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Mix Design for Wearing Course of Flexible Road Pavement by Marshall Method

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Abstract - *Hot mix asphalt wearing course in a flexible road pavement is the most important and critical layer in a pavement structure and must be of high quality. The major parameter in design of hot mix asphalt (HMA) for it to be both stable and durable is to find out the optimum bitumen content (OBC) required in achieving the desired objective. This article presents a mix design of bituminous concrete wearing course of flexible pavement. Laboratory tests were carried out on the aggregate, bitumen and paving mix samples. All the analysis were carried out in line with the ASTM testing procedures. The result of sieve analysis showed that the particle size distribution of the aggregate is in ranges recommended by the national standard. The aggregate crushing value (ACV), aggregate impact value (AIV), LosAngels abrasion (LAA) and Flakiness index (FI) respectively are 12.5%, 13.02%, 18.11% and 25.32%. The results obtained showed that the aggregate in question do possess the required qualities to be used in a wearing course material as per the standard. With respect to the bitumen, it has a specific gravity of 1.01 at 75 number of blows. The optimum bitumen content of the paving mix under study is 5.00%. Other mix parameters such as VIM (%, VMA (%), VFB (%), Stability (KN) and Flow (0.25mm) are found to be 4.00, 13.35, 71.00, 18.60 and 12.48 respectively. when the mix parameter values are compared against the required standard intervals, all the mix Parameters above which are at the bitumen content of 5.00% lie well at the interval desired as per national and ASTM (MS-2) criteria.*

Keywords: Mix design, Optimum bitumen content, Wearing course, aggregate, bitumen, paving mix.

1. INTRODUCTION

Hot mix asphalt wearing course is the most critical layer in a pavement structure and must be of high quality and have a predictable performance. It needs to possess such characteristics namely: High resistance to deformation; High resistance to fatigue and the ability to withstand high strains i.e. they need to be flexible; Sufficient stiffness to reduce stresses in the underlying layers to acceptable levels; High resistance to environmental degradation i.e. good durability; Low permeability to prevent the ingress of water; Good workability to allow adequate compaction to be obtained during construction; Sufficient surface texture to provide good skid resistance in wet weather and Predictable performance [1].

A bituminous material is a three phase material consisting of aggregate, bitumen and a very small proportion of air voids. Its mix design aims to determine the proportion of bitumen, Filler, fine aggregates, and coarse aggregates to produce a mix which is workable, strong, durable and economical [2]. The two fundamental properties expected from a bituminous paving mixture that are held to be of the utmost importance are 'stability' and 'durability'. By 'stability' is meant that property of the compacted mixture that enables it to withstand the stresses imposed on it by a moving wheel loads without sustaining substantial permanent deformation. By "Durability" is meant that property of the compacted mixture that permits it to withstand the detrimental effect of air, water and temperature change. For successful results, the pavement must be both durable and stable during its entire service life [3].

The major parameter in design of hot mix asphalt (HMA) for it to be both stable and durable is to find out the optimum bitumen content (OBC) required in achieving the desired objective. Bitumen is also a costly material and needs to be designed very carefully to achieve other properties, namely structural strength, skidding resistance, resistance to oxidation and impermeability of HMA [4].

The first mix design method for calculating the OBC for California Department of Transport was developed in 1930's by Francis Hveem. Contemporarily, Bruce Marshall in 1930's developed a mix design method for calculating the OBC for Mississippi Highway Department with a cumbersome process having some lengthy steps requiring skilled technicians and sophisticated laboratories [4].

The important highways in Ethiopia are built by Dense Asphalt (Bituminous) concrete. Asphalt Concrete (AC) is by far the most common type of HMA used in tropical countries including Ethiopia and it is usually designed by the Marshall. The material has a continuous distribution of aggregate particle sizes which is often designed to follow closely the Fuller curve to give the maximum particle density after compaction but adjusted slightly to make room for sufficient bitumen [5]. The aim of this study is to perform mix design for wearing course of flexible road pavement by Marshall method.

2. MATERIALS AND METHODS

In the study, the Marshall Test procedures that have been standardized by the American Society for Testing and Materials were adopted to evaluate the mix specimen. As per the specifications for Bituminous Concrete (BC) mix, the specimens are compacted with 75 blows on either face.

For determination of various aggregate characteristics, crushed Stone (GB1) aggregate sample was collected from production site of crushed aggregate material extracted from Monopole quarry to evaluate it for its suitability for use in wearing course of flexible road pavement as per the national standard.

The volumetric analysis including calculation of bulk density, percent air voids, percent voids in mineral aggregates (VMA), percent voids filled with bitumen (VFB) were performed. The Mechanical tests including finding of the Marshall Stability and flow value of Marshall Specimens were also made. Each of these have been carried out at different binder contents ranging from 4 to 6% with 0.5% increment at each interval. At each binder content three specimens were examined and the average of the calculated parameter values specimens' was found out in their respective units and taken as the desired parameter value. The design optimum bitumen content that balances all of the mix properties was chosen to be the required optimum bitumen content and other mix parameters corresponding to the determined optimum bitumen content were read from their respective figure and reported..

3. ANALYSIS AND DISCUSSION

3.1. Aggregate Characteristics

3.1.1. Particle Size Distribution

Knowing of particle size distribution is necessary to determine the grading of materials proposed for use in road pavement. The results are used to check the compliance of the aggregate material in question with the particle size distribution of applicable specification requirements and to provide necessary data for the control of the production of various aggregate products and mixtures containing aggregates. Its result gives the percentages of different aggregate fractions present in the aggregate sample. Accordingly, the particle size distribution of the aggregate sample as compared with national specification is presented in Figure 1. As it can be seen from the figure, the aggregate sample under study meets the requirements for the particle size distribution for use as wearing course material in roads [6].

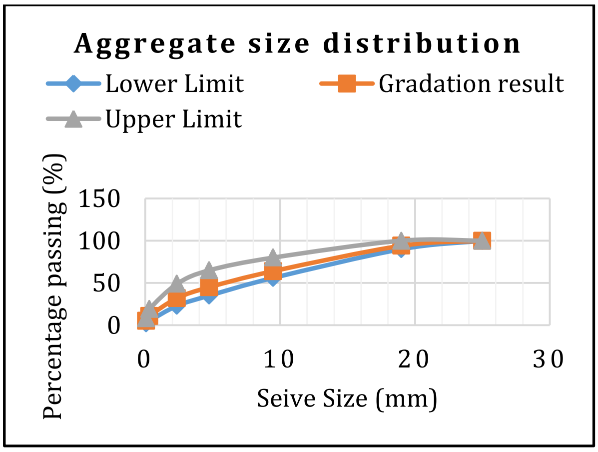

Figure-1: Particle size distribution of the aggregate material

3.1.2. Specific Gravity and Water Absorption

The specific gravities, the blending proportion by weight of the aggregate material and the water absorption of the aggregate are as tabulated in Table 1 below.

Table 1: Specific gravities of aggregate components and water Absorption

Aggregate Type	Size range	(%) by weight	Bulk Specific Gravity
Coarse	2.36mm to 25mm	52.2	2.564
Fine	0.075mm to 2.36mm	38.4	2.554
Mineral Filler	<0.075mm	9.4	2.546
Water Absorption			0.90%

3.1.3. Other Physical Characteristics

Table 2 below summarizes the important aggregate characteristics that needs to be known before the aggregate material in question is considered as the either suitable or not for use in the paving mix. Based on the results and as per the national standard, the aggregate in consideration can be said to satisfy the requirements of the aggregate material to be used as component of HMA paving mix.

Table 2: Other characteristics of the aggregate

No.	Aggregate Parameter	Test Result	Spec Limit	Remark
1	ACV	12.5%	<25%	Satisfied
2	AIV	13.02%	<25%	Satisfied
3	LAA	18.11%	<30%	Satisfied
4	Flakiness index	25.32%	<35%	Satisfied

3.2. Bitumen Characteristics

A bitumen material with a penetration grade of 60/70 was considered and its specific gravity at 75 number of blows was determined to be 1.01.

3.3. Characteristics of Paving Mix

Below discussed under 3.3.1 to 3.3.7 are the identified characteristics of the paving mix under study.

3.3.1. Maximum and Effective Specific Gravities of the Paving Mix

The maximum Specific gravity of the mix is the one that is determined at zero air void in the mix. As such, the maximum specific gravities of the mix under consideration at different bitumen contents and the respective effective specific gravities calculated are shown in Table 3 below.

Table 3: Bitumen Content vs Maximum and Effective Specific Gravities

No.	Bitumen content, P_b (%)	Maximum Specific Gravity, G_{mm}	Effective Specific Gravity, G_{se}
1	4.0	2.453	2.606
2	4.5	2.42	2.587
3	5.0	2.385	2.566
4	5.5	2.356	2.550
5	6.0	2.326	2.533

3.3.2. Densities of the Specimen

Density is one of the most important parameters in design and construction of asphalt mixtures. A mixture that is properly designed and compacted will contain enough air voids to prevent rutting due to plastic flow but low enough air voids to prevent permeability of air and water [7]. The densities of the paving mix at differing bitumen content are tabulated in Table 4 below. As it can be observed from Figure-2, the maximum density of the mix that can be achieved is 2263 kg/m^3 which can be obtained at the bitumen content of 5.10%.

Table 4: Densities of Paving Mix at Differing Bitumen Content

No.	Bitumen content, P_b (%)	Mix density (Kg/m^3)
1	4.0	2249
2	4.5	2256
3	5.0	2263
4	5.5	2260
5	6.0	2252

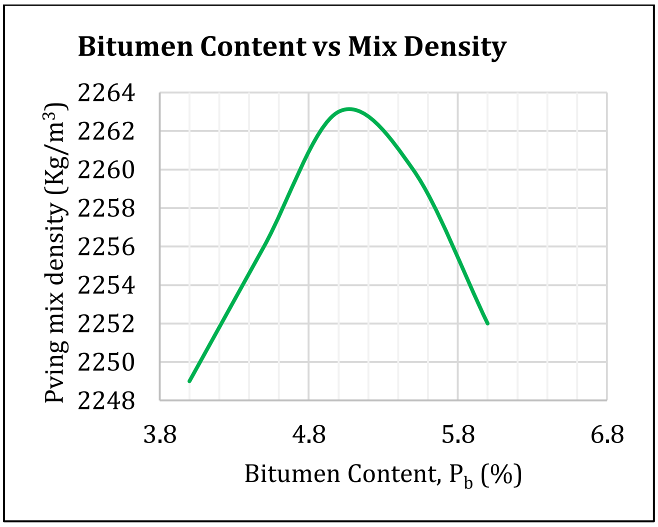

Figure-2: Plot of bitumen Content vs Mix density

3.3.3.. Void in Paving Mix (VIM)

Table 5: VIM of the mix with respect to Bitumen Contents

No.	Bitumen content, P_b (%)	Void in Mix, VIM (%)
1	4	6.3
2	4.5	5.5
3	5	4.1
4	5.5	3.2
5	6	2.3

Obtaining adequate density is a major requirement in the construction of hot mix asphalt (HMA) pavements. Density is very much related to the air voids [8]. Table 5 above summarizes the relationship between bitumen content and the respective amount of voids in the paving mix (VIM).

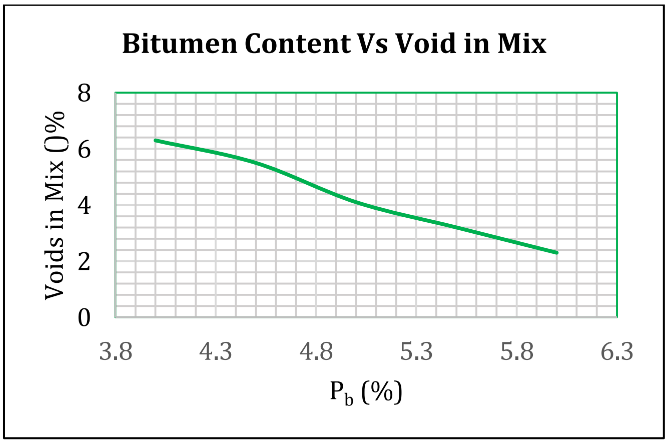

Figure-3: Plot of bitumen Content vs VIM

3.3.4. Void in Mineral Aggregate (VMA)

VMA is the volume of intergranular void space between the aggregate particles of a compacted paving mixture. It includes the air voids and the volume of the asphalt not absorbed into the aggregate. Stated another way, VMA describes the portion of space in a compacted asphalt pavement or specimen which is not occupied by the aggregate. VMA is expressed as a percentage of the total volume of the mix. When aggregate particles are coated with asphalt binder, a portion of the asphalt binder is absorbed into the aggregate, whereas the remainder of the asphalt binder forms a film on the outside of the individual aggregate particles. Since the aggregate particles do not consolidate to form a solid mass, air pockets also appear within the asphalt-aggregate mixture [9]. Table 6 below and the respective plot (Figure - 4) show the relationship between bitumen content and VMA of the paving mix.

Table 6: VMA with respect to Bitumen Contents

No.	Bitumen content, P_b (%)	Void in Mineral Aggregate, VMA (%)
1	4.0	15.4
2	4.5	15.4
3	5.0	16
4	5.5	16.1
5	6.0	17.2

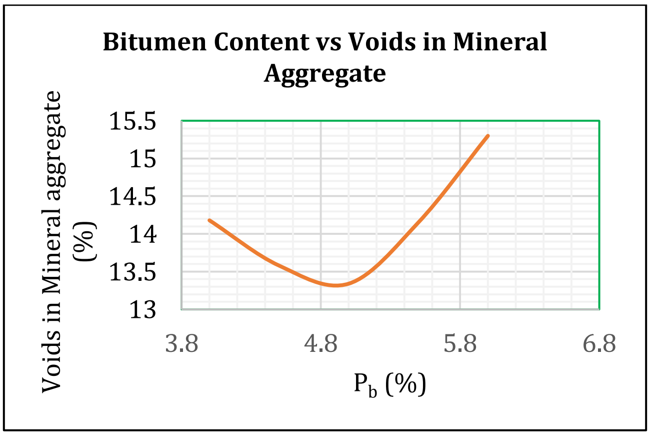

Figure-4: Plot of bitumen Content vs VMA

3.3.5. Void Filled with Bitumen (VFB)

Table below (Table 7) shows the relationship between different proportions of the bitumen and the respective VFB.

Table 7: Voids filled with Bitumen with respect to Bitumen Contents

No.	Bitumen content, P_b (%)	Voids Filled with Bitumen, VFB (%)
1	4.0	51.1
2	4.5	62.5
3	5.0	71.7
4	5.5	81.3
5	6.0	85.8

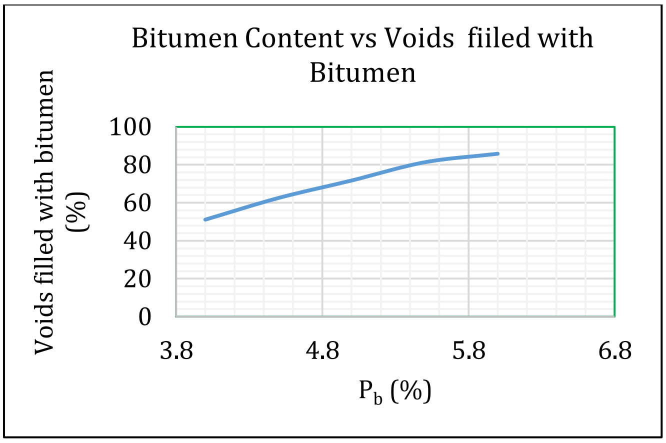

Figure-5: Plot of bitumen Content vs VFB

3.3.6. Stability

The stability of the bituminous mix measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute. Load is applied to the specimen till failure, and the maximum load is designated as stability. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) due to the loading. The flow value is recorded in 0.25 mm (0.01inch) increments at the same time when the maximum load is recorded. [2].

Table 8: Mix Stability with respect to Bitumen Contents

No.	Bitumen content, P_b (%)	Stability (KN)
1	4.0	17.5
2	4.5	17.4
3	5.0	19.0
4	5.5	16.1
5	6.0	14.7

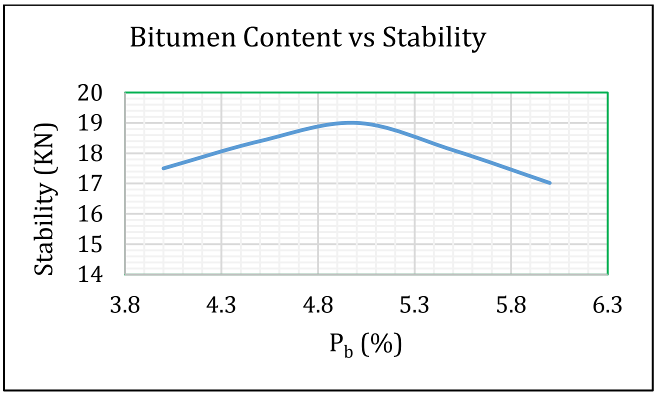

Figure-6: Plot of bitumen Content vs Mix Stability

3.3.7. Flow

Table 9: Mix Flow with respect to Bitumen Contents

No.	Bitumen content, P_b (%)	Flow (0.25 mm)
1	4.0	11.20
2	4.5	11.60
3	5.0	12.32
4	5.5	12.80
5	6.0	13.60

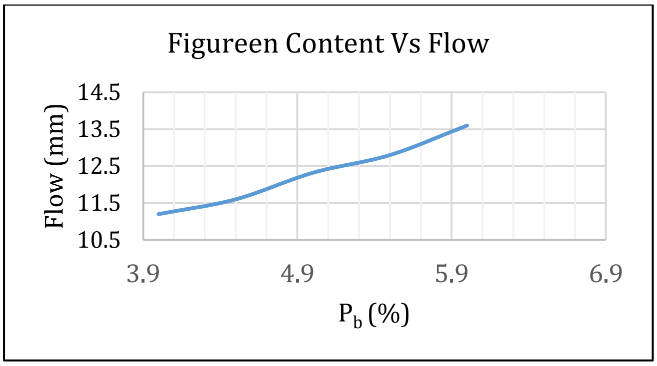

Figure-7: Plot of bitumen Content vs Mix Flow

Table 9 and Figure 7 above show the relationship between flow and bitumen content, indicating that the flow value of the specimens increase with increase in bitumen content. The rate of increase is being higher for higher proportions of bitumen.

3.4. Optimum Bitumen Content

Table 10 below presents the optimum bitumen content of the mix calculated based on the maximum bulk density, the marshal mix stability and percent air void of 4%, Mid way between 3 and 5 which are recommended as minimum and maximum respectively by the national standard.

Table 10: optimum bitumen content based on the mix Parameters

Parameter	Value at OBC	Optimum Bitumen content, OBC (%)
Bulk Density (Kg/m^3)	2263.50	5.10
Void in mix (%)	4.00	5.00
Stability (KN)	19.00	4.89
Optimum Bitumen Content (%)		5.00

3.5. Mix Properties at OBC (at 5.00%)

Table 11: Mix Parameters at optimum bitumen content

Mix Properties	Values read from graphs
VIM (%)	4.00
VMA (%)	13.35
VFB (%)	71.00
Stability (KN)	18.60
Flow (0.25mm)	12.48

3.5. Selection of Final Mix Design

The final selected mix design is usually considered as the most economical one that will satisfy all of the established criteria stated in MS-2. However, the mix should not be designed to optimize one particular property but should be a compromise selected to balance all of the mix properties. Table 12 shows the mix properties, the design criteria (as specified in MS-2) [5] and the range of bitumen content over which compliance with criteria is achieved (obtained from the graphs presented in section 3.3 above).

Table 12: Mix Parameters vs requirement range

Mix Property	MS-2 criteria	% range of bitumen content giving compliance with MS-2 criteria
VIM	3 – 5%	4.70 – 5.65
VMA	Min. of 13%	4.18 – 5.42
VFB	65% – 75%	4.83 – 5.60
Stability	Min. of 8KN	4.00 – 6.00

As can be seen from the two successive tables just above, when the mix parameter values read from graphs and tabulated in Table 12 are compared against the required intervals tabulated in Table 13 above, all the mix Parameters which are read at bitumen content of 5.00% lie well at the interval desired as per MS-2 criteria.

4. CONCLUSION

Based upon the above results, the following conclusions are drawn.

- As can be observed from the respective relationship between mix density and stability with bitumen content, both parameters increased with increase in bitumen content until the maximum is attained and further increase resulted in decrease in both parameters. Whereas VMA showed the reverse trend than the two.

- As bitumen content increased, VFB and Flow generally increased (comparatively, flow being at slightly steeper slope) and VIM showed the reverse trend than the two.

- The optimum bitumen content of the paving mix under study is 5.00%.

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