THE EVALUATION OF ASPHALT MIX DESIGN IN ORDER TO EXTEND THE SERVICE LIFE IN ASPHALT PAVEMENT

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Abstract - Pavement permanent deformation is a major distress in South African (SA) flexible roads. Pavement permanent deformation refers to the change in shape of a solid pavement due to stress and strain without the pavement changing back to its original form. Permanently deformed surfaces form a rut which is referred to as a permanent depression into a road as a result of deformation of the asphalt pavement or subbase material. Rutting might lead to the bigger structural failures in the pavements. Every load applied on the surface cause permanent deformation which leads to rutting.
The failure of asphaltic pavement to carry traffic loading without rutting is a major problem on Butterworth roads in the Eastern. Fatigue failure has been a huge problem in many roads in SA by not meeting the design service level. Aged binder also has a huge significance in the distress of asphalt mixtures. The stiffness of asphalt mix increases due to stiff or less elasticity in binder. This will result in fatigue damage and brittleness of the asphalt pavement in low temperatures.
The main aim of this study is evaluate the asphalt mix design in order to extend the service life of asphalt pavement. The study is limited in the evaluation of asphalt mixture design and its effect on asphalt mixes by means of laboratory tests only.
The methodology adapted to meet the objectives of this study implicated a field investigation and laboratory investigation. All the tests were carried using Testing methods - TMH1. The laboratory investigation was conducted to characterize permanent deformation property of asphalt mixtures by means of grading of aggregates, determination of suitable binder content, determination of resistance to flow and voids analysis by Marshall method and bulk relative density of the briquettes.

The study has discovered that rubberize asphalt has a higher resists to deformation. This is due to the characteristics of the rubber crumb binder which enables the HMA to resist fatigue on the road thus extends the road service life and performs well under extreme heavy traffic load.
Previous research states that the shear resistance of fine aggregate has a vital role on the mixture resistance (Verhaeghe et al, 2011)

Keywords - Deformation, Asphalt, Rutting, Hot Mix Asphalt (HMA)

I. INTRODUCTION

Due to pavement fatigue experienced in South African roads, the study intends to evaluate the asphalt mix design of flexible road thus improve the road performance in South African Roads. The study was conducted on the main road of Butterworth in the Eastern Cape which experience permanent deformation.

In flexible pavements, fatigue is recognized to be the major mechanism resulting in distress. Dondi et al, (2015) states the main factors that influence HMA performance are, binder content, compaction, material grading, temperature and traffic loading.
The experience of permanent pavement deformation and rutting in Butterworth roads can be used as a reference with other South African roads which experiences rutting and pavement deformation in the asphalt wearing course surface.

The research approach to this investigation was conducted using different laboratory tests in order to evaluate the binder content of asphalt, the volumetric composition, the binder content, void content, stability of asphalt mix design and the loading conditions related to the asphalt mix design.

II. OBJECTIVES OF THE STUDY

The main aim of this study is to evaluate the asphalt mixture design in order to extend the service life in asphalt pavement

III. STUDY LIMITATIONS

The study is based in Butterworth, Eastern Cape and is only limited to the evaluation of asphalt mixture design and its effect on asphalt mixes.

IV. PROBLEM STATEMENT

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.

Rutting in asphalt layers is initiated by an asphalt mix that is too low in shear strength to resist the imposing of repeated higher axle loads, environmental condition and construction errors in the road.

V. RESEARCH QUESTION

What are the essential asphalt mixture compositions that have higher resists on rutting in flexible pavement?

VI. ASPHALT MIX DESIGN

Factors affecting asphalt mixture durability

a. Environment

Environmental conditions have a major effect on asphalt concrete durability. When designing flexible pavements and asphalt mixtures, temperature is a primary consideration. The influence of temperature as an environmental factor affects the rutting resistance, structural stiffness, and cracking resistance of asphalt mixtures.

b. Temperature

The climatic conditions to which a pavement will be subjected will affect both the materials selection and the layer thickness determination.

Large daily and yearly temperature fluctuations create stresses in the surface materials which can cause them to crack as the material volume changes (Emmanuel et al, 2009).

Temperature furthermore has a significant effect on the aging of asphalt binders and asphalt mixtures throughout the service life of the pavement. It is the variant of the atmospheric temperature that affects the type and amount of bitumen that should be used in flexible pavements. Also, the variation in temperature between the top and bottom surfaces of the pavement affects its deflection and load-bearing capacity.

Table 1. Effect of temperature on natural rubber

Temperature	Effect description
-10^{o}C	Brittle and opaque
20^{o}C	Soft, resilient and translucent
50^{o}C	Plastic and sticky
120^{o}C - 160^{o}C	Vulcanised when agents e.g., sulphur are added
180^{o}C	Break down as in the masticator
200^{o}C	Decomposes

c. Moisture

Moisture damages the asphalt aggregate bond thus results in the deterioration of the bond through adhesive failure at the interface or cohesive failure within the asphalt or aggregate. These failures cause the asphalt to separate or strip from the aggregate, leaving the aggregate without a binder to keep the aggregate particles and the pavement together (Kassir, 2009).

The moisture can damage asphalt mixtures through, loss of cohesion within the asphalt binder, loss of adhesion between the asphalt binder and the aggregate and aggregate degradation particularly when freezing occurs in the mixture.

d. Drainage

Moisture damage might occur in asphalt mixtures if moisture is allowed to infiltrate through inter-connected voids and becomes trapped in the mixture. Furthermore increase in moisture content in flexible pavement result in a loss in base and subgrade soil strength and stiffness.

e. Aggregate Properties

In order to design asphalt mixes properly, one has to understand the basic properties of aggregates, interactions between aggregates and binders, and the effect of different aggregate characteristics on the performance of asphalt concrete mixtures.

Asphalt pavements vary in longevity because of the various factors that cause deterioration of the chemical and physical association of the binder to the aggregate (Kassir, 2009).

It has been mentioned that rutting occurs in mixtures with low shear resistance or strength compared to the repeated stress it is subjected to. The shear strength of frictional and cohesive materials, including asphalt mixtures, has been expressed using the following equation:

$\tau = c + \sigma\tan\varphi$

Where:

τ = Shear strength c = Cohesion σ = Normal stress φ = Angle of internal friction

The properties of the aggregates used in asphalt that are generally associated with asphalt mixture durability are the toughness and abrasion resistance, durability and soundness, plastic fines as measured by the sand equivalent and gradation.

1. Volumetric Properties

A volumetric property is the primary mixture design factor affecting both durability and fatigue cracking resistance.

This delivers adequate volume of asphalt binder to appropriately coat the aggregates and to minimize the aging during construction and service life of the pavement surface.

2. Pavement Design and Durability of Flexible Pavement

Pavement design is the process of selecting the appropriate materials and layer thicknesses to withstand the expected level of traffic under the environmental conditions in a given location.

According to Daniel et al (2013), a flexible pavement should have the following properties in order to be durable;

a. Structurally adequate.

The primary objective of the pavement is to prevent the overstressing of the natural soils (subgrade). Thus, it follows that a thinner pavement can be used over a stronger subgrade.

In the past, mainly empirical methods were used to design pavements. These methods do not consider pavement distress explicitly. In recent years, the more rational mechanistic – empirical methods have been developed and are being implemented. Generally two procedures have been used in the mechanistic empirical methods to limit rutting: one to limit the vertical compressive strain on top of the subgrade and the other to limit the total accumulated permanent deformation on the pavement surface based on the permanent deformation properties of each individual layer. Given that with increased tire pressures most of rutting occurs in the asphalt surfacing layer rather than the subgrade, the first approach appears inappropriate for consideration of rutting in pavement structural design (Rabbira, 2002).

b. Properly drained.

The road design should prevent water from moving into the pavement and minimize the water infiltration into the pavement.

c. Properly constructed.

The way a pavement is constructed has a major effect on the durability of asphalt roads. Construction related issues usually result in localized defects and distresses while deficiencies associated with mixture composition are usually more widespread.

d. Construct with durable materials.

Underwood et al, (2012) state that the materials placed in the pavement must be able to resist the effects of moisture, aging, traffic and environmental loading. This includes the asphalt surface. According to Arabani et al. (2010), the primary resolutions to construct a more durable pavement is to construct a thicker asphalt pavement and use an asphalt mixture with modified characteristics.

3. Mixture proportion Design

a. Aggregate gradation design.

According to the requirements of aggregate gradation scope of AC-13, AC-20, AC-25 asphalt mixtures in JTG F40-2004, the mineral aggregate gradation is designed and shown in the figure below.

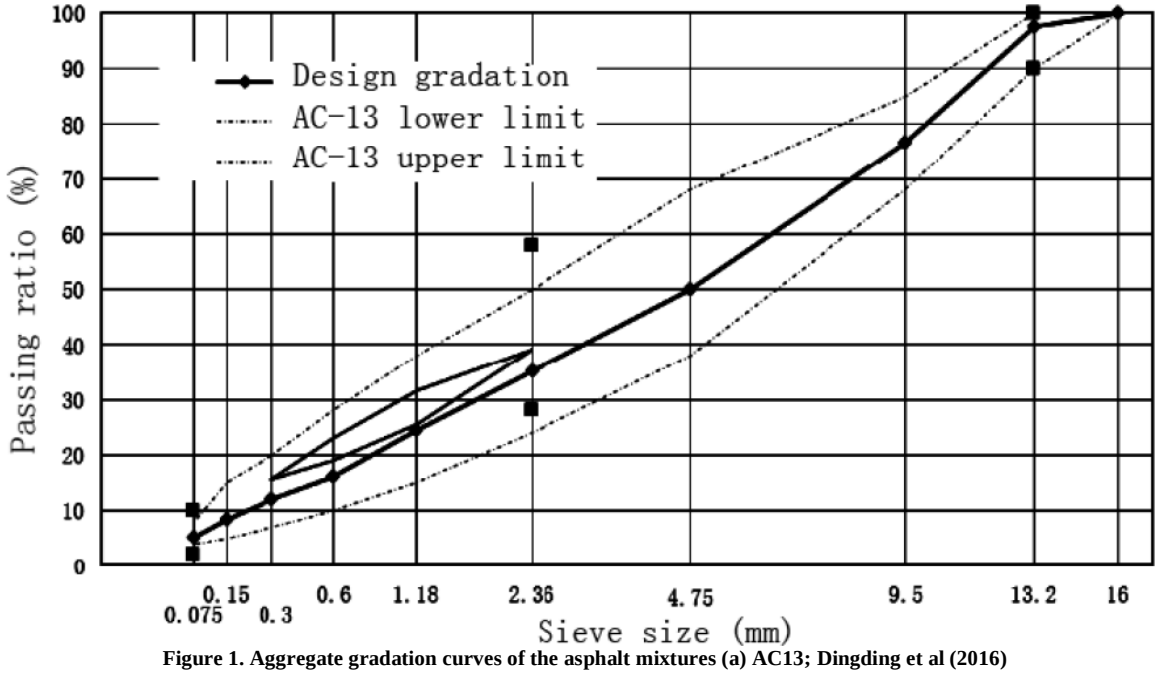


Figure 1. Aggregate gradation curves of the asphalt mixtures (a) AC13; Dingding et al (2016)

4. Effect of Binder Properties

Mohammed at el (2014), state that bitumen can be described as a viscous liquid or solid consisting essentially of mineral oil which are soluble in carbon sulphide, and is substantially non-volatile and softens gradually when heated.

5. Asphalt Mixture Composition

The aggregate composes 94 - 95% of the mix while asphalt constitutes the remaining 5–6%. Asphalt–aggregate interactions in asphalt pavements directly influence the adhesion of asphalt to the aggregate. These interactions are directly related to the bond strength between the asphalt and the aggregate and also determine the efficiency of the asphalt aggregate interaction in the presence of water. (Kassir, A.F., 2009)

6. Angularity of Aggregate

Saad (2015), states that HMA properties are highly affected by the aggregate characteristics. In addition, Haobo (2015) also state that the aggregate characteristics are the principal material quality element that influence rut susceptibility.

Taher et al (2011) also agrees with Saad (2015) and Haobo (2015) by stating that the aggregate gradation is an effective factor for fatigue resistance of asphalt mixture.

7. Mineral Filler (Lime)

Al Suhaibani et al (1992) concluded from this study with regard to rutting that rutting in asphalt concrete is highly dependent on the softening point of the mastic, that is binder plus filler, which in turn depends on the type and proportion of filler. Furthermore he concluded that rutting is highly affected by the amount of hydrated lime but not by the Portland cement, and the asphalt mixes made with limestone dust exhibit lower rut depth than those containing either Portland cement or hydrated lime.

8. Effect of void content

Rutting performance has a close relationship with type of road construction, type of pavement and percentage of voids in asphalt mixtures. Also, rheological properties of asphalt such as penetration and viscosity could be effective factors (Taher et al. 2011).

VII. METHODS AND MATERIALS

Below is the method and materials used during the laboratory investigation of the case study.

a. Methodology

The methodology adapted to meet the objectives of this study implicated a field investigation and laboratory investigation. All the tests were carried using Testing methods - TMH1. The laboratory investigation was conducted to characterize permanent deformation property of asphalt mixtures by means of grading of aggregates, determination of suitable binder content, determination of resistance to flow and voids analysis by Marshall method and bulk relative density of the briquettes.

b. Materials

Below is table 1 which illustrates the materials used in the case study.

Table 1: Materials

Material		
Number	**Aggregate size**	**Description and source**
1	13.2mm	Calcitic hornfels, crushed stones from Msobomvu Quarry
2	9.5mm	Calcitic hornfels, crushed stones from Msobomvu Quarry
3	6.7mm	Calcitic hornfels, crushed stones from Msobomvu Quarry
4	4.75mm – Crusher Dust	Calcitic hornfels, crushed stones from Msobomvu Quarry
Binder		
Type	Bitumen – Medium Continuously Graded	60/70, Rubber crumb and AE-2 Polymer
Grade	Bulk Relative Density	1.025
Source	Mixing Temperature	140^{o}c-160^{o}c
Penetration	Compaction Temperature	160^{o}c

VIII. RESEARCH OUTPUT

There are several factors that contribute to a well quality and stable HMA pavement. These qualities and performance of HMA can be analyses through the asphalt performance to display good stability, impermeability, durability, workability, flexibility, resistance to deformation and fatigue in the pavement layer. The research output obtained during the case study in order to evaluate the asphalt mixture design in order to extend the service life in asphalt pavement is discussed below.

8.1 Gradation curve

The gradation was used to determine the grading of the material which is within the upper and lower limit of the gradation curve. Figure 2 illustrates the particle size distribution of four fractions of stones and filer to produce the required design grading.

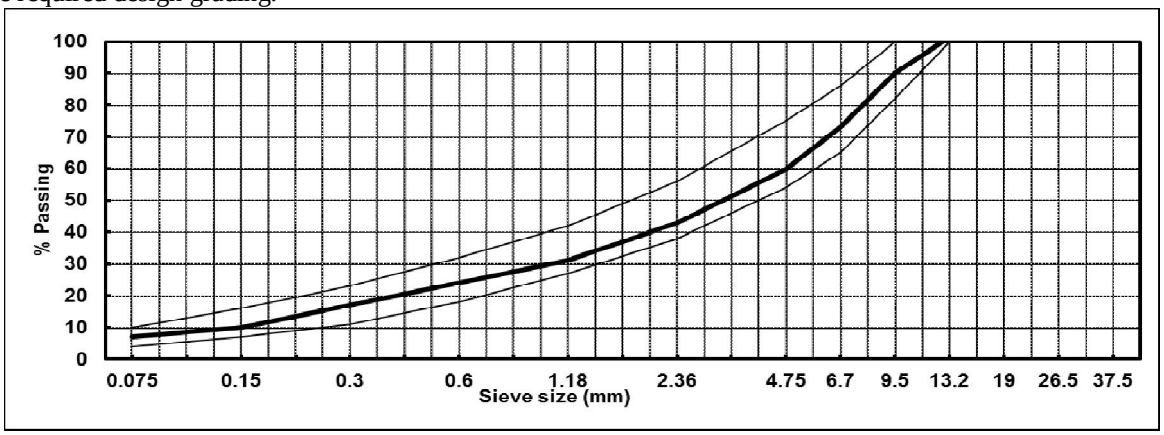


Figure 2. Applied gradation curve graph with upper and lower limit

The above Figure 2 shows that the material grading analyses were within the upper and lower limit. Such material can be referred to as well graded and meet the design specification. This method was used to determine the volumetric design of the HMA materials. This method helped to determine the grading of aggregates and coarse aggregate angularity. The aggregate which were used in the design mix of HMA were asymmetrical to comply with the composition restriction specific to the nominal maximum particle size.

Table 2 Quantity of material used in three different asphalt mix designs

Material Sizes	Mix 1		Mix 2		Mix 3	
	60/70 Pen Asphalt - Unmodified Asphalt		AE-2 asphalt -modified Asphalt		Rubber asphalt- modified Asphalt	
13.2 mm	5%	60 (g)	5%	60 (g)	5%	60 (g)
9.5 mm	15%	180 (g)	15%	180 (g)	180%	180 (g)
6.7 mm	35%	420 (g)	35%	420 (g)	420%	420 (g)
4.75 mm	45%	540 (g)	43%	520 (g)	43%	520 (g)
Lime	0%	0 (g)	2%	20 (g)	2%	20 (g)
Total	**100%**	**1200g (Total proposed mass)**	**100%**	**1200g (Total proposed mass)**	**100%**	**1200g (Total proposed mass)**

		Asphalt Bitumen Content		
Binder Content	4.5 %	54.34 g	54.34 g	54.34 g
	5.0 %	60.77 g	60.77 g	60.77 g
	5.5 %	64.42 g	64.42 g	64.42 g
	6.0 %	69.85 g	69.85 g	69.85 g

The above table 2 represents the quantities of material used in the design of three different asphalt design mixes which are the 60/70 pen pure unmodified asphalt, AE-2 Polymer bitumen binder and Rubberized asphalt binder

The 60/70 pen asphalt as unmodified asphalt was blended based on the volumetric specification in table 2 and was used as a control mix. The AE-2 and Rubber asphalt were used as modified asphalt using the designed proportions on table 2. The performance of these three trials HMA mixes was compered in order to select the most appropriate HMA design.

8.2 Results

Below are the results used to evaluate the asphalt mixture design in order to extend the service life in asphalt pavement.

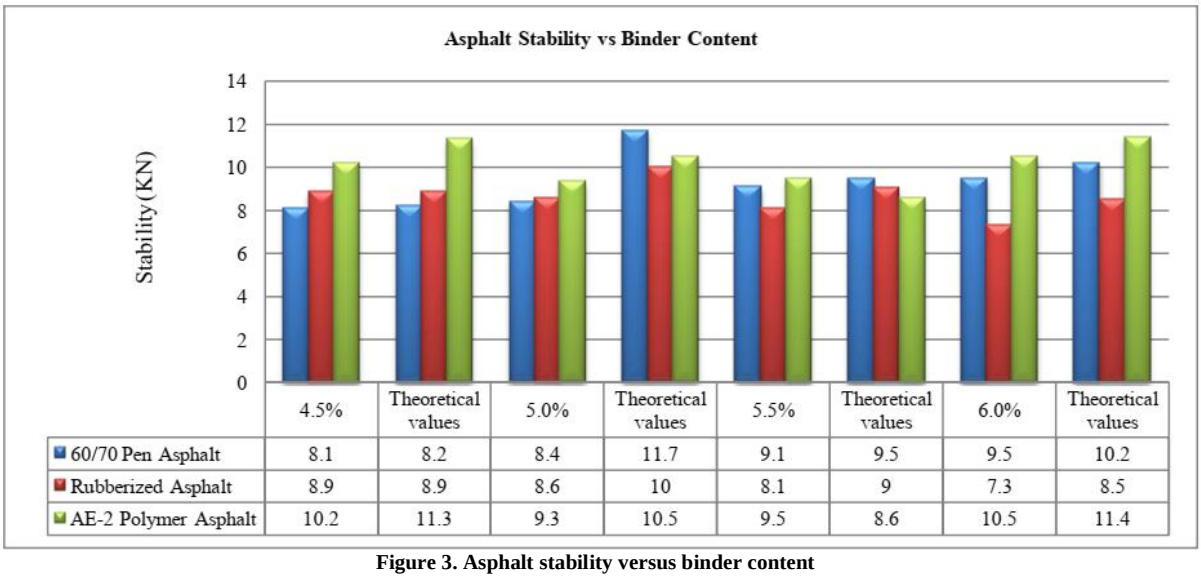


Figure 3. Asphalt stability versus binder content

The laboratory results indicated that at 4.5%, both modified rubberized asphalt and AE-2 polymer modified asphalt displays a higher stability as compared with the controlled mix of unmodified pen asphalt. This is in line with Saad and Ibitihal (2014) who states that the stability of modified asphalt mix displaces an increase in stability and stiffness as compared with unmodified asphalt mix.

The study also indicated that the 60/70 pen asphalt increases in stability with increase in binder content from 4.5% binder to 6.0% binder. Whoever this contradicts with the findings of Saad and Ibtihal where at a given asphalt material volumetric mixes, the stability of 60/70 pen asphalt increase between 4.5% binder to 5.0% and decrease between 5.5% to 6.0% binder.

The Rubberized asphalt shows a decrease in stability from 4.5% to 6.0%. On the other hand according to Arabani et al. (2010), the primary resolutions to construct a more durable pavement is to construct a thicker asphalt pavement and use an asphalt mixture with modified characteristics. The literature values for rubberized asphalt fluctuate from a lower stability to a higher stability and decreases again. Only at 5% binder that the rubberized asphalt displays a higher value of stability.

The AE-2 polymer asphalt displays properties of stability as per the study in line with the rubberized asphalt. This also is reflected the same as per the literature by Saad and Ibitihal (2014).

8.3 Asphalt Mix Design 60/70 Pen Unmodified Asphalt

Below are the design curve graphs of asphalts which were used as part of discussion for the finding of Asphalt mix design 60/70 Pen Unmodified Asphalt.

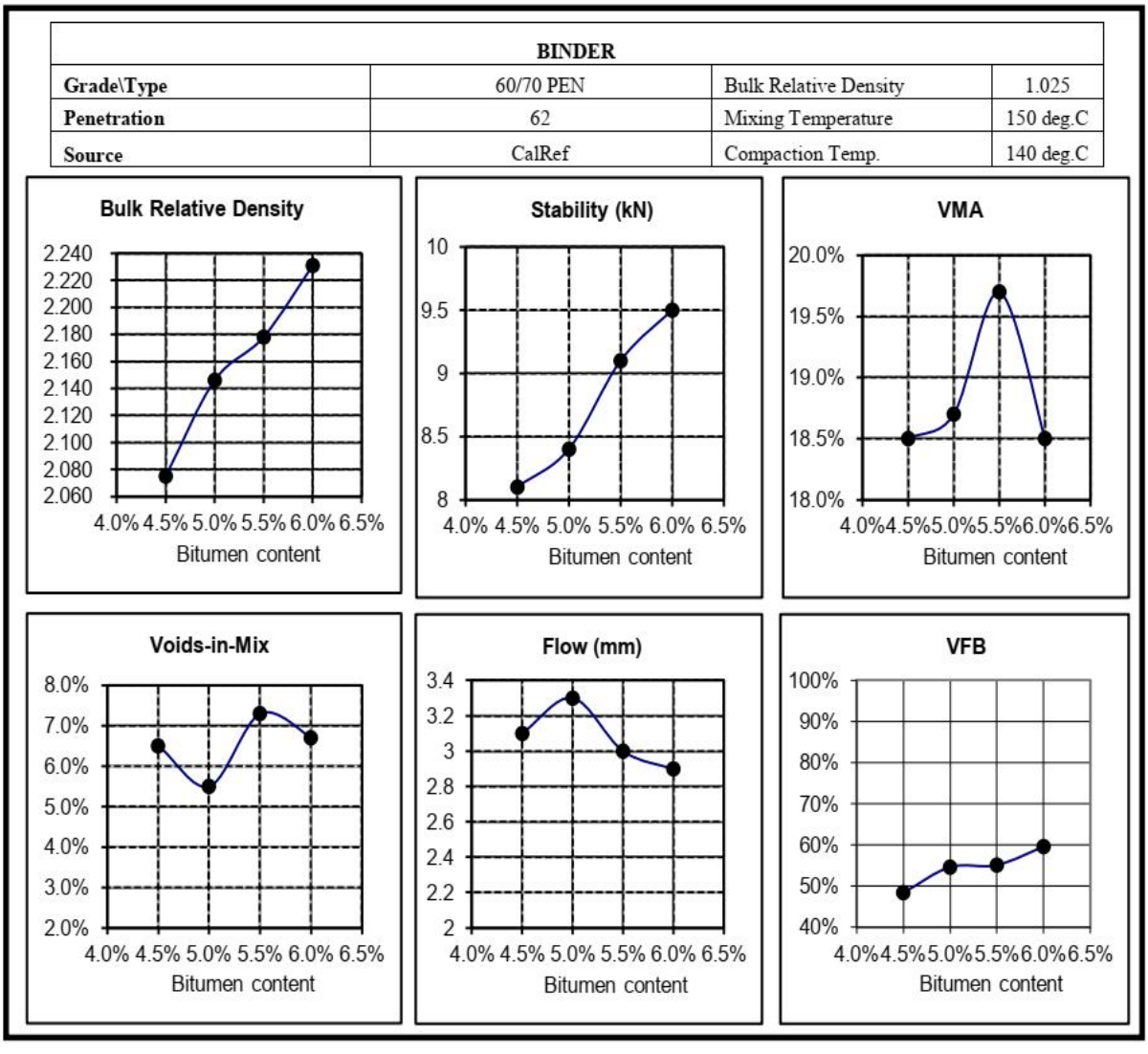


Figure 4 Graphs of design curves for asphalt characteristics of 60/70 Pen Unmodified Asphalt

16.3 Asphalt Mix Design - EA 2 Polymer asphalt

Below are the design curve graphs of asphalts which were used as part of discussion for the finding of Asphalt mix design for AE-2 polymer asphalt.

BINDER			
Grade\Type	Bitumen-Medium continuously graded	Bulk Relative Density	1.025
Penetration	62	Mixing Temperature	140 - 160 deg.C
Source	CalRef	Compaction Temp.	160 deg.C
Fillers			
Number	**Type**	**Description**	
1	Filler	Lime	

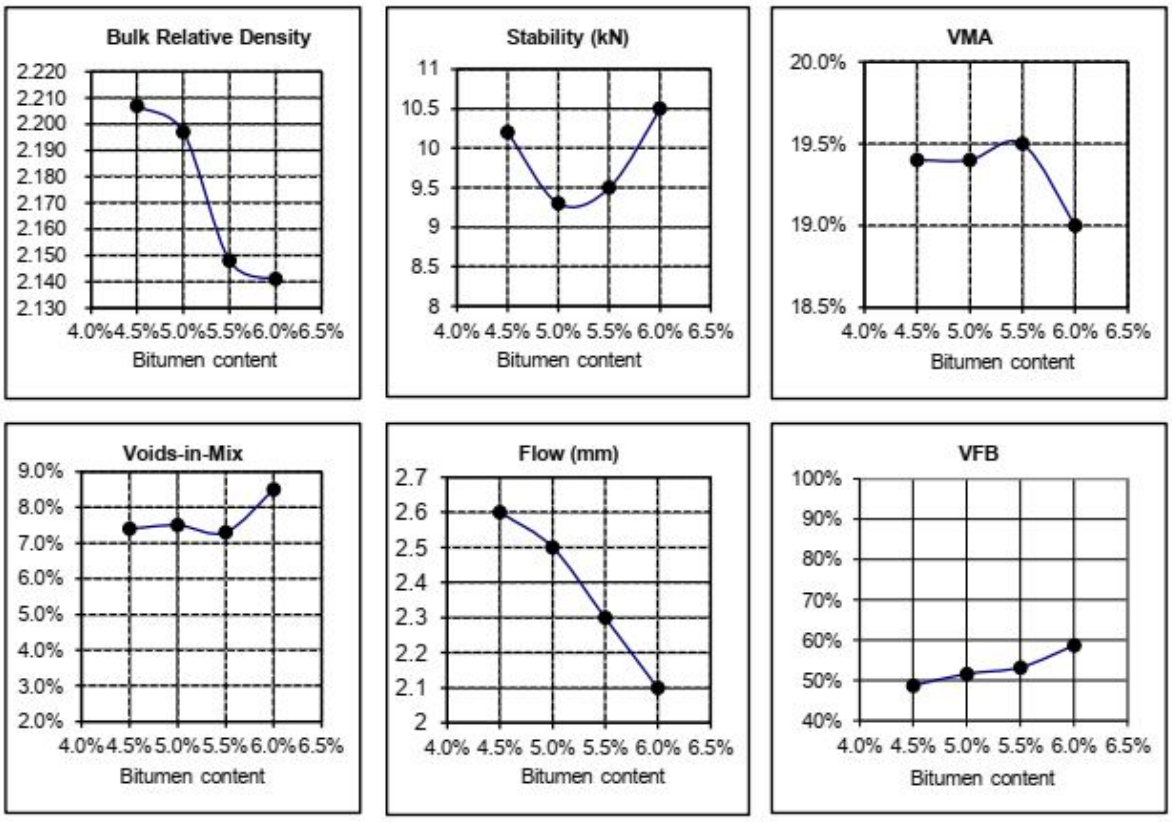


Figure 5 Graphs of design curves for asphalt characteristics of EA-2 polymer asphalt

Figure 5 shows that the bulk relative density decreases of EA-2 polymer asphalt as the bitumen content increases. The stability flow decreases with increase in bitumen content from 4.5% to 5.0% and increases from 5.0% of binder to 6.0%. . The void in mineral aggregates is constant from 4.5% bitumen binder to 5.0% and sudden increases from 5.0% to 5.5% binder and decreases thereafter to 6.0%. The void in mix shows a fluctuation from 4.5% to 6.0%. The flow shows a decrease with increase in bitumen content from 4.5% bitumen binder to 6.0%. The void filled binder shows an increase with increase in the binder content.

8.4 Asphalt Mix Design - Rubberized Asphalt

Below are the design curve graphs of asphalts which were used as part of discussion for the finding of Asphalt mix design for rubberized asphalt.

BINDER			
Grade\Type	Bitumen-Medium continuously graded	Bulk Relative Density	1.025
Penetration	63	Mixing Temperature	140 - 160 deg.C
Source	CalRef	Compaction Temp.	160 deg.C
Fillers			
Number	**Type**	**Description**	
1	Filler	Lime	

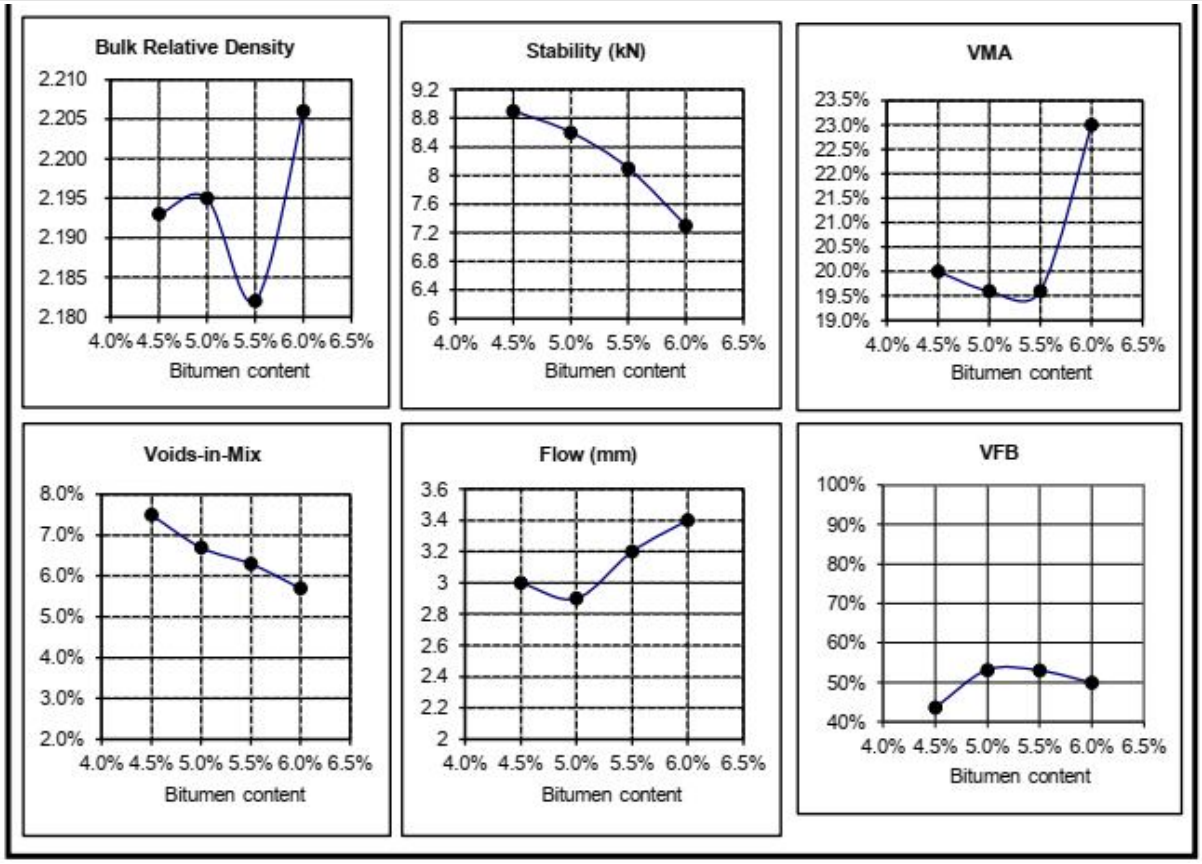


Figure 6 Graphs of design curves for asphalt characteristics of rubberized asphalt.

Figure 6 shows that the bulk relative density of rubberized asphalt slightly increases with increase in bitumen content from 4.5% to 5.0% and decrease from 5.0% to 5.5% binder and further increases again to 6.0% binder content. The stability flow decreases with increase in bitumen content from 4.5% to 6.0% binder. The void in mineral aggregates decreases from 4.5% bitumen binder to 5.5% and a sudden increase thereafter to 6.0%. The void in mix shows a decrease from 4.5% to 6.5%. The flow shows a decrease with increase in bitumen content from 4.5% bitumen binder to 5.0% and an increase thereafter from 5.0% to 6.0%. The void filled binder shows an increase with increase in the binder content from 4.5% to 5.0% and a slight decrease from 5.0% to 6.0%.

CONCLUSIONS

It was discovered that that the modified rubberize asphalt has a higher resists to deformation. This is due to the characteristics of the rubber crumb binder which enables the HMA to resist fatigue on the road thus extends the road service life and performs well under extreme heavy traffic load. The findings are in line with Saad and Ammar (2015), who concluded that the application of modified asphalt mix design, enables to improve the quality and service life of asphalt roads in terms of permanent deformation and fatigue resistance due to traffic loading and environmental conditions.

Further findings indicated that the quality of aggregates, the air void content and the effective volume of binder in the asphalt mixture are the three volumetric properties that most affect both the durability and fatigue cracking resistance of asphalt concrete mixtures.

The pavement layers need to be adequately thick to carry the projected traffic flow loading and protect the subgrade layer.

RECOMMENDATIONS

Asphalt is a major product of many refineries, forms the basis of a major industry, and is one of the indispensable materials of life in many parts of the world. Adequate and proper construction should be practiced which includes sufficient compaction in all pavement layers, adequate pavement thickness, compaction control in all layers, proper bond between the Asphalt layers, minimizing of segregation and proper joint construction in selected layers.

In order for the industry to progress and evolve, it is necessary to understand the issues associated with the technology surrounding the production and utilization of asphalt, including loading and production of the bituminous product, and the associated health, safety, and environmental issues.

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