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The Effect of Rutting in Flexible Pavement as a Result of Aggregate Gradation On Asphalt Mixes

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ABSTRACT

Aggregates play a major role in asphalt mixes. The asphalt mix is made up of approximately 80 – 90% of aggregates. It is thus important to evaluate the effect of aggregate gradation in asphalt mixes. This is due to the escalating rate of South African roads experiencing permanent pavement deformation, particularly in Butterworth (Eastern Cape). Rutting of the asphaltic layer contributes to a lesser service life road as per designed service life. The main factor that contributes to rutting of asphalt roads is aggregate gradation. The aim of this study is to determine the effects of aggregate gradation in asphalt mix in order to extend the service life of asphalt roads as a result of pavement deformation. The laboratory test will be Marshall Flow, Marshall Stability and air voids in mineral aggregates. Volumetric bituminous mixes will be used using the Marshall Design criteria for analyses of performance of aggregate gradation and Dynamic creep test. Through the evaluation of air voids, voids in mineral aggregate (VMA), stability, flow, resilient modulus and Elastic modulus, the outcomes indicate that asphalt mixtures of upper limit aggregate gradation band are the most suitable material to resist rutting and permanent deformation of asphalt roads.

Keywords: Deformation, asphalt, rutting, hot mix asphalt (HMA)

INTRODUCTION

There are many factors which contribute to permanent deformation on flexible roads. Rutting of asphaltic pavement is recognized to be a major pavement problem in South African roads. This is due to external and internal factors. The external factors are however not limited to temperature, climatic changes, axle loading on the pavement, tire pressure between the asphaltic layer and the volume of traffic, and the construction application of the road layers. The internal factors are however not limited to the asphalt mix design, volumetric composition of the mix design, bitumen content and aggregate properties. Previous study by [1] indicated that there are nine factors that contribute to low performance of asphalt roads. With the increase in traffic and loading on the provincial and national roads in South Africa, the quality of the aggregate has become of great importance in the manufacturing of high quality asphalt. Aggregate gradation is the key factor that influences rutting. Aggregates are one of the main construction ingredients used in the construction industry and the largest fraction on asphalt pavement [1]. This limits the quantity of clay and other damaging constituents and protects against breakdown of aggregates during construction, under traffic and environmental effects throughout the service life of the pavement.

The main aim of this study is to evaluate the effects caused by aggregate gradation on asphalt in order to extend the service life of asphalt roads. The study is based in Butterworth, Eastern Cape and is only limited to the evaluation of aggregate gradation on asphalt road which are permanently deformed. The Main Road in Butterworth, Eastern Cape is permanently deformed at the wearing course surface, which has led to rutting. The main factor which contributes to the problems of asphalt fatigue is inadequate asphalt mix design, which decreases the road serviceability life span.

The research question is what is the most appropriate aggregate gradation limit on asphalt mix that is suitable to resist rutting on flexible pavement under repeated axial loading?

Asphalt Mix Design

Asphalt is a combination of aggregates, bitumen binder, filler and air voids. These are referred to as asphalt volumetric composition. For asphalt pavement to resist permanent deformation, the asphalt volumetric composition needs to be designed effectively with relevance to the quality and quantity of these components that makes up asphalt. The final asphalt mix is depended on the aggregate gradation, aggregate angularity, quantity of aggregate and binder content.

FACTORS AFFECTING ASPHALT MIXTURE DURABILITY

Aggregate Gradation

Aggregates play a major role in asphalt mixes as they have the characteristics to absorb and control stresses on the road pavement. For the purpose of this study, 19mm nominal size was used. In [7], it is states that Hot Mix Asphalt (HMA) properties are highly affected by the aggregate characteristics. In addition, [4] also state that the aggregate characteristics are the principal material quality element that influence rut susceptibility. [8] also agrees with [7] and [4] by stating that the aggregate gradation is an effective factor for fatigue resistance of asphalt mixture. In asphalt mixes, coarser coated aggregates perform better than fine aggregates gradation [2]. The durability of asphalt mix is affected by toughness and abrasion resistance, durability and soundness, plastic fines and gradation [5].

Factors Affection Rutting

Literature indicates that there are three factors that affect rutting. [1] states that the first factor that influences rutting is the friction between the vehicle tire and the bitumen coated aggregates. The second factor is the aggregate characteristics to interlock together. The last mechanism is the loss of adhesion between the bitumen and aggregate. According to [1] the most effective parameter that affects asphalt mix to resist deformation is aggregate characteristics. The resistance to rutting is dependent on the aggregate gradation. Coarser aggregates have a higher resistance to pavement deformation and the type of aggregate have an effect on the performance on asphalt roads. Open-gap graded asphalt mixes have low resistance to rutting [7]. He further states that the best type of aggregate to resist rutting is Dolomite. [7] reached a different conclusion stating that gradation of aggregates in asphalt mixes does not affect the performance of the pavement. He continues by stating that fine aggregate angularity has an effect on rutting resistance.

METHODOLOGY

Methodology

The methodology adapted to meet the objectives of this study implicated laboratory tests. All the tests were carried using testing methods - TMH1. The laboratory investigation was conducted to characterize pavement permanent deformation property of asphalt mixtures by means of grading of aggregates, determination of suitable binder content, determination of resistance to flow, voids analysis and bulk relative density of the briquettes using Marshal test and Dynamic test. The specimen used was 100mm diameter and 150mm height.

Aggregate

Aggregate which were selected was 19mm, Calcitic hornfels crushed stone from Msobomvu Quarry in Butterworth.

Binder

Table -1 represents the type of binder which was used during the case study.

Table -1 Description of Binder Used in Case Study

Binder		
Type	Bitumen – Medium Continuously Graded	60/70 Pen
Grade	Bulk Relative Density	1.025
Source	Mixing Temperature	140ºc-160ºc
Penetration	Compaction Temperature	160ºc

RESEARCH OUTPUT

High traffic and repetitive axle load result in negative restructure on the roads earlier than expected and causes expenditure to maintenance or repair. Thus, it is essential to advance the quality of asphalt which performs the role as a binder in order to achieve the following;

- Increasing elasticity and viscosity.
- Reduction of temperature susceptibility.
- Higher aging resistance and softening point.
- Improve cohesion

Table -2 Passing Percentage for The Upper Limit

Sieve Size (mm)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
19.000	0.0	0.0	100.0
13.200	17.8	1.2	98.8
9.500	80.6	5.4	93.4
6.700	199.2	13.3	80.1
4.750	212.3	14.2	65.9
2.360	236.8	15.8	50.0
2.000	107.5	7.2	42.8
1.180	98.0	6.6	36.3
0.600	60.0	4.0	32.3
0.425	119.6	8.0	24.3
0.300	31.6	2.1	22.1
0.150	20.0	1.3	20.8
0.075	120.5	8.1	12.7
PAN	190.5	12.7	0.0
	1494.4	**100.0**	

Table -3 Passing Percentage for Middle Limit

Sieve Size (mm)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
19.000	0.0	0.0	100.0
13.200	2.7	0.2	99.8
9.500	40.4	2.7	97.2
6.700	181.2	11.9	85.3
4.750	189.6	12.4	72.8
2.360	197.5	13.0	59.9
2.000	115.4	7.6	52.3
1.180	101.3	6.6	45.7
0.600	90.6	5.9	39.7
0.425	110.5	7.3	32.5
0.300	89.6	5.9	26.6
0.150	45.7	3.0	23.6
0.075	136.0	8.9	14.7
PAN	223.6	14.7	0.0
	1524.1	100.0	

Table -4 Passing Percentage for and Lower Limit Gradation Bands

Sieve Size (mm)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
19.000	0.0	0.0	100.0
13.200	250.5	10.8	89.2
9.500	260.7	11.2	78.0
6.700	354.6	15.3	62.7
4.750	253.7	10.9	51.8
2.360	365.5	15.7	36.0
2.000	242.5	10.4	25.6
1.180	119.8	5.2	20.4
0.600	103.6	4.5	16.0
0.425	120.4	5.2	10.8
0.300	68.5	3.0	7.8
0.150	70.6	3.0	4.8
0.075	60.7	2.6	2.2
PAN	50.6	2.2	0.0
	2321.7	**100.0**	

Table -5 Marshal and Dynamic Creep Test Results

Description	Units	Fine gradation		Medium gradation		Coarse gradation	
		Fine gradation	Literature Value	Medium gradation	Literature Value	Coarse gradation	Literature Value
Binder	%	5.0	5.2	5.0	5.0	5.0	4.8
Bulk Relative Density	Kg/m	2.075	2.633	2.234	2.341	2.247	2.354
Maximum Theoretical. Density	Kg/m	2.498	2.387	2.1245	2.154	2.254	2.154
Voids in Mix	%	6.5	3.8	5.7	3.8	5.6	4.6
VMA	%	18.5	15.5	17.8	14.8	18.6	15.8
V.F.B	%	48.4	74.2	64.3	74.1	53.2	72.2
Stability	KN	8.1	8.5	8.2	8.9	9.4	8.7
Flow	mm	3.1	3.65	3.6	3.6	3.3	3.3
Flow Ratio	-	2.6	2.3	2.5	2.5	2.8	2.4
Film thickness	mm	6.2	6.7	7.5	7.3	6.6	6.7
Binder absorption	%	0.5	1.61	0.5	1.61	0.5	1.61
Indirect Tensile Strength	KPa	1540	1480	1530	1420	1520	1407
Filler/Bitumen Ratio	-	1.50	1.33	1.43	1.52	1.76	1.67
Dynamic Creep E-Modulus	MPa	14.1	22.4	26.3	17.7	15.5	13.15

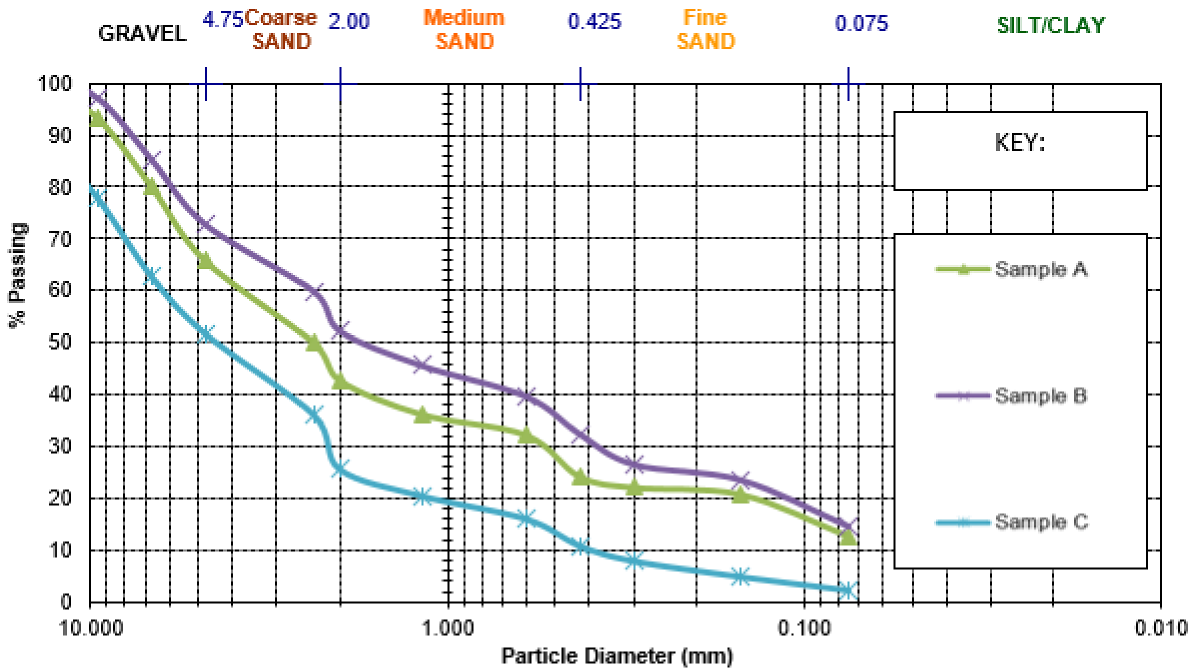

Fig. 1 Upper limit, middle limit and lower limit gradation bands for 19mm nominal maximum aggregate size

The research evaluates the effectiveness of aggregate gradation on flexible pavement. The main aim of this study was to evaluate the effects caused by aggregate gradation on asphalt in order to extend the service life of asphalt road. Table -2 representing the passing percentage for the upper limit, middle limit and lower limit gradation bands. Table -2 is a representation of the variation of aggregate gradation selected from sieve analysis diagram in figure 1. The selected percentages in each variation were selected and separated to upper limit, middle limit and lower limit gradation bands.

Table -3 represents the results for Marshal and Dynamic Creep test which were obtained during the laboratory evaluation of aggregate gradation from selected fine gradation, medium gradation and coarse gradation. The results were compared with literature in order to select the most appropriate aggregate gradation band to resist rutting in asphalt roads. The asphalt mixture parameters that were evaluated comprise of air voids, VMA, stability, flow and resilient modulus. These parameters were used to determine the effectiveness of aggregate gradation in asphalt flexible pavement.

DISCUSSION

Air Voids

The results indicated that the air voids increases between the lower limit to the upper limit gradation bands. This also is reflected the same as per literature by [1]. The increase in air voids reduces the stiffness strength in asphalt roads thus reduces the road service life. According to [3], when the asphalt mix have low air voids it will have greater strength and resistance to fatigue.

VMA

The VMA decreases between the lower limit and middle limit. However, it increases between the middle limit to the upper limit. This is also reflected by [1] where the air voids decrease from the lower gradation band to the middle band and increase on the upper limit gradation band. Increase in the VMA value indicates better resistance to rutting.

Stability

The stability value increases between the lower gradation band to the upper gradation bands. However, as per literature by [1], the stability values fluctuate between the lower gradation band to the upper band from a lower stability value to a higher stability and decreases again. The aggregate gradation on the upper limits has higher stability value which is an indication of high resistance of asphalt road to pavement deformation.

Flow

The flow value fluctuates between the lower gradation bands to the upper band. This increase is from lower flow value to higher flow value. However, the literature values decrease from the higher flow value to lower flow value between the lower gradation limit to upper limit.

Resilient Modulus

The resilient modulus as per the study fluctuates from a lower resilient value to a higher resilient value between the lower limit to the upper limit. However, this is reflected different by [1] where the resilient value decreases between the lower limit to the upper limit.

Asphalt mixes with high resilient modulus value indicate mixes that have better stiffness and resistance to deformation.

Indirect Tensile Strength

The results indicated that the indirect tensile strength decreases between the lower limit to the upper limit gradation bands. This also is reflected by [1]. Asphalt mixes with high indirect tensile strength value indicate mixes that have better stiffness and resistance to deformation.

CONCLUSIONS

- The laboratory results indicated that low deformation is experienced for asphalt mixtures using the aggregates of the upper limit. The aggregates of lower limit experiences a higher deformation rate as compared with the aggregates of upper limits.
- There is higher creep stiffness on asphalt mixtures of upper gradation band and lower creep stiffness for gradation mixtures at the lower band. This agrees with literature by [1] who stated that a higher stiffness value indicates a better resistance asphalt pavement to deformation.
- The reduction of voids in asphalt mixes reduces the chances of asphaltic pavement to experience deformation.
- The upper limit gradation (coarse aggregate) indicated higher VMA thus is resistant to permanent deformation as compared with the aggregates on the lower limit bands. The minimum required VMA is 13%.

RECOMMENDATIONS

Aggregate plays an important role in pavement permanent deformation. The aggregate gradation is the most important parameter for a project specification in order for the mix design to yield asphalt mixtures that meets the design service life. The selected gradation should be economically available and suitable for quality use.

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