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# INFLUENCE OF GRADATION ON THE PERFORMANCE OF ASPHALTIC MIXES

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**ABSTRACT**

An assessment of asphaltic mixes on failed sections along Ado – Ikere road, Southwest Nigeria has been carried out. The study has been designed to fully understand and account for the incessant pavement failures aside soil characterization. Samples of asphalt concrete were collected from failed sections along the road. The samples were subjected to density measurements, bitumen extraction, sieve analysis, hot mix Marshall Stability and flow tests. Values ranging between 6.01 – 6.45 %, 320 – 365 kg, 3.6 – 5.9 mm, 4.2 – 6.0 % were obtained for bitumen content, stability, flow, voids in total mix, respectively. The results revealed influence of gradation on the performance of asphaltic mixes. Poor gradation of aggregates resulting in low stability and flow as well as excess voids in the concrete was apparent and capable of inducing pavement failure. The asphaltic mixes significantly fell out of the limits in the criteria of the 2007 Federal Ministry of Works and Housing Standard Specifications for Roads and Bridges (FMW). Strict adherence to standards regarding asphalt concrete mix used for pavement construction is imperative to rule out the nature of asphaltic mixes as a possible cause of premature failure of road pavements.



## I. INTRODUCTION

Hot mix asphalt (HMA) is the most common material used for surface course of asphalt pavements in different countries. There are several methods for designing asphalt mixtures, such as the Marshall, Hveem and Superpave methods. The Marshall mix design has been the most widely used method in many countries including Nigeria and the tropical countries [1 - 3]. The method is based on empirical experiments. It is a process to manipulate three variables of aggregate, asphalt binder content and the ratio of aggregate to asphalt binder with the objective of obtaining an HMA that is deformation resistant, fatigue resistant, moisture damage resistant, skid resistant, durable and workable [2, 4, 5]. It is noted that the optimum asphalt content of a mix is highly dependent on aggregate characteristics such as gradation and absorptiveness. Aggregate gradation is directly related to optimum asphalt content [6, 7].

A minimum amount of air void should be maintained to avoid instability during compaction process and to provide space for bitumen flow in long-term consolidation under traffic loads. A sufficient amount of air voids should be designed to make room for expansion of binder in hot weather conditions and compaction by road traffic to avoid bleeding and loss of stability which may occur and the pavement will deform readily under severe loads. However, an air void content on the very high side allows for intrusion of air and water. It also increases the rate of hardening of binders which promotes premature embrittlement of pavements and differential compaction subject to traffic loads with the resultant formation of ruts and grooves along the wheel track [8, 9].

Beside the physical properties of aggregate, gradation plays a vital role in durability of asphalt pavement. It is one of the crucially important features of aggregate blend. The gradation of the aggregate should be so adjusted that voids in mineral aggregate (VMA), voids in total mix (VTM) and asphalt film thickness criteria are also met. The gradation within the specified grading envelope is most desirable [7, 9, 10].

## II. THEORETICAL REFERENCE

An asphalt concrete mixture must be designed, produced and placed in order to obtain the desirable mix properties including stability, durability, flexibility, fatigue resistance, skid resistance, impermeability and workability. It must resist water damage, deformation and cracking, provide a good tractive surface, and be obtained at economic rate. The asphalt content is expected to ensure that the resulting air-void content and percent voids filled with asphalt fall within prescribed limits, that the Marshall stability exceeds a specified minimum level, and that the flow value does not exceed a prescribed maximum value [2, 5, 11].

The percentage of air voids in asphalt directly relates to the longevity of the pavement. The level of compaction any asphalt mix receives directly impacts the quality and lifetime of that pavement. Understandably, the more air voids a pavement has, the more that pavement is compromised in terms of pavement strength, fatigue life, durability, raveling, rutting and susceptibility to moisture damage.

In order to meet these demands, the mindful and effective manipulation of the three variables; the aggregate, asphalt binder and the ratio of asphalt binder to aggregate is mandatory. Aggregates constitute approximately 95% of asphalt mix by weight [7, 8]. The durable asphalt mix is attributed to the properties of aggregates (physical and chemical), properties of binder, percentage of binder used and arrangement of aggregate particles (or gradation).

This research work seeks to assess the Influence of Gradation on the performance of asphaltic mixes with regards to road failure along Ado-Ikere Road, southwest, Nigeria (Figure 1).

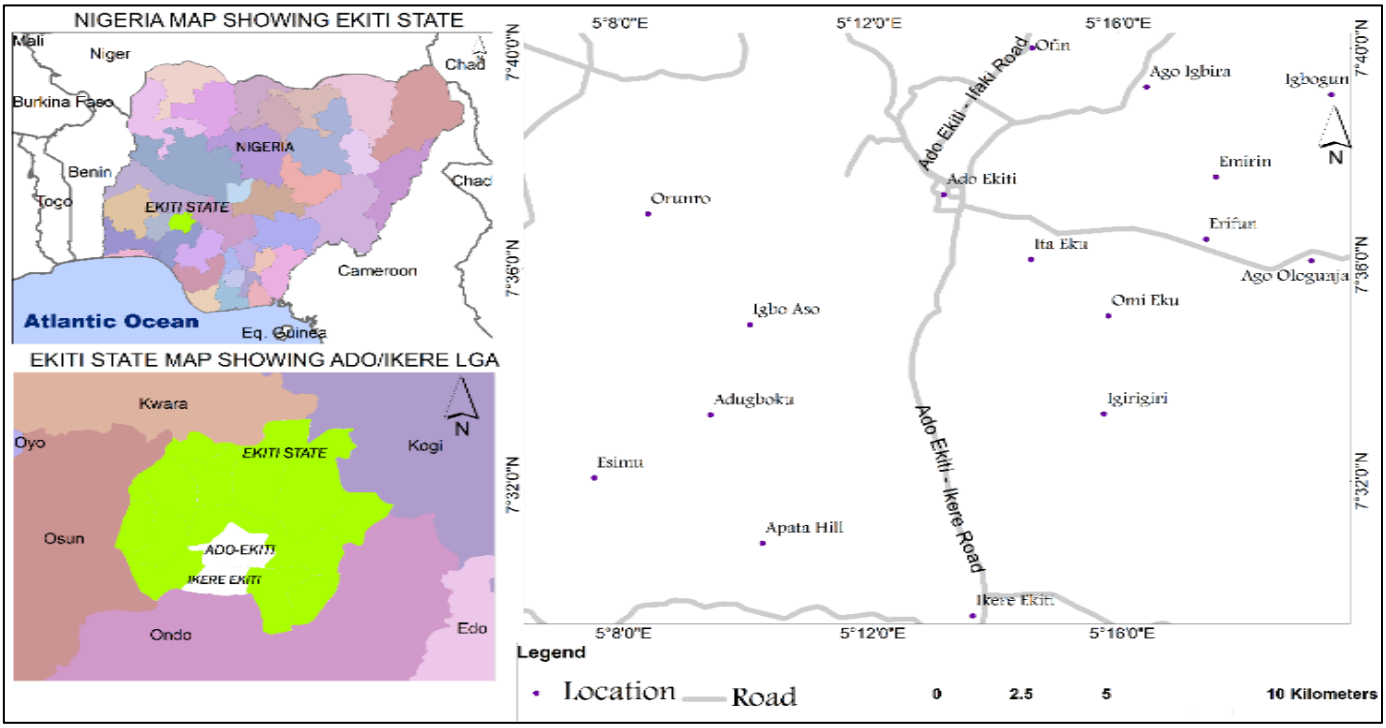


Figure 1: Location map showing Ado – Ikere Road.
Source: Author, (2023).

## III. MATERIALS AND METHODS

Samples of asphalt concrete were collected from three failed sections along Ado-Ikere road, Ekiti State, Nigeria (Figure 1). The laboratory work utilized integrated investigations involving determination of the asphalt density, binder contents, Marshall stability, Marshall flow, void in mix, void filled with bitumen and grading envelope.

Bitumen Extraction and Grain-size Analysis experiments for gradation of aggregates were carried out on the samples. The bitumen extraction test enabled the separation of the binder from the mineral aggregates in the asphaltic paving mixture. The Centrifuge method for Bitumen Extraction Test as per standard by American Society for Testing Materials ASTM 2172 [12] was adopted.

The procedure in AASHTO T 27 / ASTM C 136 [16] was adopted for the gradation and sieve analysis test [13 - 15]. In the void and density analysis, the bulk density, voids in total mix (VTM), voids in mineral aggregate (VMA), and voids filled with asphalt (VFA) were determined. The Marshall stability test was performed as per Standard ASTM D 1559 / AASHTO T-245 [11].

The Marshall stability and flow test provides the performance prediction measure for the Marshall mix design method. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute. Selecting the required proportions of aggregates (fine and coarse), fillers, and bitumen for the design of pavement is critical to achieving the expected properties of the asphaltic concrete [4, 13].

The results obtained were examined in the context of the provisions of the 2007 Federal Ministry of Works and Housing Standard Specifications for Roads and Bridges to determine the compliance [2, 10].

## IV. RESULTS AND DISCUSSIONS

### IV.1 PROPERTIES OF ASPHALT CONCRETE

Values ranging from 6.01 – 6.45 %, 320 – 365 kg, 3.6 – 5.9 mm, and 4.2 – 6.0 % were obtained for bitumen content, stability, flow, voids in total mix, respectively (Table 1). The results revealed varying levels of compliance with the criteria of the FMW Standard Specifications (Figures 2 – 6) [10].

Table 1: Properties of asphalt concrete along Ado-Ikere Road.

| Location | Properties | Test Results | FMW Limits |
|---|---|---|---|
| POINT A | BC | 6.45 | 5.0 – 8.0 % |
| | Stability | 365 | ≥ 350 kg |
| | Flow | 3.6 | 2 mm – 4 mm |
| | Voids in mix | 4.5 | 3 % - 5 % |
| POINT B | BC | 6.19 | 5.0 – 8.0 % |
| | Stability | 355 | ≥ 350 kg |
| | Flow | 4.0 | 2 mm – 4 mm |
| | Voids in mix | 4.2 | 3 % - 5 % |
| POINT C | BC | 6.01 | 5.0 – 8.0 % |
| | Stability | 320 | ≥ 350 kg |
| | Flow | 5.9 | 2 mm – 4 mm |
| | Voids in mix | 6.0 | 3 % - 5 % |

BC = Bitumen Content.
Source: Authors, (2023).

### *IV.1.1 Bitumen Content*

With regards to bitumen content, Figure 2, all samples met the standard [10]. HMA that has too little asphalt binder can have lowered fatigue resistance and problems with raveling and stripping. Bitumen should satisfy all the specifications laid down relating to penetration, softening point, ductility, flash point, wax content, loss on heating and retained penetration, solubility, viscosity at 60 $^{O}$C and 135 $^{O}$C [7, 8].

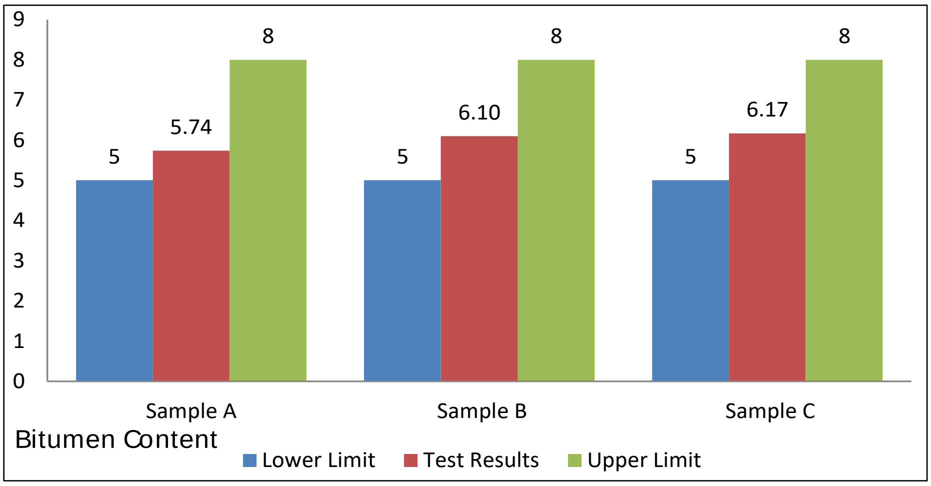


Figure 2: Bitumen content test results for bitumen samples.
Source: Author, (2023).

### *IV.1.2 Marshall Stability and Flow*

The standard of excess of 350 kg (≥ 350 kg) is prescribed for Marshall stability with a flow limit of 2 mm – 4 mm [10]. As low as 320 kg obtained, Figure 3, is a pointer to pavement failure. A mix with a very high value of stability but a low flow value is not desirable (Figure 4). Requisite examination of the aggregates for their compliance with the standard specifications and the proportions selected are essential for optimum results.

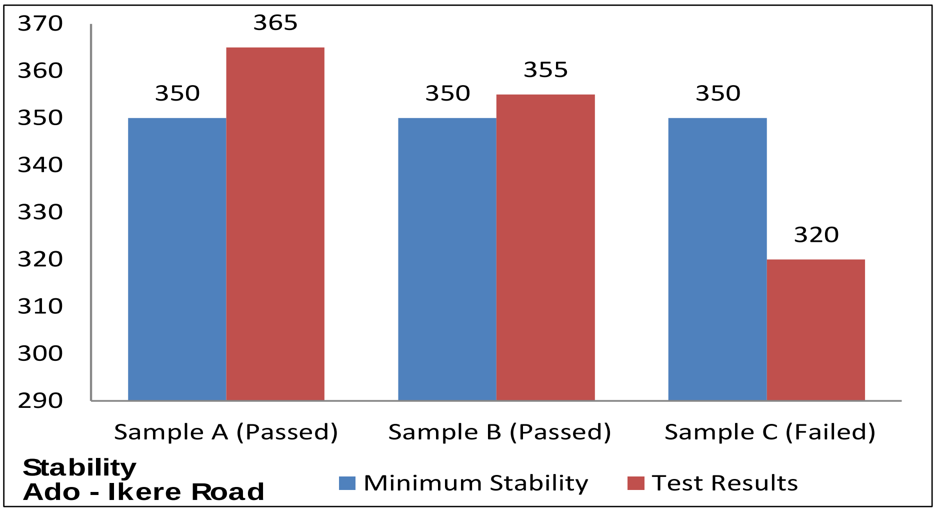


Figure 3: Stability test results for bitumen samples.
Source: Author, (2023).

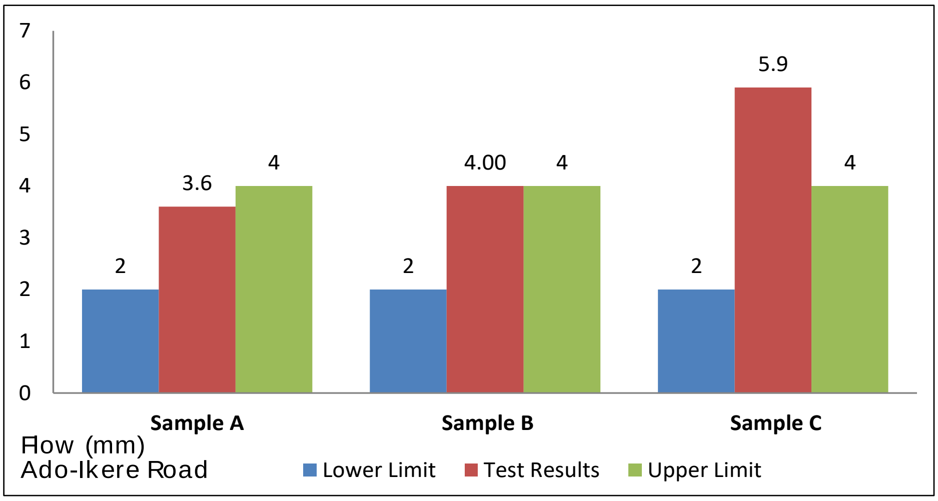


Figure 4: Flow test results for bitumen samples.
Source: Author, (2023).

### *IV.1.3 Voids in Mix*

A range of 3 % - 5 % void in mix is prescribed according to the provisions of FMW [10]. The air void content of bituminous materials is an important control parameter for the quality of bitumen being laid and compacted. Asphalt without sufficient air entrapped in the layer will deform under traffic and result in a rutted and rough surface. Almost all samples fulfilled the standard criterion except at a point with value of 6% void in mix (Figure 5).

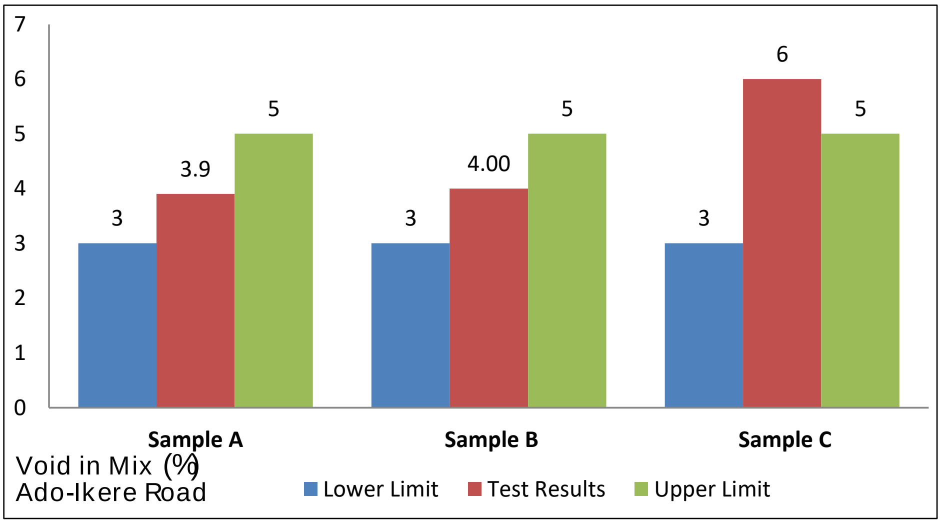


Figure 5: Void in mix test results for bitumen samples.
Source: Author, (2023).

### *IV.1.4 Sieve Analysis*

The sieve analysis of aggregates at the three points along the road (Tables 2 - 4) yielded the grading envelope for the segments as presented in Figure 6.

Table 2: Sieve analysis of aggregates extracted from sample A (ADO-IKERE PT A).

| Sieve No | Weight retain (g) | % ret | % pass | SPECIFICATION | |
|---|---|---|---|---|---|
| 25 | 0 | 0.00 | 100.00 | 100 | 100 |
| 19 | 55.6 | 5.56 | 94.44 | 100 | 100 |
| 12.5 | 132.5 | 13.25 | 81.19 | 85 | 100 |
| 9.5 | 39.7 | 3.97 | 77.22 | 75 | 92 |
| 4.75 | 183.9 | 18.39 | 58.83 | 65 | 82 |
| 2.36 | 172.9 | 17.29 | 41.54 | 50 | 65 |
| 1.18 | 83.4 | 8.34 | 33.20 | 36 | 51 |
| 0.6 | 79.4 | 7.94 | 25.26 | 26 | 40 |
| 0.3 | 61.6 | 6.16 | 19.10 | 18 | 30 |
| 0.15 | 63.6 | 6.36 | 12.74 | 13 | 24 |
| 0.075 | 28 | 2.80 | 9.94 | 7 | 14 |

Source: Author, (2023).

Table 3: Sieve analysis of aggregates extracted from sample B (ADO-IKERE PT B).

| Sieve No | Weight retain (g) | % ret | % pass | SPECIFICATION | |
|---|---|---|---|---|---|
| 25 | 0 | 0.00 | 100.00 | 100 | 100 |
| 19 | 53.3 | 5.33 | 94.67 | 100 | 100 |
| 12.5 | 130.4 | 13.04 | 81.63 | 85 | 100 |
| 9.5 | 37.5 | 3.75 | 77.88 | 75 | 92 |
| 4.75 | 185.4 | 18.54 | 59.34 | 65 | 82 |
| 2.36 | 170.6 | 17.06 | 42.28 | 50 | 65 |
| 1.18 | 86.7 | 8.67 | 33.61 | 36 | 51 |
| 0.6 | 80.4 | 8.04 | 25.57 | 26 | 40 |
| 0.3 | 63.4 | 6.34 | 19.23 | 18 | 30 |
| 0.15 | 60.2 | 6.02 | 13.21 | 13 | 24 |
| 0.075 | 30.1 | 3.01 | 10.20 | 7 | 14 |

Source: Author, (2023).

Table 4: Sieve analysis of aggregates extracted from sample C (ADO-IKERE PT C).

| Sieve No | Weight retain (g) | % ret | % pass | SPECIFICATION | |
|---|---|---|---|---|---|
| 25 | 31.8 | 3.18 | 96.82 | 100 | 100 |
| 19 | 62 | 6.20 | 93.80 | 100 | 100 |
| 12.5 | 195 | 19.50 | 74.30 | 85 | 100 |
| 9.5 | 53.5 | 5.35 | 68.95 | 75 | 92 |
| 4.75 | 171 | 17.10 | 51.85 | 65 | 82 |
| 2.36 | 158.6 | 15.86 | 35.99 | 50 | 65 |
| 1.18 | 63.2 | 6.32 | 29.67 | 36 | 51 |
| 0.6 | 58.7 | 5.87 | 23.80 | 26 | 40 |
| 0.3 | 49.2 | 4.92 | 18.88 | 18 | 30 |
| 0.15 | 51.8 | 5.18 | 13.70 | 13 | 24 |
| 0.075 | 17.3 | 1.73 | 11.97 | 7 | 14 |

Source: Author, (2023).

## IV.2 INFLUENCE OF GRADATION

The grading curves and grading envelope obtained (Figure 6) showed that none of the samples fell completely within the lower and upper limits specified by FMW standard specifications. The non-compliance of the extracted aggregates with the specification could hinder some other properties of asphalt concrete [2, 10].

The particle size distribution of the constituent aggregates is one of the most influential characteristics in determining how an HMA mixture will perform as a pavement material. Aggregate gradation influences almost every important.

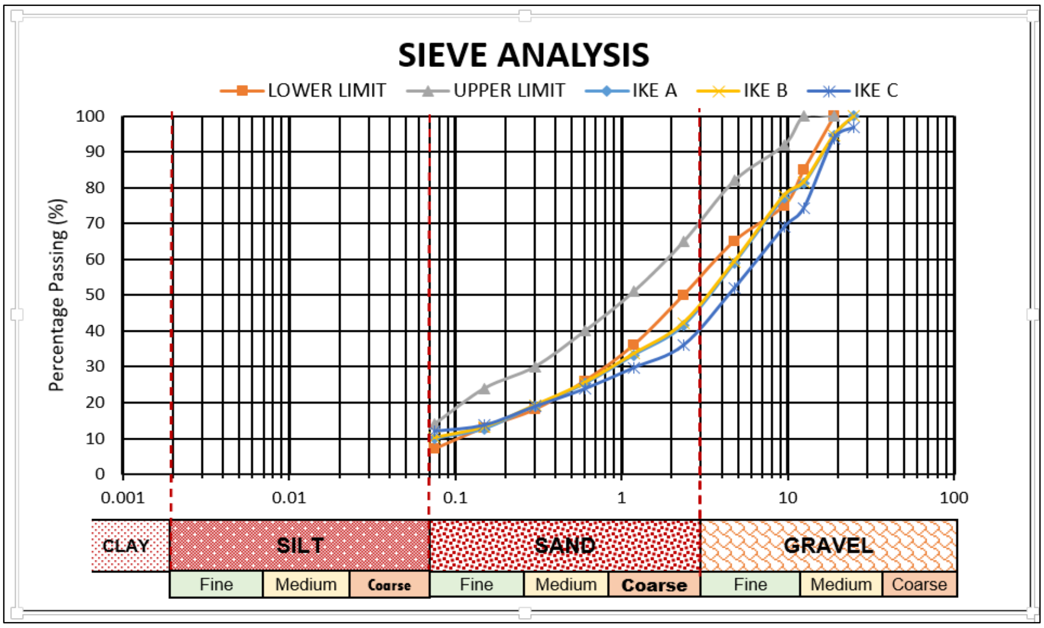


Figure 6: Grading curves and grading envelope.
Source: Author, (2023).

HMA property including stiffness, stability, durability, permeability, workability, fatigue resistance, skid resistance and resistance to moisture damage [2, 6, 9].

Poor gradation of aggregates resulting in low stability and flow as well as excess voids in the concrete was apparent and capable of inducing pavement failure. This results agreed with the works of similar authors including [3], [6] and [16]. Voids of the order of 6.0 % and flow of 6.3 mm observed along Ado – Ikere road with associated poor stability as low as 320 kg could compromise the integrity of the asphaltic concrete for road construction within the given geological environment. The road is characterized by a grading envelope indicating poor gradation with all curves completely falling out of the envelope and attendant poor stability, excess flow and voids (Figure 6). These would readily precipitate pavement failure along the road.

The main purpose of highway pavement traditionally has been to provide smooth surface over which vehicles can move safely from one place to another. However, the flexible pavements under investigation readily show defects like rutting, fatigue failure, low skid resistance and so on, causing the pavement to fail before design life [2, 12, 16]. The poor gradation of aggregates has led to unsatisfactory results which significantly impact on the performance of asphalt concrete leading to premature failure of the pavement. It is essential to put in place an effective procedure for quality assurance quality control (QA/QC) and subsequent characterization.

## V. CONCLUSIONS

An assessment of the asphaltic mix on failed sections of Ikere-Ado Ekiti road has been carried out. The results revealed varying levels of compliance with the criteria of Federal Ministry of Works and Housing Standard Specifications for Roads and Bridges. Well graded aggregates and mineral filler resulting in maximum density when mixed with optimum quantity of bitumen readily yields a mix with very high stability.

The use of poorly graded mineral aggregates resulted in the mix having poor stability, inadequate flow and excess voids. These unsatisfactory results significantly impact the performance of asphalt concrete leading to premature failure of the pavement.

In order to ensure satisfactory behaviour and performance of the mixture under traffic, a mix design must be performed under strict compliance with the standard specifications. Quality assurance test must be ensured before the commencement of work and during project execution. This should take cognizance of soil characterization results in line with the anticipated axle load and capacity. Asphaltic mixes used as wearing course of the pavements should receive considerable attention.

## VI. AUTHOR’S CONTRIBUTION

**Conceptualization:** Akintunde Akinola Oyedele.
**Methodology:** Akintunde Akinola Oyedele.
**Discussion of results:** Akintunde Akinola Oyedele.
**Writing – Original Draft:** Akintunde Akinola Oyedele.
**Writing – Review and Editing:** Akintunde Akinola Oyedele.
**Resources:** Akintunde Akinola Oyedele.
**Supervision:** Akintunde Akinola Oyedele.
**Approval of the final text:** Akintunde Akinola Oyedele.

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## VIII. REFERENCES

[1] Almeida, J.R., Boeira, F.D., Specht, L.P., Cervo, T.C., Pereira, D.S., Centofante R., Barbosa JR., Silva, C.C. “Avaliação laboratorial do tipo e teor de ligante e da granulometriana deformação permanente de misturas asfálticas.” Transportes, vol. 26, no. 2, pp. 1-15. DOI:10.14295/transportes.v26i2.1407, 2018.

[2] Akinleye, M.T., Tijani, M.A. “Assessment of Quality of Asphalt Concrete used in Road Construction in South West Nigeria.” Nig J. Technol Dev, vol. 14, no. 2, pp. 52-55, 2017.

[3] Carmo, C.A.T., Pereira, G.S., Marques, G.L.O., Borges, P.R. “Structural sensivity of an asphalt pavement to asphalt binder content and mix design method.” TRANSPORTES, vol. 28, no. 4, ISSN: 2237-1346, 2021.

[4] Al-Humeidawi, B.H. “Experimental characterization of rutting performance of HMA designed with aggregate gradations according to Superpave and Marshall methods.” World J. Eng & Technol, vol. 4, pp. 477-487. DOI: 10.4236/wjet.2016.43048, 2016.

[5] Hemida, A., Abdelrahman, M., Deef-Allah, E. “Quantitative evaluation of asphalt binder extraction from hot mix asphalt pavement using ashing and centrifuge methods.” Transportation Eng., vol. 3, 100046, https://doi.org/10.1016/j.treng.2021.100046, 2021.

[6] Akiije, I., Oyekan, G.L. “Stabilization assessment of aggregates in asphalt concrete mixtures.” Int J. Scient & Eng Researc., vol. 3, no. 4. pp. 695-699, 2012.

[7] Eberhardsteiner, L., Blab, R. “Design of bituminous pavements – a performance-related approach”. Road Mat & Pavement Design, vol. 20, no. 2, pp. 244-258, DOI: 10.1080/14680629.2017.1380689, 2019.

[8] Mohammed, A., Aliyu, I., Sulaiman, T.A., Umar, H.A., Jubril, Y. “Appraisal of Asphalt Concrete with Coal Bottom Ash as Mineral Filler.” FUOYE J. Eng & Technol., vol. 6, no. 2, pp. 105-110, 2021.

[9] Roberts, F.L., Kandhal, P.S., Brown, E.R., Lee, D-Y., Kennedy, T.W. “Hot Mix Asphalt Materials, Mixture Design, and Construction.” Vol. 8, National Asphalt Pavement Association, Research and Education Foundation, Lanham. 603 p. 1996.

[10] Federal Ministry of Works and Housing - FMW. “Pavement and materials design in highway manual part 1: Design.” 3. Federal Ministry of Works, Abuja, Nigeria. 2007.

[11] Fang, M., Park, D., Singuranayo, J.L., Chen, H., Li, Y. “Aggregate gradation theory, design and its impact on asphalt pavement performance: a review.” Int J. Pavement Eng., vol. 20, no. 12, pp.1408-1424, DOI: 10.1080/10298436.2018.1430365, 2019.

[12] ASTM D2172-05. “Standard test methods for quantitative extraction of asphalt binder from asphalt mixtures.” ASTM International. West Conshohocken, PA. 2005.

[13] ASTM (American Society for Testing and Materials). “Standard test method for sieve analysis of fine and coarse aggregates. C136.” West Conshohocken, PA, USA. 2001.

[14] American Association of State Highway and Transportation Officials (AASHTO). “Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Twentieth Edition.” American Association of State Highway and Transportation Officials, Washington, D.C. 2000.

[15] ASTM (American Society for Testing and Materials). “Standard test method for Marshall stability and flow of asphalt mixtures. D6927”. West Conshohocken, PA, USA. 2005.

[16] Ogundipe, O.M. “Marshall stability and flow of lime-modified asphalt concrete.” Transportation Researc Procedia, vol. 14, pp. 685 – 693, 2016.