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An Assessment of the Quality of Hot Mix Asphaltic Concrete along Abuja–Lokoja Highway

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Abstract

Rutting failure in hot mix asphaltic concrete has become a menace bedeviling both newly constructed and old road pavements in Nigeria. At the final stage of rehabilitation and expansion of 170 kilometers Abuja–Lokoja dual carriageway highway, the road is already showing features of rutting at several portions. This paper investigates the causes of rutting usually experienced on the Abuja-Lokoja road that results in vehicle accidents and damages. Samples of asphaltic concrete were randomly cored at the rutted and normal sections of the road. Each sample was analyzed in the laboratory using the Nigerian and ASTM standards. The result indicated that the coarse aggregate ratio and the fine aggregate coarse ratio of the cored samples tested ranged between 0.33 - 0.49 and 0.54 - 0.64 as against Bailey's recommendation of 0.6 – 1 and 0.35 - 0.5 respectively. The excess fine aggregate in the asphaltic concrete was discovered to have distorted the aggregate interlocking required to resist the shearing load on the road when vehicles navigate through it. Therefore, the excess fine aggregate is suspected to be the cause of the rut failure on the road.

Keywords

Asphalt; Rutting; Marshall stability; Aggregate gradation; Bailey criteria

1.0 Introduction

Good roads, well-developed waterways, railways, and airline networks make up a reliable transportation system. To expedite any nation's economic, cultural, and social development, a good transportation system is important (Imran et al., 2016). Economic growth in Nigeria is dependent on the level of good and accessible road transportation networks Siyan et al., (2015) as every nation's road network has a significant impact on its economic growth because good roads facilitate the ease of socio-economic activities among other benefits. Nigeria has about 200,000Km road network, which accounts for 95%

of the domestic traffic flows of people, goods, and services. The road network comprises 33,000Km Federal Highways and 117,000Km Local Government feeder roads (Road Sector Development Team, 2014). Most Nigerian roads are usually smooth surfaces finished with hot mix asphaltic concretes designed to be adequately stable and not deforming when subjected to traffic loads, resistant to weathering, skid-resistant, and wearing resistance (Flexible Pavements of Ohio, 2020).

Recommended aggregate when producing durable concrete must possess good hardness, toughness, and texture (Sanusi et al., 2020). Such aggregates will also equip asphalt with sufficient strength to resist unfavorable weather conditions and traffic loading, and improve its workability for efficient placement of the mix (Abedali, 2004).

Traditionally, Marshall and the Hveem methods are commonly employed when designing asphaltic concrete mixes. These two methods were established by Bruce Marshall and Francis Hveem in the late 1930s amid-19220s respectively (Weng, 2006). It is agreed that the procedure for Marshall Mix includes the selection of aggregate blend and asphalt binder that conforms to the local regulatory body's specifications, preparation of sample mixes in volumetric, and lastly, determination of Marshall and flow values of the compacted mix (Abedali, 2004; Weng, 2006). The difference between the two methods (Marshall and Hveem) of asphaltic design is that Hveem makes use of centrifuge kerosene equivalent to determine the initial approximate bitumen ratio before the volumetric Tsai et al., (2012), while, Marshall's methods adopt mathematical computation (Mistry & Roy, 2020). The limitation of Marshall and Hveem's design methods is that pavement behaviors after construction could not be predicted because they are empirical. Due to this fact, Strategic Highway Research Program (SHRP) developed a Superior Performing Asphalt Pavement (Superpave) mix design to take care of the limitations in the late 1980s/early 1990s (Anderson & Bahia, 2007).

In Nigeria, the Federal Ministry of Works (FMW) is the only regulatory body for HMA design. The recommended mend Marshall mix design for all HMA is carried out in Nigeria for road construction. Generally, Marshall stability and Marshall flow are the major parameters determined from Marshall testing of asphalt (Australian Asphalt Pavement Association (AAPA), 2004; Nigerian Federal Ministry of Works, 2007; Vavrik et al., 2002). These two parameters primarily evaluate the effects of asphaltic cement in the Marshall Mix design procedure and vertical deformation of the sample at the failure level respectively (Roberts, 1996; Weng, 2006). HMA having high flow values indicates a plastic mixture that will experience permanent deformation when subjected to traffic loading and a mixture with higher voids than normal (ASTM D 6927-5, 2010). Also, low flow value shows that there is insufficient asphalt in the mix which leads to asphaltic brittleness, which causes non-durability and premature cracks and/or other forms of failures during the pavement lifetime (ASTM D 6927-5, 2010; Roberts, 1996; Weng, 2006). Tables 1 and 2 show the Marshall properties and aggregate gradation specified by the FMW.

Table 1: Marshall Design Specification (Nigerian Federal Ministry of Works, 2007; ASTM D 6927-5, 2010)

Test	Result Range
Marshal flow	2 – 4
Bitumen content (%)	5 – 8
Marshal Stability (Kg)	≥ 350
Void in total Mix (%)	3 – 5

Table 2: Aggregate gradation standards for wearing courses (Nigerian Federal Ministry of Works, 2007; ASTM D 6927-5, 2010)

Sieve Size	Percentage passing for 12.5mm nominal aggregates size											
	Nigeria		South Africa		ATM		Asphalt Institute		Superpave		Superpave Restricted	
	Min	max	min	Max	Min	max	min	max	min	max	min	Max
25	100	100	100	100	100	100	100	100	100	100	-	-
19	100	100	100	100	100	100	100	100	100	100	-	-
12.5	85	100	90	100	90	100	90	100	90	100	-	-
9.5	75	92	-	-	-	-	-	-	-	-	-	-
6.3	65	82	-	-	-	-	-	-	-	-	-	-
4.75	-	-	54	75	44	74	44	74	-	-	-	-
2.36	50	65	38	57	28	58	28	58	28	58	39.1	39.1
1.25	36	51	-	-	-	-	-	-	-	-	25.6	31.6
0.6	26	40	-	-	-	-	-	-	-	-	19.1	23.1
0.3	18	30	13	23	5	21	5	21	-	-	15.5	15.5
0.15	13	24	-	-	-	-	-	-	-	-	-	-
0.075	7	14	4	10	2	10	2	10	2	10	-	-

Generally, roads across the globe including Nigeria experience failure at different modes during their lifetime after HMA has been designed and laid. The failure ranges from transverse and longitudinal cracking, potholes, raveling, water bleeding to rutting, and many more (Anderson & Bahia, 2007; Imran et al., 2016). Likewise, the causes of the failures differ from one another which include poor quality control during construction, deformation due to overloading, climate change (annual rainfall and temperature variation), poor drainage, expansive subgrade soil, high water table, poor aggregate gradation, etc. (Anderson & Bahia, 2007; Imran et al., 2016; Mistry & Roy, 2020; Tsai et al., 2012). Furthermore, poor laboratory and in-situ tests and weak local professional bodies in highway design, construction, and management could also lead to highway failure (Okigbo, 2012). Deterioration of highway pavement is a very serious problem that causes unnecessary delays in traffic flow, distorts pavement aesthetics, causes damage to vehicles, and most significantly, causes road traffic accidents (Ogundipe, 2008).

This paper investigated the causes of rutting as one of the major road failures experienced on most highways in Nigeria. The failures possess a wave-like shape and have resulted in several accidents and vehicular damages leading to loss of lives and properties (Ogundipe, 2008). This research further examined the causes of rutting failures on Nigerian roads after construction with a huge sum of money, thereby providing guilds for HMA design. As reported in this study, 170 kilometers Abuja–Lokoja dual carriageway highway has been one of the major roads that connect the Southern to Northern parts of Nigeria for decades. The reason for the selection of this road was that, at the final stage of rehabilitation and expansion of the road that has been in existence for the past 15 years, the road is already afflicted with rutting failures at several locations. Figure 1 shows the rutted sections of the concerned road.

***Figure 1**: Rutted sections of Abuja-Lokoja highway*

Rutting has been one of the common failures asphalt pavement experienced (Chilukwa & Lungu, 2019). Rutting is the displacement of asphaltic pavement material which creates channels or wave-like shapes on the vehicular wheel path. One of its disadvantages is that it holds water within the affected portion, thereby further causing other failures like potholes (Adlinge & Gupta, 2009). In Zambia and some parts of Nigeria, rutting failure is usually experienced at the bus stops, police checkpoints, intersections, climbing lanes, railway crossings, and other heavily loaded areas, where there is slow movement or static loading (Chilukwa & Lungu, 2019; Mwanza, 2008). However, the aforementioned factors are not usually experienced on the Abuja-Lokaja road, yet the road still experienced rutting failure. According to Ogundipe, (2016), asphalt pavements rutting is caused by the deposition of permanent deformation on either subgrade/underlying-layering or asphaltic surface layer. Long-time ago, subgrade deformation was contemplated to be the primary cause of rutting failure, therefore, the designers then do apply limiting factors to the vertical strain at that level. In recent times, researchers have identified that rutting failure occurred at the asphalt surface layer Garba, (2002); Mwanza, (2008) in which the failure could result from an individual or combination of permanent deformations (Chilukwa & Lungu, 2019).

As argued by some authors (Adlinge & Gupta, 2009), a very narrow and a wide rut are indications of surface and subgrade failure respectively. Also, insufficient compaction could induce rutting failure. Figure 2 shows the deformation behavior of asphaltic pavements subjected to repeat permanent loading.

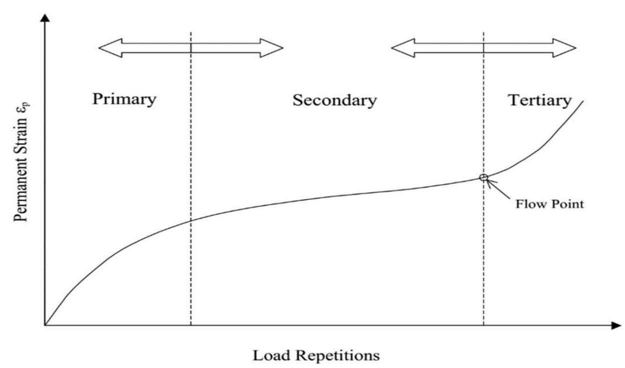

***Figure 2**: Deformation behavior of asphaltic pavements subjected to repeated permanent loading* (Chilukwa & Lungu, 2019)

According to Wake, (2015), rutting research has shown that Bailey's method provides a good result for rutting performance when compared to conventional Asphalt Institute mixes. However, the Bailey method works based on the Nominal Maximum Aggregate Size (NMAS), which is defined as one sieve size larger than the first sieve to retain 10% or more of the total aggregate by mass. He further used ratios based on Eqn. (1) to (4) which are; a half sieve, a primary control sieve (PCS), a secondary control sieve (SCS), and a tertiary control sieve (TCS) to describe aggregate blends based on three (3) ratios which are presented in the eqn. (5) to (7). These ratios are; the coarse aggregate weight ratio (CA), the coarse part of the fine aggregate weight ratio (FAc), and the fine part of the fine aggregate weight ratio (FAf) (Anderson & Bahia, 2007). Table 3 shows the calculated and chosen control sieves for various nominal maximum aggregate sizes (NMAS) (Daniel & Rivera, 2009; Rivera, 2008). While, Table 4 shows the Bailey design specifications for coarse aggregate ratio (CA), fine aggregate coarse ratio (FAc), and fine aggregate fine ratio (FAf) for different nominal sizes of aggregates for fine graded dense mix (Anderson & Bahia, 2007).

$$Half\ Sieve = 0.5\ \times NMSA \quad 1$$

$$PCS = NMSA\ \times 0.22 \quad 2$$

$$SCS = PCS\ \times 0.22 \quad 3$$

$$TCS = SCS\ \times 0.22 \quad 4$$

Table 3: Control Sieves for Different Nominal Maximum Aggregate Sizes

NMAS	25.0		19.0		12.5		9.5	
	Cal.	Cho.	Cal.	Cho.	Cal.	Cho.	Cal.	Cho.
Half	12.5	12.5	9.5	9.5	6.25	6.3	4.75	4.75
PCS	5.50	4.75	4.18	4.75	2.75	2.36	2.09	2.36
SCS	1.05	1.18	1.05	1.18	0.52	0.60	0.52	0.60
TCS	0.26	0.30	0.26	0.30	0.13	0.15	0.13	0.15
Note: Cal. And Cho. means Calculated and Chosen respectively								

$$Coarse\ Agg.Ratio(CA\ Ratio) = \frac{(\%\ Passing\ Half\ Siev\quad \%\ Passing\ PCS)}{(100 - \%\ passing\ half\ Sieve)} \quad 5$$

$$Fine\ Agg.Coarse\ Ratio(FAc\ Ratio) = \frac{(\%\ Passing\ SCS)}{(\%\ Passing\ PCS)} \quad 6$$

$$Fine\ Agg.Fine\ Ratio(FAf\ Ratio) = \frac{(\%\ Passing\ TCS)}{(\%\ passing\ SCS)} \quad 7$$

Table 4: Ratio Guideline for Fine Graded Dense Mix

NMAS (mm)	37.5	25.0	19.0	12.5	9.5	4.75
CA Ratio	0.6 – 1	0.6 – 1	0.6 – 1	0.6 – 1	0.6 – 1	0.6 – 1
FAc Ratio	0.35 – 0.5	0.35 – 0.5	0.35 – 0.5	0.35 – 0.5	0.35 – 0.5	0.35 – 0.5
FAf Ratio	0.35 – 0.5	0.35 – 0.5	0.35 – 0.5	0.35 – 0.5	0.35 – 0.5	0.35 – 0.5

A study conducted on the Nigeria road maintenance state that Bailey method predictions for aggregate gradation do not meet the guidelines specified in Table 4 (Okigbo, 2012). The predictions are as follows:

- A gradation with Coarse Aggregate (CA) ratio lower than the prescribed limits will be susceptible to segregation having patches of predominantly fine aggregates or patches of predominantly coarse aggregates. Sections with predominantly fine aggregates will have a higher tendency to rut while sections with predominantly coarse aggregates will become too porous or start to ravel and wear away.
- A gradation with Coarse Aggregate (CA) ratio higher than the prescribed limits will reduce the effectiveness of the strength contributed by the large part of the coarse aggregate to the strength of the pavement. This is because the large aggregates do not touch each other due to the interceptors, which are generally half the size of the large aggregates pushing the large aggregates apart. The interceptors now act as the coarse aggregate with voids too small to accommodate particles passing through the Primary Control sieve. This makes the fine aggregate push apart the interceptor frame structure created hence reducing the strength and increasing the susceptibility of the mix to rutting.
- If the Fine Aggregate coarse (FAc) or the Fine Aggregate fine (FAf) is higher than recommended, the fine aggregates will push their way in between the coarse aggregates thereby overfilling them and resulting in a mix that will be too tender and easily deformable.

When the Fine Aggregate coarse (FAc) or Fine Aggregate fine (FAf) ratios drop too low, then the small gaps are under-filled. This will not only cause the Voids in Mineral Aggregates (VMA) to rise but also deprives the mix of the lubricating effect of the fine particles, which may make it difficult to compact the mix to the proper level. Improperly compacted pavement can have too many voids for water and air to invade, which can cause the asphalt binder to be stripped from the aggregate or allow excessive frost heaves in the winter.

2.0 Materials and Methods

In this study, a windscreen survey was carried out on the Abuja-Lokoja route. The road condition was examined at every 500m interval for rutting failure. The total road length considered was 14.5Km out of which three rutted and normal sections each were observed. Three samples each were cored out at the examined rutted and normal section for the laboratory analysis as shown in Figure 3 in accordance with (BS EN 12504, 2002; AASHTO T 24M/T 24-15, 2018). A total number of eighteen asphaltic sample were cored at the CH64+000 (8^{0}36′50″N, 6^{0}54′50″E), CH62+000 (8^{0}37′35″N, 6^{0}54′58″E) and CH53+000 (8^{0}42′20″N, 6^{0}56′18″E) for rutted sections and CH63+300 (8^{0}37′35″N, 6^{0}54′58″E), CH61+000 (8^{0}38′27″N, 6^{0}55′58″E) and CH49+950 (8^{0}44′6″N, 6^{0}57′16″E) for the normal sections respectively. The cored samples were subjected to testing for Marshall stability and flow, bitumen content, air voids, and particle size distribution for aggregate in accordance with British and ASTM Standards.

***Figure 3**: Asphaltic sample coring along Abuja-Lokoja road*

Sample preparation for testing was carried out in the laboratory on the cored samples which include the immersion and heating of the samples in a water bath at a temperature of 60 ± 2°C for 30 – 40 minutes as recommended by (BS EN 12697-28, 2020; ASTM D 6927-15, 2010).

After the sample preparation, the cored samples were subjected to Marshall stability and flow testing in accordance with the specification of (ASTM D6924-15, 2010; BS EN 12691-34, 2020). Also, bitumen was extracted from some cored samples to determine the percentage of air voids and bituminous content in the samples using British Standard BS EN 12697-8, (2019); BS EN 12697-39, (2018) respectively as shown in Figure 4. However, the residual aggregates from the extraction were washed and sieved for aggregate gradation testing in accordance with the method specified by (BS EN 12697-2, 2019a). Bailey's mathematical computation method was adopted to identify the deficiencies within the aggregates mixes and the determination of the aggregate fraction(s) that may require(s) adjustment.

***Figure 4**: Bitumen Extraction from samples*

3.0 Results and Discussion

From the window survey, it was observed that ruts occurred only at points where there is a negative change in grade along the roadway. The Marshall stability test results presented in Table 5 show the average of three tested samples carried out for each experiment. The percentage of voids in mixes of Chainage CH53+000 and CH61+000 are 4.9% and 3.5% respectively which fall within the acceptable limit of 3 to 5% specified by FMW/Marshall shown in Table 1. The void result of chainage (CH49+950, CH62+000, and CH64+000) was found to be 2.1%, 2.6%, and 2.3% respectively. This falls below the acceptable range of (ASTM D 6927-5, 2010; Nigerian Federal Ministry of Works, 2007). However, CH63+300 having a 5.3% void exceeded the 5% upper limit of (ASTM D 6927-5, 2010; Nigerian Federal Ministry of Works, 2007). Although, it has been reported that, the higher the air voids in road pavement, the lesser the strength, fatigue life, durability, raveling, rutting, and susceptibility to moisture damage (John et al., 2021; Zaltuom, 2018). It was further stated by John et al., (2021) that asphaltic pavement having an air void lesser than 3% has little resistance to expansion in hot weather conditions and this could lead to cracks and easy penetration of water, thereby, causing more injuries to the pavement by scattering the soil stabilization. Therefore, air void contributed to the rutted failure of the road as the laid asphalt was not homogeneously hot mixed.

Marshall Stability test results in Table 5 for both rutted and normal sections of the studied highway ranged from 563 to 1059kg. The result indicates that the tested road Marshall stability is higher than the specified value (350kg) provided by ASTM D 6927-15 ASTM D 6927-5, (2010); Nigerian Federal Ministry of Works, (2007) available in Table 1. This implies that the hot mix asphaltic concrete designed for the concerned road has more than enough strength to resist the designed stress, therefore, Marshall Stability has not contributed in any way to the rutted failure of the road.

Marshall flow results reported in Table 5 ranged from 3 to 4% which shows that Marshall flow results of entire tested samples are within the specified range (2 to 4%) of Nigeria and ASTM standard (ASTM D 6927-5, 2010; Nigerian Federal Ministry of Works, 2007).

The bitumen content results in the same Table 5 ranged from 4.9 to 6.1%. This shows that the entire samples tested to fall within the acceptable range of 5 to 8% except for the Chainage CH64+000 which has a value of 4.9% which is marginal to the acceptable limit specified by the local authority and ASTM standards (Nigerian Federal Ministry of Works, 2007; ASTM D 6927-5, 2010). In the research of John et al., (2021); Mistry & Roy, (2020); Zaltuom, (2018), binder content was found to be within the range of 3.5 to 5.59% which further confirmed the obtained result in this research. Therefore, the result is considered reliable.

In general, it could be established from the above analysis that, the Marshall stability, Marshall flow, and Bitumen content are not responsible for the Abuja-Lokoja's highway failure to rut. Although, air void content results show deficiency which is one of the contributing factors to the rutting failure. However, this cannot be solely used to predict Abuja-Lokoja's highway to rut failure.

Table 5: Marshall Properties of the Cored Samples

Results	CH 64+000	CH 62+000	CH 53+000	CH 63+300	CH 61+000	CH 49+950
Void in Mix (%)	2.3	2.6	4.9	5.3	3.5	2.1
Marshall Stability (Kg)	563	900	731	1331	1079	1059
Marshall Flow(mm)	3	4	4	3	4	4
Bitumen Content (%)	4.9	6.7	6.1	6.1	5.4	5.9
Section Remark	Rut	Rut	Rut	Normal	Normal	Normal

Figures 6 to 17 compare the particle size gradation of the samples taken from different sections of the studied road to the recommended maximum and minimum limits of the Nigerian regulatory body (FMW) and ASTM standard (ASTM D 6927-5, 2010; Nigerian Federal Ministry of Works, 2007). It is expected that aggregates to be used for asphaltic hot mix design should fall within the maximum and minimum limit. The aggregate gradation curves for both the rutted and normal sections have more than 95% of their curves within the gradation envelope specified by the FMW which indicates that the abrasion effect due to traffic loadings has not distorted the gradation of the aggregates used. When the particle size distribution of the rutted section was compared to the envelope specified by ASTM, it showed a similar trend as the normal section.

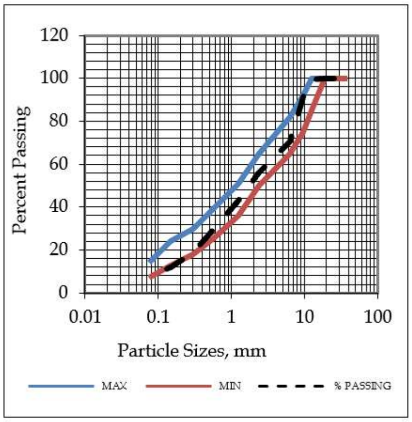

***Figure 6**: Samples from Chainage CH49+950 vs FMW specification*

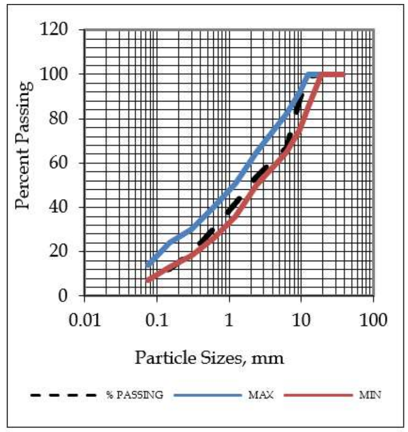

***Figure 7**: Samples from Chainage CH61+000 vs FMW specification*

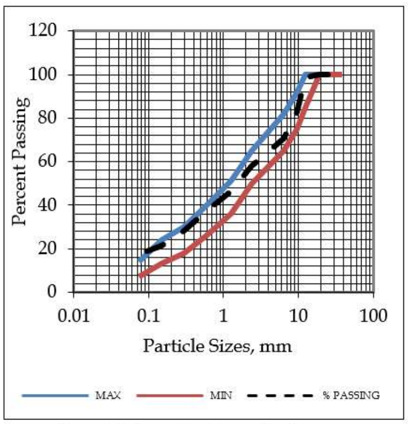

***Figure 8**: Samples from Chainage CH62+200 vs FMW specification*

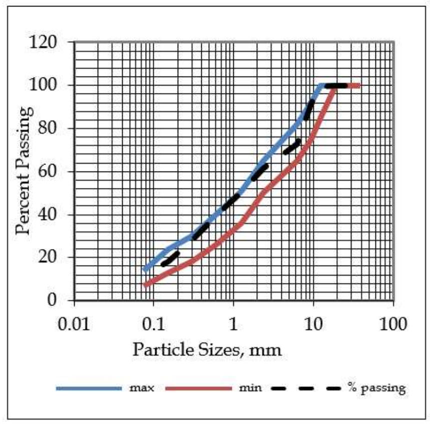

***Figure 9**: Samples from Chainage CH63+300 vs FMW specification*

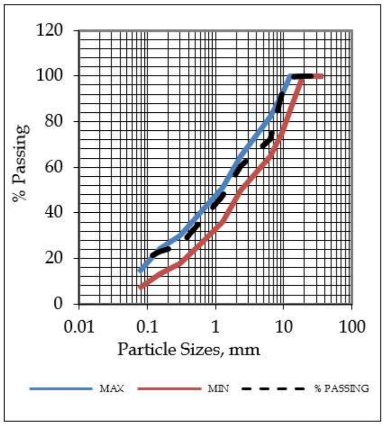

***Figure 10**: Samples from Chainage CH64+000 vs FMW specification*

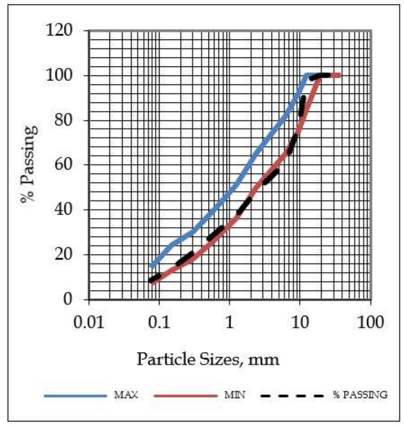

***Figure 11**: Samples from Chainage CH53+000 vs FMW specification*

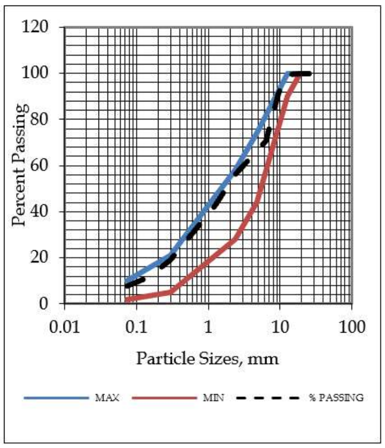

***Figure 12**: Samples from Chainage CH49+950 vs ASTM specification*

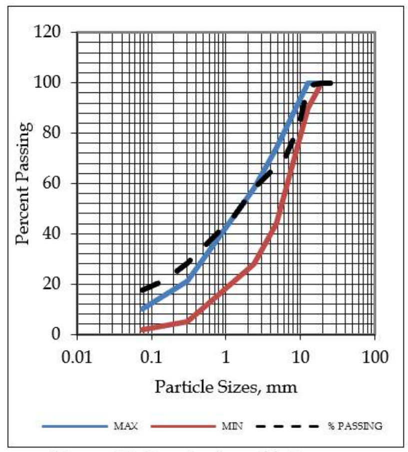

***Figure 13**: Samples from Chainage CH61+000 vs ASTM specification*

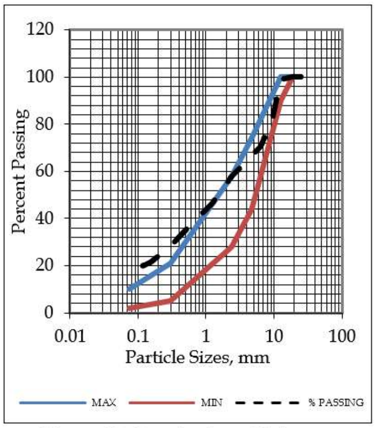

Figure 14: Samples from Chainage CH62+000 vs ASTM specification

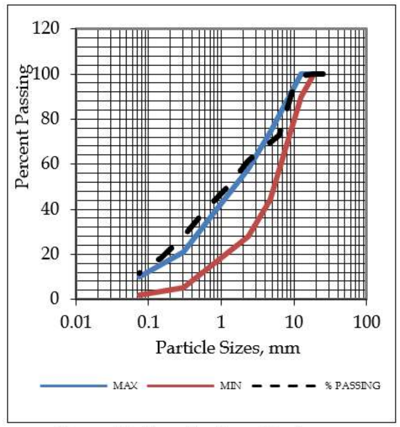

Figure 15: Samples from Chainage CH63+300 vs ASTM specification

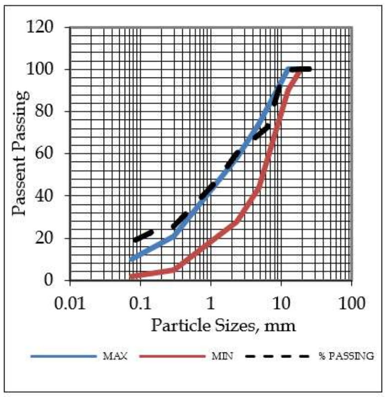

Figure 16: Samples from Chainage CH63+000 vs ASTM specification

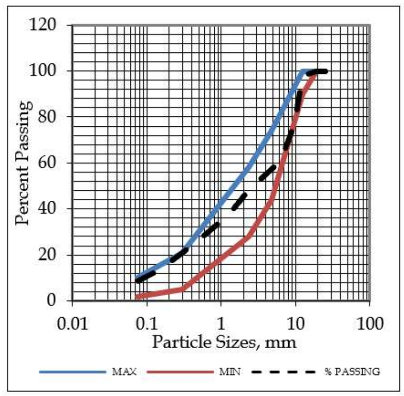

Figure 17: Samples from Chainage CH64+000 vs ASTM specification

Table.6: Conformity of Sample Gradations to Bailey's Criteria

Bailey Parameters	CH 49+950	CH 61+000	CH 62+000	CH 63+300	CH 64+000	CH 53+000
NMAS	99.5	99.3	98.8	99.4	99.7	97.8
Half Sieve	70.6	67.1	70.5	73	72.4	61
PCS	56.2	53.8	58	61.5	60.3	48.3
SCS	30.2	30.1	37.3	39.5	36.2	28.8
TCS	11.8	12.5	21.5	18.3	23	13.8
CA	0.49	0.40	0.42	0.43	0.44	0.33
FA_C	0.54	0.56	0.64	0.64	0.60	0.60
FA_F	0.39	0.42	0.58	0.46	0.64	0.48

All the samples also have their computed coarse aggregate (CA) ratio less than the recommended range by Bailey which can make the mixes susceptible to segregation having patches of predominantly fine aggregates or patches of predominantly coarse aggregates. Sections with predominantly fine aggregates will have a higher tendency to rut while sections with predominantly coarse aggregates may become too porous or start to ravel and wear away. Furthermore, the computed Fine Aggregate coarse (FAc) ratio was higher than the recommended range by Bailey. This will make the fine aggregates push their way in between the coarse aggregates thereby overfilling them and resulting in a mix that will be too tender and easily deformable.

4.0 Conclusion

Aggregates passing through the half sieve size, the primary control sieve size, the secondary control sieve size, and the tertiary control sieve size are the major determinants of mixes' structural stability as their ratio determines how strong the interlock between different aggregate sizes within a mix is. Although the Federal Ministry of works has ranges specified for the half sieve size, PCS, SCS, and the TCS, the ranges specified by the federal ministry of work for these sieve sizes are too wide, which creates so much room for distortion in the required ratio of the control sieve sizes to take place. This is the major reason why some mixes that pass through the specified envelope would still rut when subjected to shearing loads.

The mix will rut because the shearing forces from vehicle tires that act on the asphaltic concrete surface forces the excess fine aggregates to push their way in between the coarse aggregates thereby overfilling them and preventing them from safely transferring the load to the underlying binder course.

All Marshall properties considered have little or no effect on the susceptibility of an asphalt mix to structural deformation because most of the materials' properties were within the limits specified by the Federal Ministry of Works for Marshall properties.

Based on the findings and observations during and after the research, the following recommendations are made.

- Further studies should be done to identify the effect of other Marshall properties on rutting in hot mix asphaltic concrete.
- Other properties of aggregates such as flakiness should not be overlooked because when aggregates are too flaky, they break under load and can lead to a distortion of the already designed aggregate gradation.
- The Bailey method should be used alongside the gradation envelope to serve as a control or check for how well aggregates interlock and to ascertain that the required quantities of each control sieve aggregate size are present in every mix.
- Bailey's criteria are used alongside the gradation envelope for correction and modification of mix gradation.

5.0 Reference

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