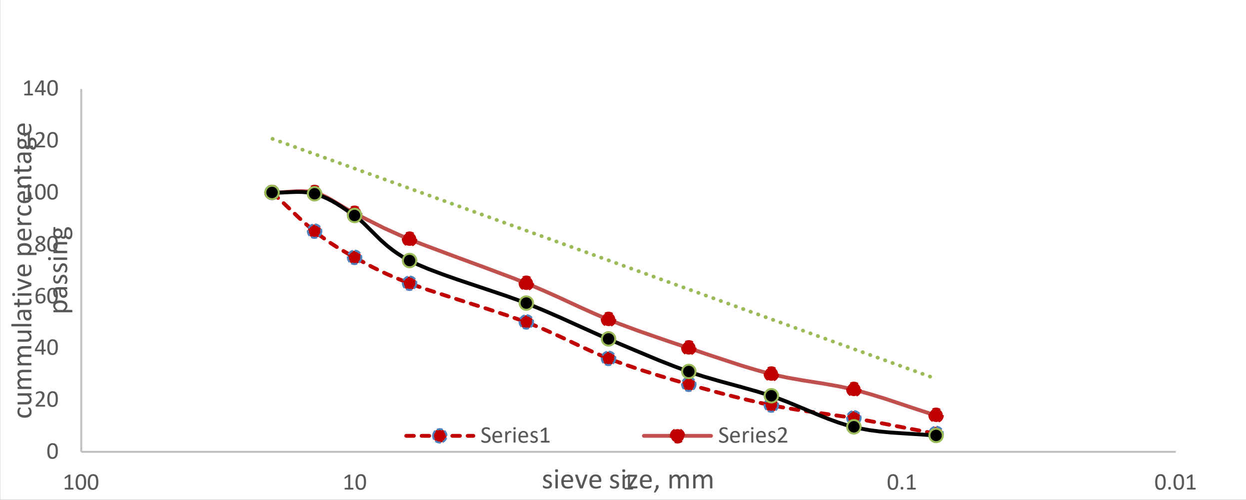

Figure 1: Blend Proportion Graph

3.2 Bulk Density

Table 5: Bulk density result for the aggregates

Materials	Bulk Densities	Result
Sand	Uncompacted	1.43
	Compacted	1.53
Carbon Powder Waste	Uncompacted	1.74
	Compacted	2.05
Stone dust	Uncompacted	1.65
	Compacted	1.86

Coarse Aggregate	Uncompacted	1.66
	Compacted	1.68

Table 5 presents the bulk densities for the un-compacted and compacted sand, CPW, SD and coarse aggregates. The compacted value was 7% higher than the un-compacted values for sand. 18% for CPW, 13% for SD and for coarse aggregates, no appreciable difference between the compacted and un-compacted values for 5% more.

3.3 Specific Gravity Result

Table 6: **S**pecific gravity for aggregates

Materials	Specific Gravity	Range
Sand	2.65	2.50-2.65
Stone dust	2.4	2.20-2.80
Carbon Waste Powder	2.53	1.50-2.55

The specific gravity values obtained for mineral filler, stone dust and carbon powder as shown in Table 6 are respectively 2.65 (2.5-2.65 standard range), 2.40 (2.20-2.80 standard range) and 2.53 (1.50-2.55 standard range)

3.4 Moisture Content

Table 7: Moisture content for aggregate

Materials	Moisture Content
Stone dust	0.13
Coarse Aggregate	0.1
Carbon Waste Powder	0.44

Table 9 shows that the filler material, 9.5mm aggregates, 12.5mm aggregates and CWP have respective moisture content value of 0.21, 0.13, 0.10 and 0.44% respectively and they all falls within the standard specification.

3.5 Aggregate Impact and crushing test

Table 10 presents the AIV and ACV for the aggregates. The result shows that the AIV and ACV are respectively 8.78% and 20.06% which are within the limit of specification

Table 10: AIV and ACV

Other Tests	Result (%)
AI V	8.78
ACV	20.06

3.6 Bitumen Test

Table 11: Bitumen test results

Bitumen Result	Result	Standard Range
Flash Point	351^0C	232^0C Minimum
Fire Point	371^0C	232^0C Minimum
Penetration	64mm	100mm Maximum
Specific Gravity	1.03	1.01-1.06
Softening Point	52.35	56^0C Maximum

From the test conducted, the value for flash and fire test was 351°C and 371°C respectively and the standard values are 351°C and 371°C, thereby making the material suitable for use. Also, the value for penetration test was 98.67mm which is below the standard maximum value of 100, thereby making the material suitable for use. The value for specific gravity was 1.03 and it falls within the standard range of 1.00 – 1.05, hence, the Bitumen is suitable for road application. The softening point value was 52.15°C which is below the maximum standard value of 56°C.

3.7 Marshall Stability Test for Control and Partial Replacement

From the test conducted, the maximum stability value obtained was at 5.5% with a value of 5.48kN, whereas the standard stability value by AASHTO was <8KN. This result was also illustrated in Figure 2 for highest stability with corresponding least flow of 5.1mm.

Table 12: Volumetric analysis and Mechanical test result of the Marshall sample for the control

%B/C	Stability (KN)	Flow(mm)	VMA	%air void	Unit weight(kg/cm3)	VFB
4.5	2.80	10	3.57	4.33	2380	45.72
5.0	3.38	8.4	4.33	3.87	2430	43.26
5.5	5.48	5.1	2.43	3.51	2520	51.00
6.0	4.31	7.8	3.89	3.52	2460	47.30

6.5	3.30	8.0	5.74	3.50	2470	43.90

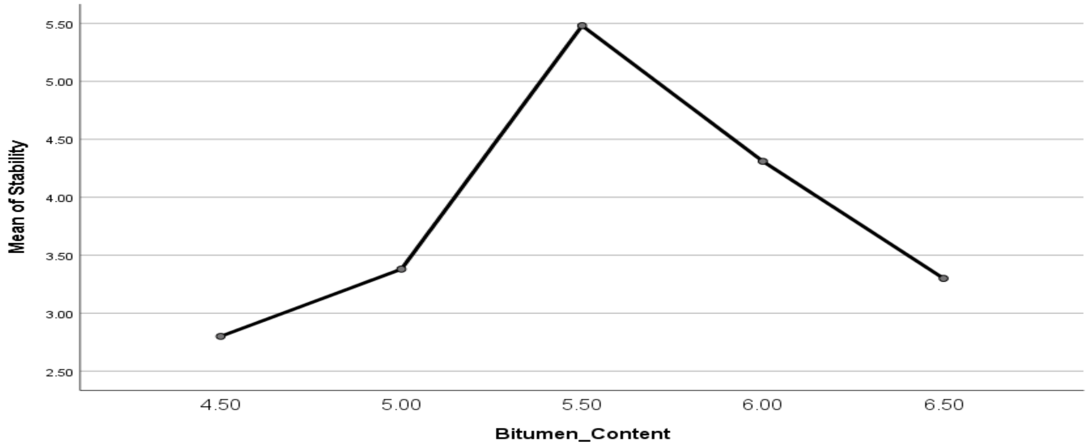

Figure 2: Stability Versus Bitumen content

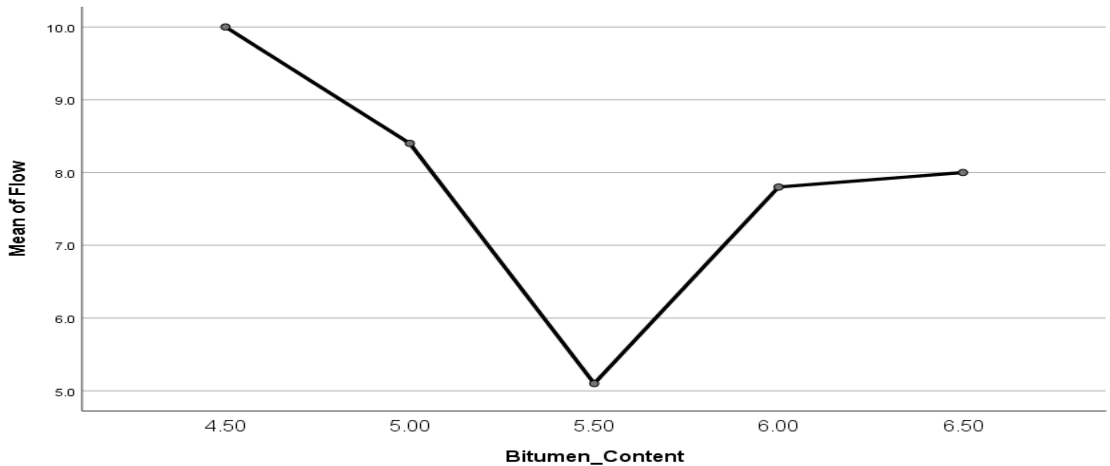

Figure 3: Flow versus Bitumen content

Table 13: Volumetric analysis and Mechanical test result of the Marshall

Percentage replacement (%)	**20**	**40**	**60**	**80**	**100**
Stability (kN)	3.69	5.10	4.79	3.30	4.91
Flow (mm)	7.10	8.25	6.35	4.00	7.63

As CP replaces the conventional filler with 20% CP and 80% conventional filler as shown in Table 13, the stability reduces below the control value (0% CP), as more CP replaced the conventional material, the stability increases above that of 20% and then fall afterwards. It was clearly seen that, when CP completely replaces the conventional material, the stability reduces by about 10% compare to the control value.

4.0 Conclusion

All the physical properties for the asphaltic component such as stone dust, fillers, aggregates and binder (Bitumen) shows satisfactory results, hence they can be used to produce asphalt concrete for flexible pavement construction. The waste carbon also shows appreciable physical properties making it suitable as a replacement to conventional filler material. The stability increases with flow to as high as 5.5% Bitumen content before dropping, while flow shows reversible case. 40% with CP replacement of the conventional filler shows the highest stability value which was also about 10% less compare to conventional material.

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