

Strength Characteristics of Asphaltic Concrete Produced with Conventional and Non-Conventional Fillers

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ARTICLE INFO

Received: November, 2019

Accepted: January, 2020

Published: January, 2020

Keywords:

Strength Characteristics

Asphaltic Concrete

Conventional Fillers

Non-conventional Fillers

ABSTRACT

The increasing demand for a durable and stronger road pavement necessitated the need to introduce non-conventional materials into the production of asphaltic concrete (AC). This research studied the strength characteristics of conventional and non-conventional fillers used in AC. The conventional fillers used were Dangote cement (DC) and Elephant Supaset cement (ESC) while the non-conventional fillers used were hydrated lime (HL) and glass powder (GP). The mechanical properties of aggregates and bitumen used in the production of AC samples were determined by performing standard tests on them and each filler was used to produce asphaltic concrete samples in varying percentages of 20, 40, 60, 80 and 100% by weight. Marshall stability test was performed on the AC samples to determine their stability and resistance to plastic deformation. The performance of all the materials used as fillers showed close values of stability for 20 and 40% partial replacements. At 60, 80 and 100% partial replacements, ESC gave the highest values of stability of 3.95, 4.20 and 5.10 kN respectively. The flow values at different proportions of partial replacements for conventional and non-conventional fillers ranged between 13 – 18 mm for all the fillers used. However, in all circumstances, the stability and flow values meet up with the minimum criteria contained in the table of typical Marshall design criteria of the Asphalt Institute for light and medium traffic roads with 10^4 – 10^6 estimated single axle loads (ESALs). The usefulness and suitability of AC produced with non-conventional fillers can be explored as they are capable of reducing the pressure on the ecosystem and give a durable road pavement.

1. INTRODUCTION

Asphaltic concrete is composed of binder (material binding the constituents together-bitumen), mineral aggregates, filler and modifier combined in different percentages to produce a mix (Rashwan, 2016). The superiority and stability of asphalt mixtures are affected by several features in conjunction with the gradation of aggregates, type and amount of filler materials. It has been noticed recently in Nigeria that the disintegration of many of the asphalt pavements may be due to the fillers used in them, causing heavy losses to the economy, and which may also cause many accidents. Filler acts as one of the major constituents in asphalt concrete mixture. Fillers help to fill voids in the mix and also influence the aging characteristics of the mix (Rashwan, 2016).

Recently, traffic volume in many countries has increased and this increase meant that pavements are exposed to higher stresses (Jaya, 2015). Higher density of traffic in terms of commercial vehicles; increase in private vehicles ownership; overloading of trucks; poor road usage attitude; bad road maintenance culture; significant variation in daily and seasonal temperature of pavements; all these have been responsible for the development of distresses such as raveling, rutting, and fatigue failures of bituminous surfaces (Tomar and Koshta, 2013).

Suitable materials combination and modified asphaltic concrete have been found to result in longer life for wearing courses depending on the type and percentage of mineral fillers used (Tomar and Koshta, 2013). Researchers have extensively investigated the use of various by-products as fillers in improving the properties of the asphaltic concrete (Sobolev and Naik, 2005). Mineral filler plays a significant role in the engineering properties of asphaltic concrete and conventionally, stone dust, cement and lime are used as fillers (Tomar and Koshta, 2013).

Depending on the size, aggregates are classified as coarse-grained, fine-grained and fines (particles size fraction of an aggregate which passes the 0.063mm sieve). Generally, the aggregate materials that are finer than 0.075 mm (75 μ m which is No. 200 BS sieve) in size are known as filler. Filler is characterized as comprising of finely divided minerals like slag dust, rock dust, hydraulic binder, hydrated lime, fly ash, glass powder, etc. In an asphalt concrete, the filler, whether natural or artificial, may stiffen the asphalt concrete and affect the workability and compaction characteristics of the mix (Anderson *et al.*, 1982). Fillers impart significantly on the properties of asphalt-concrete mixtures. The amount of filler influences the optimum asphalt content (Hyyppa, 2017). The workability when mixing and compacting the asphalt-concrete mixture; an important property of asphalt-concrete, is also affected by the filler used (Zulkati *et al.*, 2012).

In Nigeria, the production of asphaltic concrete has been characterized by the use of conventional materials which has caused a lot of ecological imbalance and has put pressure on the ecosystem, however, the need for a durable, cost-effective and high performing roads forms the thrust of this research into the use of non-conventional fillers in asphaltic concrete. This research will provide technical information to Engineers on the usefulness of non-conventional fillers viz-a-viz their conventional counterpart.

2. METHODOLOGY

Materials

The materials were sourced locally and carefully selected to be of the highest grade and quality and screened of deleterious materials that are capable of affecting the material's properties. Some of these materials are contained in Figures 1, 2 and 3.

- i. Coarse aggregate
- ii. Fine aggregate
- iii. Conventional fillers
 - a. Dangote 3X Cement (DC)
 - b. Elephant Supaset Cement (ESC)
- iv. Non-conventional fillers
 - a. Hydrated Lime (HL)
 - b. Glass Powder (GP)
- v. Bitumen (60/70 penetration grade).



Figure 1: Dangote 3X Cement and Elephant Supaset Cement used as Conventional fillers.



Figure 2: Hydrated Lime and Glass Powder used as Non-Conventional Fillers.

Preparation of Samples

Asphaltic Concrete samples were produced with different proportions of fillers, coarse aggregate and fine aggregate, in 5, 55, and 45% proportions respectively of 1200 g total weight of the sample in accordance with the Asphalt Institute (1997) requirement, AC sample produced with GP as filler is known as glasphalt. The mass of filler in the sample constituents used to produce the AC of 5% of filler content in 1200g was 60 g. Conventional fillers of DC and ESC were used to produce AC samples in varying proportions of 20, 40, 60, 80 and 100% by weight separately. Likewise, HL and GP were also used to produce AC and glasphalt samples respectively in varying percentages of 20, 40, 60, 80 and 100% by weight. A thorough mixing and stirring was ensured in each case by heating to a temperature range of between 100 to 120°C. The AC samples were poured into a circular mould having a diameter of 105 mm and a height of 115.4 mm with extension collar. A total of 63 AC samples shown in Figure 3 were produced altogether.



Figure 3: Asphaltic Concrete Samples.

Methods

Standard tests were performed on the materials to determine their physical properties and suitability for use in AC. Soundness Test to BS EN 196-3:2016 and fineness test to BS EN 196-6:2018 were performed on cement, particle size analysis to ASTM D 6913/6913M - 17, Aggregate Crushing Value (ACV) test to BS 812-110, 1990 and Aggregate Impact Value (AIV) test BS 812-112, 1990 were performed on aggregates. Penetration test to ASTM D5 / D5M-13, Ductility test to ASTM D113-17, Softening point test to ASTM D36 / D36M-14e1, Flash and fire point tests to ASTM D92-16b and Water in bitumen test (Dean and Stark Method) to ASTM D95-05 were performed on bitumen to determine its mechanical properties. Marshall Stability Tests to ASTM D 6927 – 15 was carried out on the AC produced with both conventional and non-conventional fillers to determine their resistance to plastic flow and deformation.

3. RESULTS AND DISCUSSION

Soundness and Fineness Test

The results of soundness test which measures the ability to resist volume expansion of cement when heated and fineness test which is a measure of the weight of cement particle whose size greater than 90 microns are contained in Table 1.

Table 1. Soundness and Fineness Test.

Type of Cement	DC	ESC	DC	ESC
Average Soundness (mm)	0.95	1.27	Average Fineness (%)	2 4

The two conventional Portland cement DC and ESC exhibited average soundness values of 0.95 mm and 1.27 mm respectively which are within the limit of the standard requirement in BS EN 197-1:2000 that put the ceiling value of soundness at 10 mm for ordinary Portland cement, rapid hardening cement, low heat cement and high alumina cement, the values obtained are below the 10 mm maximum value, this indicates that the two types of cement will not experience excessive volume expansion when subjected to heat during the production of AC and the AC pavement service life. The fineness test result showed that the types of cement used have fineness indices of 2% and 4% respectively, the standard requirement states that cement

should have fineness index less than 5%. The fineness test results implied that the two types of cement used have more than 95% of their particles finer than 90 microns and are therefore suitable for AC production since their respective fineness indices are within the specified maximum limit of 5%.

Particle Size Distribution

The result of particle size distribution is shown in Figure 4. Particle size distribution is important for analyzing materials because the size of particles can affect a wide range of properties, such as the strength of AC produced with it, the solubility of a mixture, surface area and so on. The result indicated that the material is well graded, their sizes vary from coarse to fine. The aggregate has a coefficient of uniformity (C_u) value of 7.91 and a coefficient of curvature of 1.24. Therefore, as C_u is greater than 6 and C_c is within the range of 1 to 3, this confirms that the soil is well-graded and suitable for AC production ASTM D 2487 - 17.

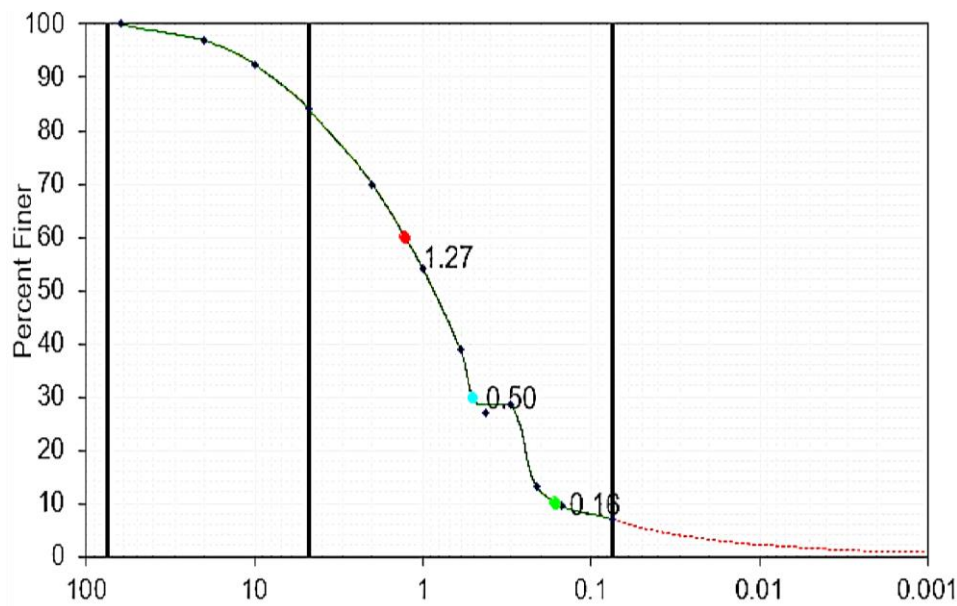


Figure 4: Particle Size Distribution Curve.

Aggregate Impact Value (AIV) and Aggregate Crushing Value (ACV)

The results of AIV which is a measure of resistance to sudden impact or shock of the coarse aggregate and ACV which measures the resistance of a coarse aggregate to gradually applied compressive load carried out on coarse aggregates are presented in Table 2. The average AIV value was obtained to be 20.43%; this value lies within the limit set for road surfacing according to BS 812-112, 1990 for the surface course, the required range of AIV value is 20 - 30%. The average ACV was 29.45%; this falls between 27% - 31% recommended by BS 812: 110:1990. The results of AIV and ACV tests showed that the aggregate used has adequate resistance to impact and compressive loads.

Table 2. AIV and ACV of Coarse Aggregates

Samples	AIV	ACV
ACV (%)	27.94	21.24

Penetration Test

The result of the penetration test in Table 3 helps establish the grade and consistency of bitumen. The result showed that an average penetration value of 69.33 dmm is obtained for the bitumen. This confirms that the bitumen used is a 60/70 pen. grade bitumen, a penetration value that ranged between 60 and 70 at standard test conditions (ASTM D946/D946M).

Table 3. Penetration Test

Samples	A	B	C
Final Penetration (dmm)	70	80	69
Initial Penetration (dmm)	0	11	0
Penetration (dmm)	70	69	69

Flash and Fire Point Test

The test is performed to determine the temperature at which a bituminous material will give a flash of fire and burns for a minimum of five (5) minutes. The result is shown in Table 4.

Table 4. Flash and Fire Point Test

Samples	A		B		C	
	Flash Point	Fire Point	Flash Point	Fire point	Flash Point	Fire Point
Initial Temperature (°C)	289	316	287	316	287	318
Final Temperature (°C)	0	0	0	0	0	0
Temperature (°C)	289	316	287	316	287	318

The average flash point obtained from the test result was 287.7°C; this is within the acceptable limit of the recommended range of 280°C to 300°C. In the same vein, the average fire point obtained was 316.7°C, this value lies within the specified limit of 300°C to 320°C according to standard specification for penetration-graded asphalt cement for use in pavement construction (ASTM D946/D946M).

Water in Bitumen Test

This test was carried out on bitumen to determine the percentage of water in the bituminous sample used, the result is in Table 5. The mass of water in the reflux condenser collected is expressed as a percentage by weight of the original sample. The maximum permissible limit is 5% and the average percentage of water in bitumen determined is 2.06%. This is suitable for AC production and within the acceptable limit contained in standard specification for penetration-graded asphalt cement for use in pavement construction (ASTM D946/D946M).

Table 5. Water in Bitumen Test

Sample	A	B	C
Weight of Sample (g)	50	50	50
Weight of water in condenser (g)	1.02	1.1	0.97
Percentage of water in bitumen (%)	2.04	2.2	1.94
Average % of water in bitumen	2.06		

Softening Point Test

The softening point of bitumen measures the temperature at which bitumen attains a degree of softening, the result of this test is presented in Table 6. The average softening temperature of the tested bitumen is 47.6 °C, which is above the minimum value of 45°C standard specification for penetration-graded asphalt cement for use in pavement construction (ASTM D946/D946M). The indication of this is that the bitumen is not easily susceptible to the effect of temperature when used in production AC.

Table 6. Softening Point Test

Sample	A	B	C
Softening Temperature (°C)	47	48	48
Average Softening Temperature	47.6		

Ductility Test

The ductility test is performed on bitumen to determine the length to which bitumen can be extended before it breaks. The result of the test is presented in Table 7. The average ductility value of 103 cm was obtained which is above the recommended minimum value of 100 cm as per ASTM D946/D946M; the ductility value obtained exceeds the minimum specified value which confirms its property to elongate under traffic load without getting cracked when used in AC production.

Table 7. Ductility Test

	A	B	C
Ductility (cm)	103	102	104
Average Ductility (cm)	103		

Marshall Stability Test

The Marshall Stability test carried out on the moulded AC samples produced with conventional and non-conventional fillers to determine the maximum load carried by a compacted specimen at a standard test temperature of 60°C are presented in Figures 5 and 6. The result showed a stability value of 3.42 kN when 100% of stone dust was used as filler. The Marshall Stability of AC produced with conventional fillers exhibited Stability values that ranged between 4.26 and 4.21 kN for ESC and 3.44 to 5.10 kN DC for all percentage replacements. The reactive nature of cement with other aggregates in the AC and the binder and the particle size of the cement which is able to fill the micropores in the AC is responsible for this excellent performance.

The results of the Marshall Stability of AC produced with non-conventional fillers are shown in Figure 6. The Stability values obtained for non-conventional fillers ranged between 3.44 and 4.01 kN for HL and 3.44 and 3.61 kN for glasphalt. The performance of all the materials used as fillers showed close values of stability as clearly indicated in the graphical representation of the stability results for 20 and 40% partial replacements. At 60, 80 and 100% partial replacements, ESC gave the highest values of stability of 3.95, 4.20 and 5.10 kN respectively, this could be attributed to its fineness index and soundness. However, in all circumstances, the stability values meet up with the minimum criteria stipulated in table of typical Marshall design criteria Asphalt Institute (1997) in Table 8 for light and medium traffic roads with $10^4 - 10^6$ estimated single axle loads (ESALs).

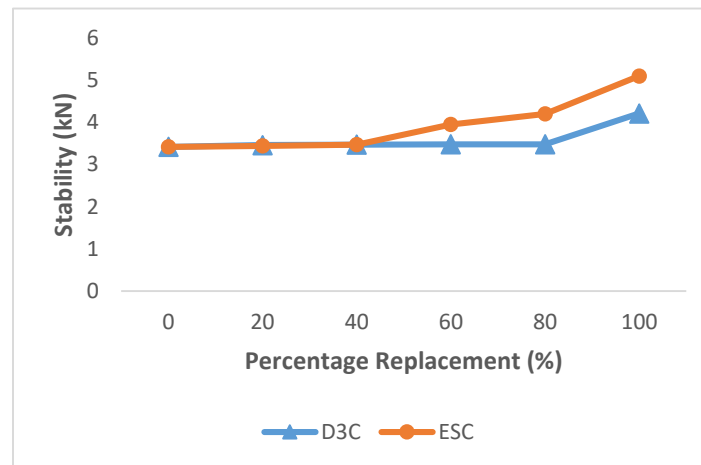


Figure 5: Marshall Stability of AC Produced with Conventional Fillers.

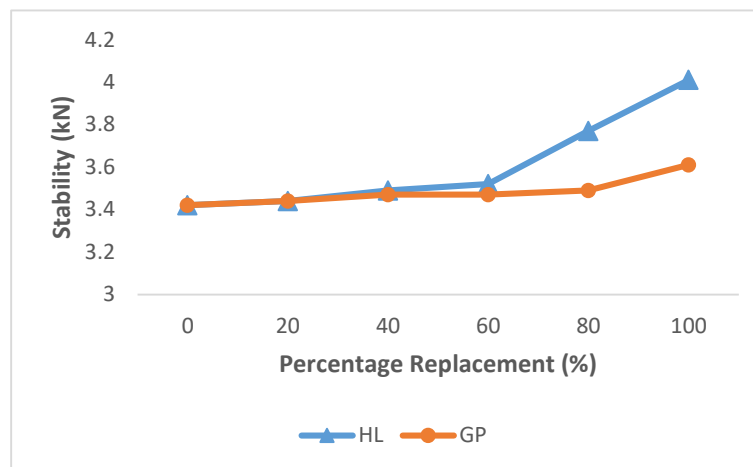


Figure 6: Marshall Stability of AC Produced with Non-Conventional Fillers.

Table 8. Typical Asphalt Institute Marshall Design Criteria

Mix Criteria	Light Traffic ($< 10^4$ ESALs)		Medium Traffic ($10^4 - 10^6$ ESALs)		Heavy Traffic ($> 10^6$ ESALs)	
	Min.	Max.	Min.	Max.	Min.	Max.
Compaction (number of blows on each end of the sample)	35	-	50	-	75	-
Stability (minimum) (N)	2224	-	3336	-	6672	-
Flow (0.25 mm (0.01 inch))	8	20	8	18	8	16
Percent Air Voids %	3	5	3	5	3	5

The flow measures the deformation of the AC samples in units of 0.25 mm between when no load is applied and the maximum load carried by the AC samples during stability test. Figures 7 and 8 contained the flow values under varying proportions of partial replacements for conventional and non-conventional fillers. The values range from 13 – 18 mm for all the fillers used. The flow values obtained for the fillers used meets the standard range of values as given in the table of typical Marshall design criteria of the Asphalt Institute, 1997. Therefore, all the fillers have good flow values under Marshall Stability Test.

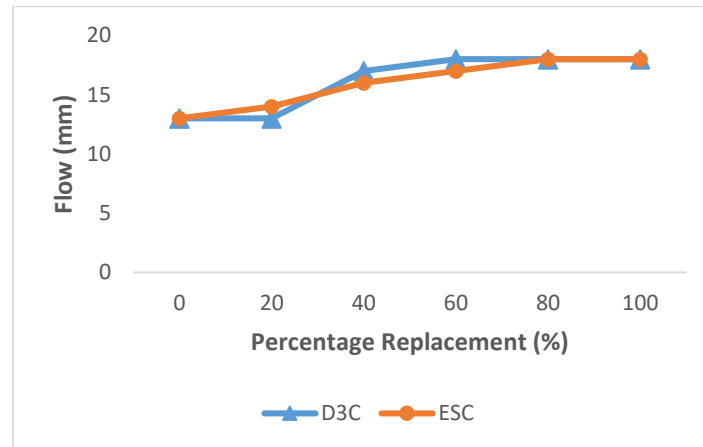


Figure 7: Flow of AC Produced with Conventional Fillers.

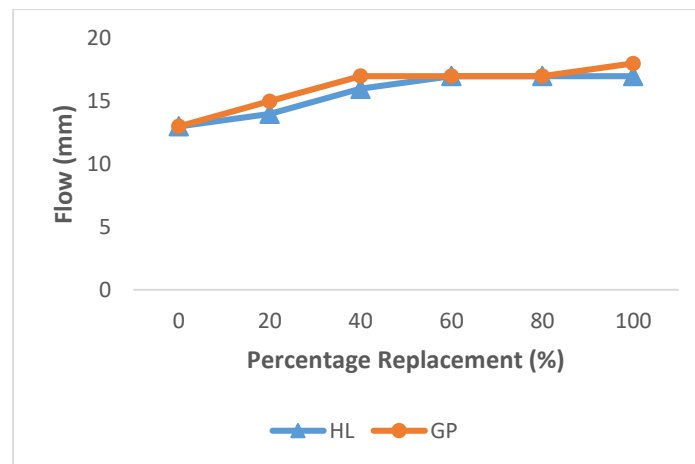


Figure 8: Flow of AC Produced with Non-Conventional Fillers.

4. CONCLUSION

The Marshall Stability values of AC produced with DC, ESC, GP and HL showed maximum stability values of 4.21, 5.10, 3.61 and 4.01 kN respectively, the differences in value of the Marshall Stability test result is as a result of the the difference in the chemical composition. These Stability values meet the requirements of the Asphalt Institute; therefore, they are suitable for use as fillers for production of AC for medium traffic roads ($10^4 - 10^6$ ESALs) with minimum expected stability value of 3.33 kN. It is noteworthy also that the stability values for AC with DC and ESC as fillers were close, this confirms GP and HL are similar with cement fillers in terms of the intrinsic properties, including the physical and volumetric properties. Therefore, the utilization of non-conventional alternative fillers can be incorporated into the production of asphaltic concrete.

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