Chapter 1

Introduction

1-1General

HMA is the composite material consisting of aggregate particle with different sizes, an asphalt binder and air voids. When mineral aggregates are bound with asphalt binder, it acts as stone framework that provides strength and toughness to the system.[1]

Usually asphalt mixtures have been designed using a trial-and-error procedure to select the aggregate gradation. Aggregates are combined in "typical" percentages that were developed from years of experience. The Bailey Method is based on how the coarse and fine aggregates pack together to form a strong aggregate skeleton. The Bailey Method was developed by Robert Bailey, a retired materials engineer for the Illinois Department of Transportation. The method develops a strategy to create a strong aggregate skeleton for rut resistance, durability, and adequate voids in the mineral aggregate. A strong aggregate structure is important because the aggregate supports most of the compressive forces. [2]

The Bailey method of gradation evaluation focus on the aggregate properties that affect the way aggregates fit together (or pack) in a confined space or volume. To analyze the packing factors, the method defines four key principles that break down the overall combined aggregate blend into four distinct fractions. Each fraction is then analyzed for its contribution to the overall mix volumetric. [3]

The packing characteristics are determined by the several factors, the shape, the strength and texture of the aggregate, the combined blend gradation, and the type and amount of compaction effort.

In this way asphalt mixtures developed with the Bailey Method can have a strong skeleton for high stability and adequate VMA for good durability the predictions of VMA changes based on the Bailey parameters were reasonable for the angular aggregate, but not for the smooth aggregate evaluated in this study. [4]

1-2 Problem statement

Since the change was made in the VMA specification and air void percentage required in HMA mixture in 1995 [MS-2] in Marshall Method, and move to Superpave method, the HMA designer or practitioners faced problems to achieve desired volumetric properties without numerous trails. This has become extremely inefficient process, frustrating in the laboratory and in-economical process because of rejecting many tons of HMA in the field because of rutting or segregation and incompatibility with volumetric properties specifications.[5]

The Bailey Method can be used in combination with knowledge of the aggregate angularity, roughness, and engineering judgment to provide guidance during the mix design procedure and improve mixture performance.

Bailey method provides much needed assistance to the designer to ensure the mixes are designed to provide required volumetric properties and better performance.

1-3 Objectives and methodology

The main objective of this research project was to evaluate the applicability of Bailey method for combining aggregates to optimize aggregate interlock and provide the proper volumetric properties, which will provide rut-resistant mixture having adequate asphalt binder, and

VMA for good durability. The method applied samples provided from aggregate sources available in Khartoum state. Such a method would allow designers to accomplish the following:

1. Select design aggregate blends that provide the desired volumetric properties for long-lasting pavements;

2. Select design aggregate blends that provide the desired internal structure to resist permanent deformation during the design service life; and Select field adjustments to aggregate blends that provide the desired design volumetric and performance characteristics for long-lasting pavements.

The steps taken to meet the main objectives were as follows:-

1. Three samples of aggregates were obtained from three different sources in Khartoum state.
2. Then sieve analysis, loose unit weight, rodded unit weight and bulk density for each type of aggregates was determined.
3. Aggregate blend combination for each area sample according to Bailey Method and tradition (trial-error) method procedures (two combined aggregates for each area) was prepared.
4. Following that Marshal test for each aggregate blend which are prepared by Bailey method and tradition (trial-error) method procedures were carried on.
5. Asphalt content according to Marshal Method was obtained.
6. Then Marshal properties for each blend of aggregate were determined.
7. Recommendations, regarding the usefulness of the Bailey Method in designing better performing asphalt mixes were derived.

Usually, engineers have relied on experience to design the aggregate blend of a mix.

However, an additional analytical tool designed for dealing with aggregate blends can be useful, especially when combined with experiential knowledge. The Bailey Method is a tool that offers a simplified explanation of the mechanics of aggregate structure, a procedure for aggregate blend evaluation, and a procedure for aggregate blend design. It was initially developed by Mr. Robert Bailey, now retired, who worked with the Illinois Department of Transportation (Vavrik, et al. 2002). The Bailey Method presents a model of an aggregate matrix based on particle compaction as influenced by particle size distribution. The procedures it describes are simple and straight forward and require no fabrication of samples because it requires only aggregate data and grading's.

The evaluation portion of the method makes general predictions about the relative VMA and compactability.

However, since the Bailey Method only looks at particle size and includes very little about other aggregate properties that significantly affect the behavior of a blend, such as texture and shape, exact results cannot be expected. Although the Bailey Method doesn't require it, the designer would probably benefit from fabricating samples for verification tests.

Still, the Bailey Method along with experience can guide the direction of the mix designs, helping to quickly reach a final design that performs well under actual road conditions.

Thesis Format:-

This thesis is composed of about four chapters. It includes introduction literature review, application of Bialy Method for Designing MA using Marshall Method, and finally conclusion and recommendations.

The references used are presented in the text between two square bracket and listed order as it appears in the text.

CHAPTER 2

Literature Review

2-1 Definition of the Bailey Method

The Bailey Method is a means to design the aggregate interlock and aggregate structure in an asphalt mixture. The principles in the method can be used from the asphalt mix design through the quality control process, but are not a mix design method. The method does not address the appropriate aggregate properties or asphalt mix properties required to produce a quality asphalt mixture. This chapter describes the Bailey Method for Aggregate Selection in HMA Mixture Design.

2-2 Basic Principles

It is necessary to develop a method for combining aggregates to optimize aggregate interlock and provide the proper volumetric properties, to understand some of the controlling factors that affect the design and performance of these mixtures. The explanation of coarse and fine aggregates given in the following section provides a background for understanding the combination of aggregates.

This Method has two principles that are the basis of the relationship between aggregate gradation and mixture volumetric:

1- Aggregate packing.
2- Definition of coarse and fine aggregate.

With these principles, the two primary steps in this Method are:

- Combine aggregates by volume, and
- Analyze the combined blend.

Aggregate Packing

There are some factors that can affect the packing of aggregate particles together to fill a volume completely. There will always be space between the aggregate particles. These factors depend on:

1- Type and amount of compactive energy

Several types of compactive force can be used, including static pressure, impact (e.g., marshal hammer), or shearing (e.g., gyratory shear compactor or California kneading compactor). Higher density can be achieved by increasing the compactive effort.

2- Shape of the particles

Flat and elongated particles tend to resist packing in a dense configuration. Cubical particles tend to arrange in dense configurations.

3- Surface texture of the particles

Particles with smooth textures will reorient more easily into denser configurations. Particles with rough surfaces will resist sliding against one another.

4- Size distribution (gradation) of the particles not pack as densely

as a mixture of particle sizes.

5- Strength of the particles strength of the aggregate particles directly affects the amount of degradation that occurs in a compactor or under rollers. Softer aggregates typically degrade more than strong aggregates and allow denser aggregate packing to be achieved.

The properties listed above can be used to characterize both coarse and fine aggregates. The individual characteristics of a given aggregate, along with the amount used in the blend, have a direct impact on the resulting mix properties.

When comparing different sources of comparably sized aggregates, the designer should consider these individual characteristics in addition to the Bailey Method principles presented. Even though an aggregate may have acceptable characteristics, it may not combine well with the other proposed aggregates for use in the design. The final combination of coarse and fine aggregates, and their corresponding individual properties, determines the packing characteristics of the overall blend

for a given type and amount of compaction. Therefore, aggregate source selection is an important part of the asphalt mix design process.[3]

Coarse and Fine Aggregate

The common definition of coarse aggregate is any particle that is retained by the 4.75- mm sieve. Fine aggregate is defined as any aggregate that passes the 4.75-mm sieve (sand, silt, and clay size material). The same sieve is used for 9.5-mm mixtures as 25.0-mm mixtures.

But Bailey Method has new definition for coarse and fine is more specific in order to determine the packing and aggregate interlock provided by the combination of aggregates in various sized mixtures.

This new definitions are:

- Coarse Aggregate:

Large aggregate particles that when placed in a unit volume create voids.

- Fine Aggregate:

Aggregate particles that can fill the voids created by the coarse aggregate in the mixture.

From these definitions, more than a single aggregate size is needed to define coarse or fine. The definition of coarse and fine depends on the

nominal maximum particle size(NMPS) of the mixture.

In a dense-graded blend of aggregate with a NMPS of 37.5 mm, the 37.5-mm particles come together to make voids. Those voids are large enough to be filled with 9.5- mm aggregate particles, making the 9.5-mm particles fine aggregate. Now consider a typical surface mix with a NMPS of 9.5 mm. In this blend of aggregates, the 9.5-mm particles are considered coarse aggregate.[2]

In the Bailey Method, the sieve which defines coarse and fine aggregate is known as the primary control sieve (PCS), and the PCS is based on the NMPS of the aggregate blend. The break between coarse and fine aggregate is shown in Figure (2-1). The PCS is defined as the closest sized sieve to the result of the PCS formula in Equation (2-1).

$$PCS = NMPS \times 0.22 \qquad (2\text{-}1)$$

Where:

PCS = PCS for the overall blend

NMPS = NMPS for the overall blend, which is one sieve larger than the first sieve that retains more than 10% (as defined by Superpaveterminology)

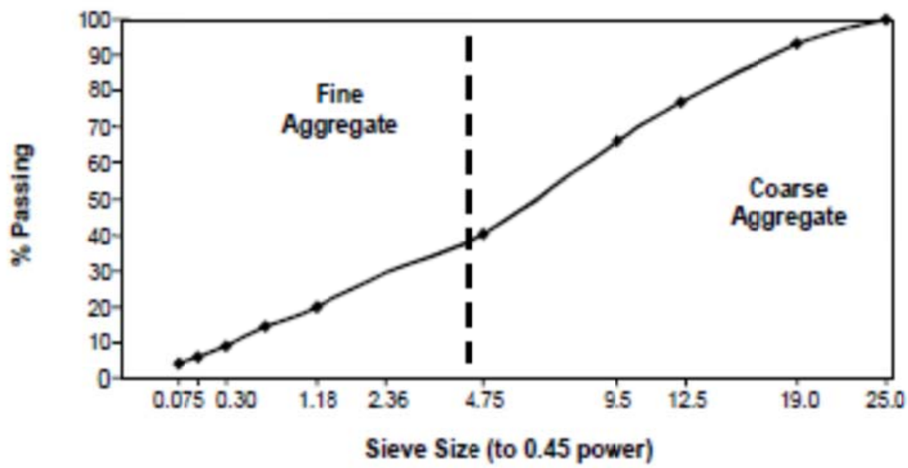


FIGURE (2- 1) Example of break between coarse and fine aggregate for 19.0 NMPS mixture.

The value of 0.22 used in the control sieve equation was determined from a two- (2- D) and three-dimensional (3-D) analysis of the packing of different shaped particles. The2-D analysis of the combination of particles shows that the particle diameter ratio ranges from 0.155 (all round) to 0.289 (all flat) with an average value of 0.22. The 3-D

analysis of the combination of particles gives a similar result with the particle diameter ratio ranging from 0.15 (hexagonal close-packed spheres) to 0.42 (cubical packing of spheres) In addition, research on particle packing distinctly shows that the packing of particles follows different models when the characteristic diameter is above or below 0.22 ratio .[3]

While 0.22 may not be exactly correct for every asphalt mixture, the analysis of gradation is not affected if the value ranges from 0.18 to 0.28.

The 0.22 factor is the average condition of many different packing configurations.

Combining Aggregates by Volume

In combining aggregates we must first determine the amount and size of the voids created by the coarse aggregates and fill those voids with the appropriate amount of fine aggregate.

Mix design methods generally are based on volumetric analysis, but for simplicity, aggregates are combined on a weight basis.

Most mix design methods correct the percent passing by weight to percent passing by volume when significant differences exist among the aggregate stockpiles.

To evaluate the volumetric combination of aggregates, additional following information must be gathered:

- For each of the coarse aggregate stockpiles, the loose and rodded unit weights must be determined.

- For each fine aggregate stockpile, the rodded unit weight must be determined.

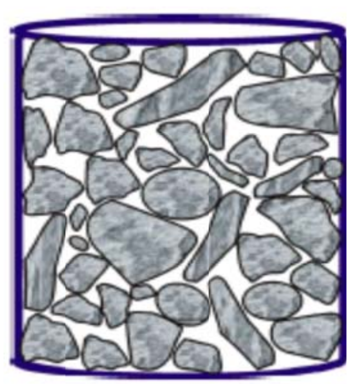


FIGURE (2-2) Loose unit weight of coarse aggregate.

Loose Unit Weight of Coarse Aggregate

It is the amount of aggregate that fills a unit volume without any compactive effort applied which is depicted in Figure (2-2).

The loose unit weight is determined on each coarse aggregate using the shoveling procedure outlined in AASHTO T-19: Unit Weight and Voids in Aggregate, which leaves the aggregate in a loose condition in the metal unit weight bucket. The loose unit weight (density in kg/m3) is

calculated by dividing the weight of aggregate by the volume of the metal bucket.

This condition represents the volume of voids present when the particles are just into contact without any outside compactive effort being applied.

Rodded Unit Weight of Coarse Aggregate

It is the amount of aggregate that fills a unit volume with compactive effort applied which is depicted in Figure (2-3).

The compactive effort increases the particle to particle contact and

decreases the volume of voids in the aggregate. The rodded unit weight is determined on each coarse aggregate using the rodding procedure outlined in AASHTO T-19: Unit Weight and Voids in Aggregate, which leaves the aggregate in a compacted condition in the metal unit weight bucket. The rodded unit weight (density in kg/m3) is calculated by dividing the weight of aggregate bythe volume of the metal bucket.

Using the aggregate bulk specific gravity and the rodded unit weight, the volume of voids for this condition is also determined. This condition represents the volume of voids present when the particles are further into contact due to the compactive effort applied.[3]

FIGURE (2- 3) Rodded unit weight of coarse aggregate.

Chosen Unit Weight of Coarse Aggregate

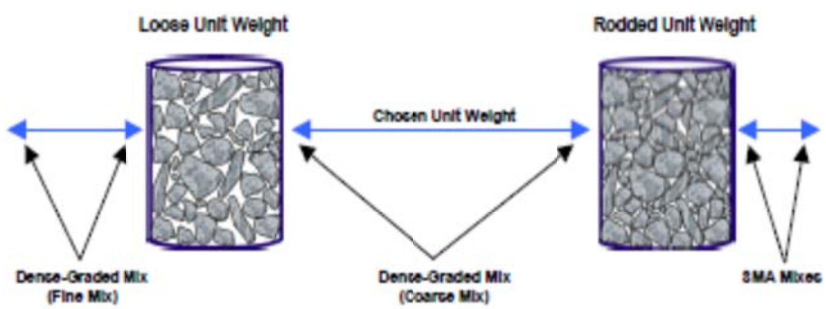
To select a chosen unit weight the designer needs to decide if the mixture is to be coarse-graded or fine-graded. Considerations for selecting a chosen unit weight are shown in Figure (2- 4).

The loose unit weight is the lower limit of coarse aggregate interlock. Theoretically, it is the dividing line between fine-graded and coarse-graded mixtures. If the mix designer chooses a unit weight of coarse aggregate less than the loose unit weight, the coarse aggregate particles are spread apart and are not in a uniform particle-to-particle contact condition. Therefore, a fine aggregate skeleton is developed and properties for these blends are primarily related to the fine aggregate characteristics.

The rodded unit weight is generally considered to be the upper limit of coarse aggregate interlock for dense-graded mixtures. This value is typically near 110% of the loose unit weight. As the chosen unit weight approaches the rodded unit weight, the amount of compactive effort required for densification increases significantly, which can make

a mixture difficult to construct in the field.

For dense-graded mixtures, the chosen unit weight is selected as a percentage of the loose unit weight of coarse aggregate. If the desire is to obtain some degree of coarse aggregate interlock (as with coarse-graded mixtures), the percentage used should range from 95% to 105% of the loose unit weight. For soft aggregates prone to degradation the chosen unit weight should be nearer to105% of the loose unit weight (*2*). Value exceeding 105% of the loose unit weight should be avoided due to the increased probability of aggregate degradation and increased difficult with field compaction.



FIGURE(2- 4) Selection of chosen unit weight of coarse aggregates.

In fine-graded mixtures, the chosen unit weight should be less than 90% of the loose unit weight, to ensure the predominant skeleton is

controlled by mixtures is presented in the section on Bailey Method

the fine aggregate structure. Additional information for fine-graded

principles and Fine-Graded Mixes.

For all dense-graded mixtures, it is recommended the designer should not use a chosen unit weight in the range of 90% to 95% of the

loose unit weight. Mixtures designed in this range have a high probability of varying in and out of coarse aggregate interlock in the field with the tolerances generally allowed on the PCS.

It is normal for an aggregate blend to consolidate more than the selected chosen unit weight due to the lubricating effect of asphalt binder. Also, each coarse aggregate typically contains some amount of

fine material when the unit weights are determined, which causes both unit weights (i.e., loose and rodded) to be slightly heavier than they would have been, had this material been removed by sieving prior to the test.

Therefore, a chosen unit weight as low as 95% of the loose unit weight

can often be used and still result in some degree of coarse aggregate interlock.

So, the amount of additional consolidation, if any, beyond the selected chosen unit weight depends on several factors:

1- Aggregate strength, shape, and texture.
2- The amount of fine aggregate that exists in each coarse aggregate when the loose and rodded unit weight tests are performed.
3- Combined blend characteristics.
4- Relation of the selected chosen unit weight to the rodded unit weight of coarse aggregate;
5- Type of compactive effort applied (Marshall, Gyratory, etc.).
6- Amount of compactive effort applied (75 versus 125 gyrations, 50 versus 75 blows, etc.).

After selecting the desired chosen unit weight of the coarse aggregate, the amount of fine aggregate required to fill the corresponding VCA is determined.

Rodded Unit Weight of Fine Aggregate

The voids created by the coarse aggregate at the chosen unit weight are filled with an equal volume of fine aggregate at the rodded unit weight condition.

The rodded unit weight is used to ensure the fine aggregate structure is at or near its maximum strength which is shown in Figure (2-5).

Rodded unit weight is determined on each fine aggregate stockpile as outlined in the rodding procedure in AASHTO T-19: Unit Weight and

voids in aggregate, which leaves the aggregate in a compacted condition in the unit weight container. For most fine aggregates, which

typically have a NMPS of 4.75 mm or less, a proctor mold, 100-mm diameter is used, which is a metal mold, approximately 0.9 liter in

volume. The rodded unit weight (density in kg/m3) is calculated by dividing the weight of the aggregate by the volume of the mold.

2-3 Determining a Design Blend

The designer should made the following decisions and used to determine the individual aggregate percentages by weight and the resulting combined blend:

1- Bulk specific gravity of each aggregate.
2- Chosen unit weight of the coarse aggregates.
3- Rodded unit weight of the fine aggregates.

4- Blend by volume of the coarse aggregates totaling 100.0%.
5- Blend by volume of fine aggregates totaling 100.0%.
6- Amount of –0.075-mm material desired in the combined blend, if MF or bag house fines are being used.

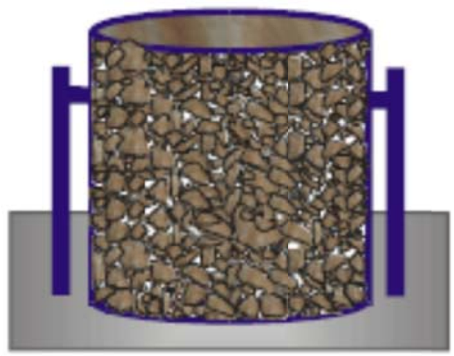


FIGURE (2- 5) Rodded unit weight of fine aggregate.

There is an example design is presented at the end this chapter, which provides the step-by step calculations required to blend a set of aggregate segregates by volume and determine the resulting combined blend by weight. Developing a computer spreadsheet to perform these calculations is relatively simple. This allows the designer to vary the

inputs for the above listed data so iterations can be made quickly to review multiple blends.

To provide a general sense of blending aggregates by volume the following steps are presented:

1. Pick a chosen unit weight for the coarse aggregates, kg/m3.

2. Calculate the volume of voids in the coarse aggregates at the chosen unit weight.

3. Determine the amount of fine aggregate to fill this volume using the fine aggregates rodded unit weight, kg/m3.

4. Using the weight (density) in kg/m3 of each aggregate, determine the total weight and convert to individual aggregate blend percentages.

5. Correct the coarse aggregates for the amount of fine aggregate they contain and the fine aggregates for the amount of coarse aggregate they

contain, in order to maintain the desired blend by volume of coarse and fine aggregate.

6. Determine the adjusted blend percentages of each aggregate by weight.

7. If MF or bag house fines are to be used, adjust the fine aggregate percentages by the desired amount of fines to maintain the desired

blend by volume of coarse and fine aggregate.

8. Determine the revised individual aggregate percentages by weight for use in calculating the combined blend.[3]

2-3 Analysis of the Design Blend

After the combined gradation by weight is determined, the aggregate packing is analyzed further. The combined blend is broken down into three distinct portions, and each portion is evaluated individually. The

1- The coarse portion of the combined blend is from the largest particle to the PCS and considered as the coarse aggregates of the blend.
2- The fine aggregate is broken down and evaluated as two portions. To determine where to split the fine aggregate, the same 0.22 factor used on the entire gradation is applied to the PCS to determine a secondary control sieve (SCS).

3- The SCS then becomes break between coarse sand and fine sand. The fine sand is further evaluated by determining the tertiary control sieve TCS), which is(determined by multiplying the SCS by the 0.22 factor. A schematic of how the gradation is divided

into three portions is given in Figure (2- 6).

An analysis is done using ratios that evaluate packing within each of the three portions of the combined aggregate gradation. Three ratios

are defined: Coarse Aggregate Ratio (CA Ratio), Fine Aggregate Coarse Ratio (FAc Ratio), and Fine Aggregate Fine Ratio (FAf Ratio).

These ratios characterize packing of the aggregates. By changing gradation within each portion modifications can be made to the volumetric properties, construction characteristics, or performance characteristics of the asphalt mixture.[3]

CA Ratio

The CA Ratio is used to evaluate packing of the coarse portion of the aggregate gradation and to analyze the resulting void structure. Understanding the packing of coarse aggregate requires the introduction

of the half sieve. The half sieve is defined as one half the NMPS.

The equation for the calculation of the coarse aggregate ratio is given in Equation (2- 2).

$$\text{CARatio} = \frac{(\text{\%Passing Half Sieve} - \text{\% Passing PCS})}{(100\% - \text{\% Passing Half Sieve})} \quad (2\text{-}2)$$

Also, a CA Ratio below the corresponding range suggested in

Table (2-1) could indicate a blend that may be prone to segregation. It is generally accepted that gap-graded mixes, which tend to have CA Ratios below these suggested ranges, have a greater tendency to segregate than mixes that contain a more continuous gradation.

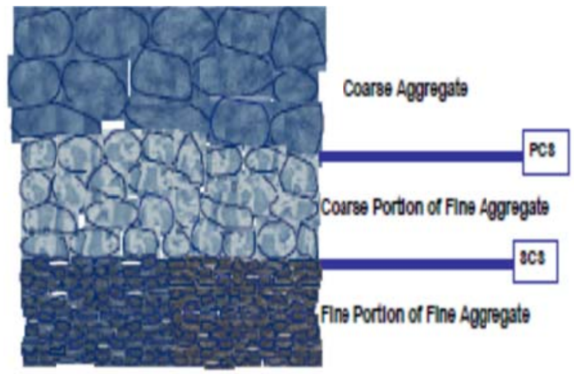


FIGURE (2- 6) Overview of the divisions in a continuous gradation that allows an analysis of gradation.

TABLE (2- 1) Recommended Ranges of Aggregate Ratios

NMPS, mm

	37.5	25.0	19.0	12.5	9.5	4.75
CA Ratio	0.80–0.95	0.70–0.85	0.60–0.75	0.50–0.65	0.40–0.55	0.30–0.45
FA_c Ratio	0.35–0.50	0.35–0.50	0.35–0.50	0.35–0.50	0.35–0.50	0.35–0.50
FA_f Ratio	0.35–0.50	0.35–0.50	0.35–0.50	0.35–0.50	0.35–0.50	0.35–0.50

NOTE: FA_c = fine aggregate coarse; FA_f = fine aggregate fine. These ranges provide a starting point where no prior experience exists for a given set of aggregates. If the designer has acceptable existing designs, they should be evaluated to determine a narrower range to target for future designs (see Evaluating Existing Mixture Designs with the Bailey Method).

Coarse Portion of Fine Aggregate

The equation that describes the fine aggregate coarse ratio (FAc) is given in Equation (2-3). As this ratio increases, the fine aggregate (i.e., below the PCS) packs together tighter.

fine portion of fine aggregate. It is generally desirable to have this ratio less than0.50, as higher values generally indicate an excessive amount

of the fine portion of the fine aggregate is included in the mixture. A FAc Ratio higher than 0.50, which is created by an excessive amount of

natural sand and/or an excessively fine natural sand should be avoided. This type of a blend normally shows a "hump" in the sand portion of the gradation curve of a 0.45 gradation chart, which is generally accepted as

an indication of a potentially tender mixture. The equation for the calculation of the FAc Ratio is given in Equation (2- 3).

$$FAc = \frac{\%\ Passing\ PCS}{\%\ Passing\ SCS} \qquad (2\text{-}3)$$

If the FAc Ratio becomes lower than the range of values in Table (2- 1), the gradation is not uniform. These mixtures are generally gap-graded and

have a "belly" in the 0.45-power grading chart, which can indicate instability and may lead to compaction problems. This ratio has a considerable impact on the VMA of a mixture due to the blending of

sands and the creation of voids in the fine aggregate.

The VMA in the mixture will increase with a decrease in this ratio.

Fine Portion of Fine Aggregate

The fine portion of the fine aggregate fills the voids created by the coarse portion of the fine aggregate. This ratio shows how the fine portion of the fine aggregate packs together. One more sieve is needed to calculate

The FAf, the TCS. The TCS is defined as the closest sieve to 0.22 times the SCS. The equation for the FAf Ratio is given in Equation (2- 4).

$$FA = \frac{\%\ \text{Passing SCS}}{\%\ \text{Passing TCS}} \qquad (2\text{- }4)$$

The FAf Ratio is used to evaluate the packing characteristics of the smallest portion of the aggregate blend. Similar to the FAc Ratio, the value of the FAf Ratio should be less than 0.50 for typical dense-graded mixtures. VMA in the mixture will increase with a decrease in this ratio.

The Summary of Ratios

1- CA Ratio—This ratio describes how the coarse aggregate particles pack together and, consequently, how these particles compact the fine aggregate portion of the aggregate blend that fills the voids created bythe coarse aggregate.
2- FAc Ratio—This ratio describes how the coarse portion of the fine aggregate packs together and, consequently, how these particles compactthe material that fills the voids it creates.
3- FAf Ratio—This ratio describes how the fine portion of the fine aggregate packs together. It also influences the voids that will remain the overall fine aggregate portion of the blend because it represents the particles that fill the smallest voids created.

These ratios are valuable for evaluating and adjusting VMA. Once an initial trial gradation is evaluated in the laboratory, other gradations can be evaluated on paper to choose a second trial that will have an increased or decreased VMA as desired. When doing the paper

analysis, the designer must remember that changes in particle shape, strength and texture must be considered as well. The ratios are calculated from the control sieves of an asphalt mixture, which are tied to the NMPS. Table 2 provides the listing of control sieves for various asphalt mixture sizes. The values in determining the aggregate ratios are the percent passing the control sieves for the final combined blend. The recommended range for the ratios is shown in table (2-1).

TABLE (2- 2) Control Sieves for Various Asphalt Mixes

	NMPS, mm					
	37.5	25.0	19.0	12.5	9.5	4.75
Half Sieve	19.0	12.5	9.5	**	4.75	2.36
PCS	9.5	4.75	4.75	2.36	2.36	1.18
SCS	2.36	1.18	1.18	0.60	0.60	0.30
TCS	0.60	0.30	0.30	0.150	0.150	0.075

** The nearest "typical" half sieve for a 12.5-mm NMPS mixture is the 4.75 mm. However, the 6.25 mm sieve actually serves as the breakpoint. Interpolating the percent passing value for the 6.25-mm sieve for use in the CA Ratio will provide a more representative ratio value.

Effect of Chosen Unit Weight Changes

Increasing the chosen unit weight above the loose unit weight will cause an increase in the air voids and VMA of the resulting mixture. The air

voids increase because of additional volume of coarse aggregate in the mixture, which increases aggregate interlock and resists compaction.

The actual amount of increase in VMA with changes in chosen unit weight will depend on aggregate shape and texture.

In a mixture with a coarse aggregate skeleton an increase of 5% in the chosen unit weight will increase VMA by 0.5 to 1.0%. In a fine-graded mixture (chosen weight less than 90% of loose unit weight) changes in the chosen unit weight will not have a significant effect on VMA because there is no coarse aggregate skeleton.

Increases in the chosen unit weight will also affect the compactability of the mixture, both in the lab and in the field. As the chosen unit weight is increased, additional coarse aggregate is designed in the blend. This additional volume of coarse aggregate locks together under compactive

effort and resists compaction. High chosen unit weight values may lead to strong mixes in the lab and field, but will be difficult to construct if taken too far.

Changing the chosen unit weight changes the percent passing the PCS in the final combined blend. During production extreme care should be taken to maintain consistency in the percent passing the PCS, especially for coarse-graded mixtures. Swings in the percent passing

the PCS will cause changes in the degree of coarse aggregate interlock, the amount of voids, and constructability of the mixture. Changes to the

percent passing the PCS are effectively changing the chosen unit weight.

Deliberate change to the chosen unit weight during construction is an

appropriate method to change the constructability of the mixture.[3]

Effect of CA Ratio Changes

The CA Ratio has a significant effect on the volumetric properties of the HMA mixture. This ratio describes the balance between the larger particles and the interceptor particles in the coarse portion of the aggregate structure. Changes in this balance change the compactability

of the mixture in both the lab and field conditions.

An increase in the CA Ratio will cause a corresponding increase in the air voids and VMA. This increase happens because more interceptor-sized aggregate particles are in the coarse portion of the aggregate structure, helping it to resist densification.

The actual amount of increase in VMA with changes in coarse aggregate ratio will depend on aggregate shape and texture. In coarse-graded mixtures an increase of 0.2 in the CA Ratio will create an increase of 0.5 to 1.0% VMA.

In addition to the effect on the volumetric, the CA Ratio can indicate possible construction problems. If the CA Ratio is too low,

the mixture will be prone to segregation. Segregation causes the road to have areas of excess coarse aggregate, which will decrease the service

life of the asphalt pavement. If the CA Ratio nears or goes above 1.0, the coarse aggregate region of the blend becomes unbalanced and neither size (large particles or interceptors) is controlling the coarse aggregate structure. This may cause the mixture to move during compaction, allowing the mat to widen.

Effect of FAc and FAf Ratio Changes

The FA Ratios have an effect on the volumetric properties of the HMA mixture. Increases in these ratios cause a decrease in the air voids and

VMA in the mixture. As these ratios increase, the packing of the fine

aggregates becomes more dense and the voids in the mixture decrease.

The actual amount of increase in VMA with changes in FAc Ratio will depend on aggregate shape and texture. A decrease of 0.05 in the FAc

Of FAf Ratio will create an increase of 0.5 to1.0% VMA.

Bailey Method Parameters

The design and analysis of an aggregate blend using the Bailey Method of gradation selection is built on four parameters:

1- Chosen unit weight describes interlock of the coarse aggregate.
2- CA Ratio describes gradation of the coarse aggregate.
3- FAc Ratio describes the gradation of the coarse portion of the fine aggregate.
4- FAf Ratio describes the gradation of the fine portion of the fine aggregate.[3]

Any Change in these parameters will affect the air voids, VMA, constructability, and performance of the resulting asphalt mixture.

These changes are the same whether the change is made in the laboratory during design or the field during construction.

When making changes to gradation, the designer must be aware of the effect of changing other aggregate properties such as shape, texture, or hardness, i.e. decreasing the amount of natural sand, increasing the amount of manufactured sand, or increasing the amount of soft aggregate in the blend.

2-4 Example Bailey Method Design Calculations

	Coarse Aggregate Number			Fine Aggregate Number			Mineral Filler
	CA-1	CA-2	CA-3	FA-1	FA-2	FA-3	
Material Grade	Coarse	Intermediate		Slag Sand			MF

	Design Value	Specification
CA Chosen Weight as % of Loose Weight	103	95 – 105
Desired % Pass 0.075 mm	4.5	3.5 – 6.0

Coarse Aggregate Blend by Volume		
25.0	75.0	
Above blending % must sum to 100		100.0

Fine Aggregate Blend by Volume		
100.0		
Above blending % must sum to 100		100.0

Combined Bulk Specific Gravity of All Aggregates	2.888
Total Volume of Coarse Aggregate	53.7
Total Volume of Fine Aggregate	46.3

Aggregate Properties	CA-1	CA-2	CA-3	FA-1	FA-2	FA-3	MF
19.0	100.0	100.0		100.0			100.0
12.5	94.0	100.0		100.0			100.0
9.5	38.0	99.0		100.0			100.0
4.75	3.0	30.0		99.0			100.0
2.36	1.9	5.0		79.9			100.0
1.18	1.8	2.5		48.8			100.0
0.60	1.8	1.9		29.0			100.0
0.30	1.8	1.4		14.2			100.0
0.15	1.8	1.3		8.8			98.0
0.075	1.7	1.2		3.0			90.0

	CA-1	CA-2	CA-3	FA-1	FA-2	FA-3	MF
Bulk Spec. Gr.	2.702	2.698		3.162	3.162		2.806
Apparent Gr.	2.812	2.812		3.600	3.600		2.806
% Absorp.	1.452	1.502		3.844	3.844		
Loose Weight kg/m³	1426	1400					
Rodded Weight kg/m³	1608	1592		2167	2167		

FIGURE (2- 7) An example of a design using two coarse aggregates, one fine aggregate, and MF.

Figure (2- 7) provide an example of a design using two coarse aggregates, one fine aggregate, and MF. This design uses aggregates of different specific gravity to show how aggregates are blended together by volume. [3]

Solution

Step 1

Determine the chosen unit of weight for each aggregate according to the loose unit weight for each coarse aggregate and the overall coarse aggregate chosen unit weight for the mixture. The chosen unit weight for the fine aggregates is simply the rodded weight of that aggregate.

Calculation

Multiply the loose unit weight percent for each coarse aggregate by the coarse aggregate chosen unit weight for the mixture.

Equation

Coarse aggregate chosen unit weight = loose unit weight □desired percent of loose unit weight

CA # 1: Chosen unit weight = 1425 kg/m3 *103% = 1469 kg/m3 (2-1a)

CA # 2: Chosen unit weight = 1400 kg/m3 *103% = 1441 kg/m3 (2-1b)

Step 2

Determine the unit weight contributed by each coarse aggregate according to the desired proportions (by volume) of coarse aggregate.

Calculation

Multiply the blend percent of coarse aggregate by the chosen unit weight of each aggregate.

Equation

Contribution = percent coarse aggregate □chosen unit weight

CA # 1: Contribution = 25% *1469 kg/m3 = 367 kg/m3 (2-2a)

CA # 2: Contribution = 75% *1441 kg/m3 = 1081 kg/m3 (2-2b)

Step 3

Determine the voids in each coarse aggregate according to its corresponding chosen unit weight and contribution by volume.

Then sum the voids contributed by each coarse aggregate.

Calculation

First calculate one minus the chosen unit weight divided by the bulk specific gravity and density of water. Multiply the result by the percent of coarse aggregate blend. Then, sum the contribution of each coarse aggregate.

Equation

Voids in CA = {1-(chosen unit weight)/ (Gsb*1000)}*Blend %

Where Gsb = bulk specific gravity.

CA#1: Voids in CA#1={1-(1468)/(2.702*1000)}*25.0=11.4 (2-3a)

CA#2: Voids in CA#2={1-(1441)/(2.698*1000)}*75.0=34.9 (2-3b)

Total Voids in CA#1 + Voids in CA#2 = 11.4 +34.9 = 46.3(2-3c)

Step 4

Determine the unit weight contributed by each fine aggregate according to the desired volume blend of fine aggregate. This is the unit weight that fills the voids in the coarse aggregate.

Calculation

Multiply the fine aggregate chosen unit weight by the volume percentage of this aggregate in the fine aggregate blend and multiply this by the

total percentage of coarse aggregate voids from (2-3c).

Equation

Contribution of each fine aggregate = fine aggregate chosen unit weight □% fine aggregate blend *% voids in coarse aggregate.

FA #1: Contribution = 2167 kg/m3 *100% *46.3% = 1002 kg/m3 (2-4)

Note: If there is more than one fine aggregate the calculation is repeated for each fine aggregate.

Step 5

Determine the unit weight for the total aggregate blend.

Calculation

Sum the unit weight of each aggregate.

Equation

Unit weight of blend = (2-2a) + (2-2b) + (3-4)

Unit weight of blend = 367 + 1081 + 1002 = 2450 kg/m3 (2-5)

Step 6

Determine the initial blend percentage by weight of each aggregate.

Calculation

Divide the unit weight of each aggregate by the unit weight of the total aggregate blend.

Equation

Percent by weight = unit weight of aggregate/unit weight of blend

CA #1: % by weight = 367 /2450 = 0.150 = 15.0 % (2-6a)

CA #2: % by weight = 1081 /2450 = 0.441 = 44.1 % (2-6b)

FA #1: % by weight = 1002 /2450 = 0.409 = 40.9 % (2-6c)

These initial estimates of stockpile splits are based on the choice of how much coarse aggregate to have in the mixture. The initial estimates of stockpile splits will be adjusted to account for fine aggregate particles in the coarse aggregate stockpiles and coarse aggregate particles in the fine aggregate stockpiles.

Step 7

In a 12.5-mm NMPS mixture, the CA/FA break (PCS) is the 2.36-mm sieve.

Calculation

For the coarse aggregate stockpiles, determine the percent passing the 2.36-mm sieve. For the fine aggregate stockpiles, determine the percent retained on the 2.36-mm sieve.

CA #1: % fine aggregate = 1.9% (2-7a)

CA #2: % fine aggregate = 5.0% (3-7b)

FA #1: % coarse aggregate = 100.0% – 79.9% = 20.1% (2-7c)

Step 8

Determine the fine aggregate in each coarse stockpile according to its percentage in the blend.

Calculation

For each coarse aggregate stockpile determine the percent passing the 2.36-mm sieve as a percentage of the total aggregate blend.

Equation

Percent fine aggregate in blend = Coarse stockpile percent of blend percent fine aggregate in coarse stockpile.

CA #1: Percent fine aggregate in blend = 15.0% *1.9% = 0.3% (2-8a)

CA #2: Percent fine aggregate in blend = 44.1% *5.0% = 2.2% (2-8b)

Step 9

Sum the percent of fine aggregate particles in all the coarse aggregate stockpiles.

All CAs: Percent fine aggregate in blend = 0.3% + 2.2% = 2.5% (2-9)

Step 10

Determine the coarse aggregate in each fine stockpile according to its percentage in the blend.

Calculation

For each fine aggregate stockpile determine the percent retained on the 2.36-mm sieve as a percentage of the total aggregate blend.

Equation

Percent coarse aggregate in blend = Stockpile percent of blend percent coarse aggregate in fine stockpile.

FA #1: Percent coarse Agg. in blend = 40.9% *20.1% = 8.2% (2-10)

Step 11

Sum the percent of fine aggregate particles in all the coarse aggregate stockpiles.

All FAs: Percent fine aggregate in blend = 8.2% (2-11)

Step 12

Correct the initial blend percentage of each coarse aggregate to account for the amount of fine aggregate it contains and coarse aggregate contributed by the fine aggregate stockpiles.

Equation

Adjusted stockpile percent in blend = (initial %) + (FA in CA)-{(initial %*Sum CA in FA)/ (Total% of CA)}

CA #1:

Adjusted stockpile percent in blend = (15.0%) + (0.3%) -{(15%*8.2%) /(15% +44.1)} = 13.2% (2-12a)

CA #2:

Adjusted stockpile percent in blend = (44.1%) + (2.2%) -{(44.1%*8.2%) /(15% +44.1)} = 40.2% (2-12b)

Step 13

Correct the initial blend percentage of each fine aggregate to account for the amount of coarse aggregate it contains and fine aggregate contributed by the coarse aggregate stockpiles.

Equation

Adjusted stockpile percent in blend

= (initial %)+ (CA in FA)-{ (initial %*SumFA in CA)/(Total% of FA)}

FA #1: Adjusted stockpile percent in blend

= (40.9%) + (8.2%) –{(40.9%*2.5%)/(40.9%)} = 46.7% (2-13)

The next steps will determine whether MF will be needed to bring the percent passing the0.075-mm sieve to the desired level.

Step 14

Determine the amount of –0.075-mm material contributed by each aggregate using the adjusted stockpile percentages.

Calculation

Multiply the percent passing the 0.075-mm sieve for each aggregate by the adjusted blend percentage for each aggregate.

Equation

Percent contribution of 0.075-mm sieve for each stockpile = adjusted stockpile percent □percent passing 0.075-mm sieve for that stockpile.

CA #1: Percent contribution 0.075 mm = 13.2% *1.7% = 0.2% (2-14a)

CA #2: Percent contribution 0.075 mm = 40.2% *1.2% = 0.5% (2-14b)

FA #1: Percent contribution 0.075 mm = 46.7% *3.0% = 1.4% (2-14c)

Step 15

Determine the amount of mineral filler required, if any, to bring the percent passing the 0.075-mm sieve to the desired level. For this mixture the desired amount of –0.075-mm material is 4.5%.

Equation

Percent of MF = {(% 0.075 mm desired-% 0.075 mm in blend)/ (% 0.075 mm in filler)}

MF: Percent MF= {(4.5-2.1)/ (90%)} = 2.7% (2-15)

Step 16

Determine the final blend percentages of fine aggregate stockpiles by adding the percent MF to the fine aggregate. In this step the blend percentage of CA is not changed. The blend percentage of FA is adjusted to account for the MF.

Equation

Final blend percent for fine agg =

Adjusted blend percent - {(% FA +% MF)/ (Total % FA)}

FA #1: Final blend percent = 46.7 %-{(46.7*2.7%)/ (46.7)} = 44.0 (2-16)

Results

The *final blending* percentages are taken from the following equation results:

Agg	Equation	Result %
CA#1	12a	13.2
CA#2	12b	40.2
FA#1	16	44.0
MF	15	2.7

CHAPTER 3

Application of Bailey Method for Designing HMA using Marshall Method.

3-1 Introduction to Marshall:

The Objective of hot mix asphalt (HMA) mix design is to determine the combination of asphalt cement and aggregate that will give long lasting performance as part of the pavement structure. Mix design involves laboratory procedures developed to establish the necessary proportion of materials for use in the HMA. These procedures include determining an appropriate blend of aggregate sources to produce a proper gradation of mineral aggregate, and selecting the type and amount of asphalt cement to be used as the binder for that gradation. Well-designed asphalt mixtures can be expected to serve successfully many years under variety of loading and environmental conditions.[6]

The mix design of hot mix asphalt is just the starting point to assure that an asphalt concrete pavement layer will perform as required. Together with proper construction practice, mix design is an important step in achieving well – performing asphalt pavements. In many cases, the cause of poorly – performing pavements has been attributed to poor or inappropriate mix design or to the production of a mixture different from what was designed in the laboratory. Correct mix design involves adhering to an established set of laboratory techniques and design criteria. These techniques and criteria serve as the design philosophy of the governing agency. They are based on scientific research as well as many years of experience in observing the performance of asphalt concrete pavements. It is critical that these laboratory methods be followed exactly as written.

Successful mix design requires understanding that basic theory behind the steps and following the intent of the written instruction. It also includes having the proper training in laboratory techniques and effectively interpreting the results of laboratory tests. This manual was prepared with these goals in mind. It contains the latest information for the design of hot – mix asphalt paving mixtures to meet the demands of modem traffic conditions and to ensure optimal performance of asphalt concrete pavements.[6]

The corresponding guidelines and procedures for selecting the design asphalt content, many of these calculations and guidelines are included in the Asphalt Institute *Computer Assisted Asphalt Mix Analysis*

computer program.

Each mix design method and the corresponding test criteria are presented without any specification requirements for materials and construction.

The compaction method and the level of compaction energy approximate the degree of compaction that will exist in the pavement after several years of traffic.

The design asphalt content is chosen to provide for all of the mix components (asphalt, aggregate, and air) to be in correct proportion at this point in time.

The Marshall and Hveem methods of mix design are both widely used for the design of hot mix asphalt. The selection and use of either of these mix design methods is principally a matter of engineering preference, since each method has certain unique features and apparent advantages.

Both methods are currently being used with satisfactory results when all of the principles of proper mix analysis are observed.

The durability of aggregates and asphalt-aggregate compatibility can be a major concern in some cases.

As stated earlier, laboratory mix design is just the starting point of the process. To ensure that the mix being placed in the pavement is the same as the mix designed and evaluated in the lab, field verification and quality control are essential.

Hot Mix Defined:

Hot mix asphalt paving materials consist of a combination of aggregates that are uniformly mixed and coated with asphalt cement, To dry the aggregates and obtain sufficient fluidity of the asphalt cement for proper mixing and workability, both must be heated prior to mixing – giving origin to the term 'hot-mix.'[3]

The aggregates and asphalt are combined in an asphalt mixing facility, continuously or in batch-mode. These two main components are heated to proper temperature proportioned, and mixed t0 produce the desired paving material. After the plant mixing is compete, the hot-mix is transported to the paving site and spread with a paving machine in a partially-compacted layer to a uniform, smooth surface. While the paving mixture still hot, it is further compacted by heavy self-propelled rollers to produce a smooth, well-consolidated course of asphalt concrete.

CLASSIFCATION OF HOT MIX ASPHALT PAVING:

Asphalt paving mixes may be designed and produced from a wide range of aggregate blends, each suited to specific uses. The aggregate composition typically varies in size from course to fine particles. Many different compositions are specified throughout the world – the mixes

designated in any given locality generally are those that have proven adequate through long-term usage and, in most cases, these grading should be used.

For a general classification of mix composition, the Asphalt Institute recommends consideration of mix designations and nominal maximum size of aggregate; 37.5 mm(1-1/2 in.), 25.0mm (1 in.), 19.0mm (3/4 in.),

12.5mm (1/2 in.), 9.5mm (3/8 in) 4.75mm (No. 4), and 1.18mm (No. 19), as specified in the American Society for testing and Materials (ASTM)Standard Specification D 3515 for *Hot-Mixed*.

Hot-laid Bituminous Paving Mixtures. The grading ranges and asphalt content Limits of these uniformly-graded dense mixes generally agree with overall practice but may vary from the practice of a particular local area.

Depending on the specific purpose of the mix, other non-uniform grading has been used with great success, such as gap-graded and open-graded aggregate composition.

The design philosophy and construction procedures of these mixes are different because of the additional void space incorporated between the larger particles. The design procedures in this manual should not be used for gap-graded or open-graded asphalt mixtures.

Mix Design Practice:

Asphalt paving mix design demands attention to the details outlined in standard test procedures. Primarily, this means following specific, written instruction. But it also means having proper training in laboratory technique and the relation of mix design testing to pavement field specification requirements.

While mix design often is treated as an isolated subject, it cannot be separated from the other related items of the material specifications. It is the purpose of this chapter, therefore, to cite the general objectives of mix design and present a guide for applying the mix design principles to asphalt paving construction specifications.

OBJECTIVES OF ASPHALT PAVING MIX DESIGN:

The design of asphalt paving mixes, as with other engineering materials designs, is largely matter of selecting and proportioning materials to obtain the desired properties in the finished construction product. *The overall objective for the design of asphalt paving mixes is* to determine (within the Limits of the project specifications) *a cost-effective blend and gradation of aggregates and asphalt* that yields a mix having;

(1) Sufficient asphalt to ensure a durable pavement.

(2) Sufficient mix stability to satisfy the demands of traffic without distortion or displacement.

(3) Sufficient voids in the total compacted mix to allow for a slight amount of asphalt expansion due to temperature increases without flushing, bleeding, and loss of stability.

(4) A maximum void content to limit the permeability of harmful air and moisture into the mix.

(5) Sufficient workability to permit efficient placement of the mix without segregation and without sacrificing stability and performance.

(6) For surface mixes, proper aggregate texture and hardness to provide sufficient skid resistance in unfavorable weather conditions.[6]

The final goal of mix design is to select a unique design asphalt content that will achieve a balance among all of the desired properties. Ultimate pavement performance is related to durability, impermeability, strength, stability, stiffness, flexibility, fatigue resistance, and workability. Within this context, there is no single asphalt content that will maximize all of these properties.

Instead, asphalt content is selected on the basis of optimizing the properties necessary for the specific condition.

Since the fundamental performance properties are not directly measured in a normal mix design, asphalt content is selected on the basis of a measured parameter that best reflects all of these desires. Considerable research has determined that air void content is this parameter. An acceptable air voids range of three to five percent is most often used. Within this range, four percent air voids is often considered the best initial estimate for a design that balances the desired performance properties. Slight refinements are then considered in the analyses of the mix testing results. [6]

Mix Type Selection:

Dense-graded HMA mixtures are generally divided into three major categories dependent upon their specific use; surface mixtures, binder or intermediate mixtures, are typically designed with layer thickness and availability of aggregates in mind. The maximum size aggregate is generally largest in the base, smaller in the binder or intermediate course, and finest in the surface course; however, this practice is not universal. Nevertheless, any properly designed HMA mix can generally serve at any level in the pavement. Surface course mixtures may become "binder" mixes if subsequently overlaid so strength requirements should not be compromised regardless of the location of the mix within the pavement. [6]

Generally, there is no single, uniform standard set of HMA classifications used by the various public agencies. There are similarities with respect to mixture types, but the geographic availability of materials and different climatic design requirements have led to various identifications. Each agency usually has its own designation for identifying various mixture types.

While most HMA mixtures have a typical design use, these mixes offer a wide range of performance characteristics and there is substantial overlap of mixture application.

This article describes the various types of HMA mixtures and typical applications. One national standard that identifies HMA according to maximum aggregate size and gradation is ASM D 3515, Standard Specification for hot-Mixed, Hot-laid bituminous paving Mixtures.

The aggregate gradations given in the various figures have been taken from this specification. Table 2.1 presents the dense-graded mixture gradations from ASTM D 3515. HMA mix types can generally be narrowed down to discussions of the mixture gradation (dense-graded or open-graded) and the maximum aggregate size (sand-asphalt up to "large-stone" mixes).

Depending on the gradation, pavement layers are confined to practical minimum and maximum lift thicknesses. The minimum thickness for a surface mix usually varies from 2 to 3 times the maximum aggregate size; however, the actual minimum thickness of any course is that which can be demonstrated to be laid in a single lift and compacted to the requited uniform density and smoothness. The maximum lift thickness is usually governed by the ability of the rollers to achieve the specified compaction for that layer.

Development and application:

- Developed by Bruce Marshall, in Mississippi state highway department.
- U.S.A army of Engineer added certain features to the test procedure through correlation studies.
- Standardized by ASTM under the designation ASTM D1559 “Resistance to plastic flow of bituminous mixtures using Marshall apparatus”.
- The method initially applicable only to hot mixed asphalt mixtures containing aggregates with maximum sizes 25 mm (1”) or less.
- A modified Marshall method is proposed for aggregate size up to 37.5 mm (1.5”).
- The Marshall method is an empirical design method, so the test procedure should be followed without any modification.

Outline of method:

Steps preliminary to specimen preparation are:

- All material proposed for use should meet the physical requirements of the project specifications.
- Aggregate blend combinations meets the gradation requirement of the project specifications.
- For performing density and void analysis, the bulk specific aggregates used in blend and the specific gravity of asphalt cement are determined.[6]

Blending of Aggregates:

Determining the proportions of two or more aggregates to achieve gradation within specification limits by using one of the following method:-

1-Graphical method

2-Numerical Method

3-Trial and Error

4-Basic Formula

The two principal features of the Marshall method of mix design are density-voids analysis and a stability-flow test of compacted test specimens.

The stability is the maximum load resistance in (N), or (Kg), or (lb) that the standard test will develop at 60°. The flow is the total movement of strain, in units of 0.25mm.[6].

3-2 Marshal Test Procedure

In the Marshall method, each compacted test specimen is subjected tests and analysis in the order listed:

(a) Bulk Specific Gravity Determination.

(b) Stability and Flow Test.

(c) Density and Voids Analysis.

Preparation of test specimens:

A series of test specimens should be prepared for a range of different asphalt contents so that the test data curves show well defined relationships, the test specimens prepared by increasing asphalt content by 0.5 % difference between each specimen and the one that follow it. The total range of asphalt content should cover the expected optimum asphalt content, *(i.e. two percent increment before and after).*

Prepare at least three specimens for each combination of aggregate and asphalt content.

Preparation of aggregate: dry the aggregate to constant weight at 105°C.

Determine mixing and compaction temperature from standard viscosity curve at 170±20 centistokes and 280±30 centistokes respectively.

Estimation of initial binder content

The expected design asphalt content can be calculated based on experience, or computational formula. One of the computational formula is:

$$P = 0.035a + 0.045b + KC + F$$

P= approximate asphalt content of the mix.

a= % of mineral aggregate retained on No. (8).

b = % of mineral aggregate passing No. (8) and retained on No. (200) sieves.

K = 0.15 for 11-15% passing No. (200).

k = 0.18 for 6-10% passing No. (200)

k = 0.2 for 5 % or less passing No. (200).

F= 0 - 0.2 % based on aggregate absorption (normally taken 0.7%).

c= percent passing NO. (200)

EQUIPMENT :

The equipment required for the testing of the 102 mm (4 in.) diameter x 64 mm (2 1/2 in.) height specimens is:

*(a) Marshall testing machine, a compression testing device. It is designed to apply loads to test specimens through cylindrical segment testing heads (inside radius of curvature of 51 mm (2 in.)) at a constant rate of vertical strain of 51 mm (2 in.) per minute. Two perpendicular guide posts are included to allow the two segments to maintain horizontal positioning and free vertical movement during the test. It is equipped with a calibrated proving ring for determining the applied testing load, a Marshall flow meter for determining the amount of strain at the maximum load in the test. A universal testing machine equipped with suitable load and deformation indicating devices may be used instead of the Marshall testing frame.

*(b) Water bath, at least 150 mm (6 in.) deep and thermostatically-controlled to 60 C $\pm$ 1 C (140 F $\pm$ 1.8 F). The tank should have a perforated false bottom or be equipped with a shelf for suspending specimens at least 50 mm (2 in.) above the bottom of the bath.

BULK SPECIFIC GRAVITY DETERMINATION:

The Bulk specific gravity test may be performed as soon as the freshly-compacted specimens have cooled to room temperature. This test is performed according to ASTMD 1188, Bulk Specific gravity of Compacted Bituminous Mixtures Using Paraffin-coated Specimens or ASTMD 2726, Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens.

STABILITY AND FLOW TESTS:

After the bulk specific gravity of the test specimens have been determined; the stability and flow tests are performed:

(a) Immerse specimen in water bath at 60 C ± 1 C (140 F ± 1.8 F) for 30 to 40 minutes before test.

(b) "Zero" the flow meter by inserting a 101.6 mm (4.00 in.) diameter metal cylinder in the testing head, placing the flow mter over the guide rod and adjusting the flow meter to read "zero".

(Note: This adjustment should be made on the guide post marked with an "O" and with the side of the upper segment of the testing head marked with an "O" being placed on the same side as the guide post so marked.

The same assembly of testing head and flow meter must then be used in testing the specimens. Specimens should be 101.6 ± 025 mm [4.00 in. ± 0.01 in.]; otherwise, an initial and final reading of flow meter is required for the determination of the flow value.

(c) Thoroughly clean the inside surfaces of testing head. Temperature of head shall require. Lubricate guide rods with a thin film of oil so that upper test head will slide freely without binding. If a proving ring is used to measure applied load, check to see that dial indicator is firmly fixed and "zeroed" for the "no-load" position.

(d) With testing apparatus ready, remove test specimen from water bath and carefully dry surface.

Place specimen in lower testing head and center; then fit upper testing head into position and center complete assembly in loading device. Place flow meter over marked guide rod as noted in (b) above.

(e) Apply testing load to specimen at constant rate of deformation, 51mm (2 in.) per minute, until failure occurs. The point of failure is defined by the maximum load reading obtained. The total number of Newton's (lb.) required to produce failure of the specimen shall be recorded as its Marshall Stability value.

(f) While the stability test is in progress, if not using an automatic recording device, hold the flow meter firmly in position over guide rod and remove as the load begins to express in units of 0.25 mm (1/100 in.). For example, if the specimen deformed 3.8 mm (0.15 in.) the flow value is 15.

DENSITY AND VOIDS ANALYSIS:

After the completion of the stability and flow test, a density and voids analysis is made for each series of test specimens:

(a)Average the bulk specific gravity values for all test specimens of given asphalt content; values obviously in error shall not be included in the average. These values of bulk specific gravity shall not be used in further

computations of voids data.

(b) Determine the average unit weight for each asphalt content by multiplying the average bulk specific gravity value by the density of water [1,000 kg/m3 (62.4 pcf)].

(c) Determine theoretical maximum specific gravity (ASTMD2041) for at least two asphalt contents, preferably on mixes at or near the design asphalt content. An average value for the effective specific gravity of the total aggregate is then calculated from these values. This value may then be used for calculation of the maximum specific gravity of mixtures with different asphalt contents.

(d) Using the effective and bulk specific gravity of the total aggregate, the average bulk specific gravities of the compacted mix, the specific gravity of the asphalt, and the maximum specific gravity of the mix determined above in (c), calculate the percent absorbed asphalt by weight of dry aggregate, percent air voids (Va), percent voids filled with asphalt (VFA) and percent voids in mineral aggregate (VMA).

PREPARATION OF TEST DATA – Prepare the stability and flow values and void data:

(a) Measured stability values for specimens that depart from the standard 63.5 mm (2 1/2 in.) thickness shall be converted to an equivalent 63.5 mm (2 1/2 in.) value by means of a conversion factor.

Applicable correlation ratios to convert the measured stability values are set forth in Table 5-3 Note that the conversion may be made on the basis of either measured thickness or measured volume.

(b) Average the flow values and the final converted stability values for all specimens of given asphalt content. Values that are obviously in error shall not be included in the average.

(c) Prepare a separate graphical plot for these values and connects plotted points with a smooth curve that obtains the "best fit" for all values.

Stability vs. Asphalt Content

Flow vs. Asphalt Content

Percent Air Voids (Va) vs. Asphalt Content

Percent Voids Filled with Asphalt (VFA) vs. Asphalt Content

Percent Voids Mineral Aggregate (VMA) vs. Asphalt Content

These graphs are used to determine the design asphalt content of the mix.

TABLE 3-1 Stability correlation Ratio

Volume of specimen cm3	Approximate Thickness of specimen		Correlation Ratio
	mm	inch	
200 to 213	25.4	1	5.56
213to 225	27.0	1 1/16	5.00
226 to 237	28.6	1 1/8	4.55
238 to 250	30.2	1 3/16	4.17
251 to 264	31.8	1 1/4	3.85
265 to 276	33.3	1 5/16	3.57
278 to 289	34.9	1 3/8	3.33
290 to 301	36.5	1 7/16	3.03
302 to 316	38.1	1 1/2	2.78
317 to 328	39.7	1 9/16	2.50
329 to 340	41.3	1 5/8	2.27
341 to 353	42.9	1 11/16	2.08
354 to 367	44.4	1 3/4	1.92
368 to 379	49.0	1 13/16	1.79
380 to 392	47.6	1 7/8	1.67
393 to 405	49.2	1 15/16	1.56
406 to 420	50.8	2	1.47
421 to 431	52.4	2 1/16	1.39
432 to 443	54	2 1/8	1.32

444 to 456	55.6	2 3/16	1.25
457 to 470	57.2	2 1/4	1.19
471 to 482	58.7	2 5/16	1.14
483 to 495	60.3	2 3/8	1.09
496 to 508	61.9	2 7/16	1.04
509 to 522	63.5	2 1/2	1.00
523 to 535	65.1	2 9/16	0.96
536 to 546	66.7	2 5/8	0.93
547 to 559	68.3	2 11/16	0.89
560 to 573	69.8	2 3/4	0.86
574 to 585	71.4	2 13/16	0.83
586 to 598	73.0	2 7/8	0.81
599 to 610	74.6	2 15/16	0.78

3-3 Designing HMA for aggregate samples from Omdurman west:

There will be two aggregate blend designs for hot mix asphalt, the first one was application of Bailey Method and the second was application of Tradition Method (try and error).

3-3-1Application of Bailey Method for Designing HMA(OWS):

The table 3-2 show that the sieve analysis (1) , specific gravity, loose density and roddeddensity for aggregates(2) , table 3-3 show the suitability tests made to aggregate obtained from Omdurman west and table 3-4 show the suitability tests made to bitumen.

TABLE 3-2 aggregate sieve analysis and density from Omdurman west source

sieve	**19.0**	**12.5**	**9.5**	**4.75**	**2.36**	**1.18**	**0.6**	**0.3**	**0.15**	**0.075**
CA1	97.6	46.1	9.6	1.8	1.7	1.5	1.4	1.3	1	0.9
CA2	100	100	96	6.4	1.8	1.6	1.5	1.4	1.2	1.0
FA1	100	100	100	92.3	86.5	68.2	54.6	21.0	10	5.4
MF	100	100	100	100	100	97.4	93.7	90.7	85.9	85.4

	BulkSG	Apparent SG	Loose weight	Rodded weight	Absorption %
CA1	2.824	2.882	1504	1795	0.9
CA2	2.789	2.866	1359	1599	1.2
FA1	2.676	2.769	_	1689	1.6
MF	2.709				

TABLE 3-3 Suitability test for aggregate from Omdurman west

TESTS	CA1	CA2	FA1
Flakiness Index	13.0 %	19.0 %	…
Sodium Sulphate Soundness	5.8 %	2.5 %	1.9 %
Aggregate Crushing Value	16.5 %	16.5 %	…
Los Angels Abrasion	21.6 %	21.6 %	…
Coating & Stripping	Above 95%	Above 95%	…
Sand Equivalent	…	…	94 %

TABLE 3-4 Suitability test for Bitumen

Sample No	Penetration	Ductility cm	Softening point C	Flash point F	Fire point F	Specific gravity
1	65	105	53	560	575	1.02
2	67	105	52	565	580	1.02

First determined the aggregate blend using Bailey Method the calculations and formulas as mentioned in chapter 2.

Step 1: Determine unit weight of coarse aggregate

CA1	=	1509	Kg/m
CA2	=	1399.8	Kg/m

Step 2: (Determine unit weight contributed by each coarse aggregate to proportion by

CA 1	=	754	Kg/m
CA2	=	700	Kg/m

Step3: Determine the voids in each coarse aggregate unit weight and contribution by volume

voids in CA1 =	23.5	%
voids in CA2 =	25.2	%
total voids =	48.7	%

Step4: Determine unit weight contributed by each fine aggregate to desired volume blend of fine aggregate volume

FA1 =	836 Kg/m3
FA2 =	0
Sum =	836 kg/m3

Step5: Determine unit weight for total aggregate blend

Unit weight of blend=	2291	kg/m3

step6 : Determine the initial blend percentage by weight of each

CA1 =	32.9	%
CA2 =	30.6	%
FA1 =	36.5	%
FA2 =	0.0	%

Step7: Determine the percentage passing the 2.36mm sieve for coarse and percentage retained on the 2.36 mm sieve

CA1=	1.8	%
CA2=	2.9	%
FA1=	10.3	%
FA2 =	100	%

Step 8: Determine the fine aggregate in each coarse stockpile according in the blend

CA1 = 0.6%

CA2 = 0.9 %

Step 9: Sum the percentage of the fine aggregate particles in all coarse

All CAs= 1.5 %

Step 10: Determine the coarse aggregate in each fine stock pile

FA1 = 3.8 %

FA2 = 0.0 %

Step 11: sum the percentage of the coarse aggregate particles in all fine

All FAs = 3.8 %

Step12: Correct the initial blend percentage of each coarse percent in blend)

CA1 = 31.6 %

CA2 = 29.6 %

Step 13: Correct the initial blend percentage of each fine percent in blend

FA1 = 38.8 %

Step14: Determine the amount of 0.075mm for each aggregate using the stockpile percentages

CA1 = 0.3 %

CA2 = 0.4 %

FA1 = 2.2 %

Total = 3.0 %

Step15: Determine the amount of mineral filler required

percent of MF = 1.8

Step16: Determine the final blend percentage of fine aggregate

RESULT

CA1= 31.6 %

CA2= 29.6 %

FA1=	37.0 %
MF=	1.8 %
Total	100 %

Above result used to calculate combined aggregate blend as in table (3-5).

TABLE 3-5 aggregate blend using Bailey Method – Omdurman west source

Sieve	19.0	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Blend	**100**	**81.8**	**65.2**	**42.8**	**36.4**	**25.6**	**14.0**	**8.6**	**6.3**	**4.4**
Spec	100	95-66	88-52	70-37	52-26	40-18	30-13	23-8	16-6	4-10
Med	100	80.5	70.0	53.5	39.0	29.0	21.5	15.5	11.0	7.0

Preparation of test specimens using Bailey Method:

- Prepared three specimens for each combination of aggregate and asphalt content as in table (3-6).

TABLE 3-6 weight of aggregates used for prepared specimens

Aggregate type	**Percentage used by weight of aggregate**	**Weight required per mold**
CA1	31.6	1200*0.316 = 379.2
CA2	29.6	1200*0.296 = 355.2
FA1	37	1200*0.37 = 444
MF	1.8	1200*0.018 = 21.6
Total	100	1200 g

- Preparation of aggregate: dried the aggregate to constant weight at 105°C.
- Determine mixing and compaction temperature from standard viscosity curve at 155centistokes and 295 centistokes respectively.

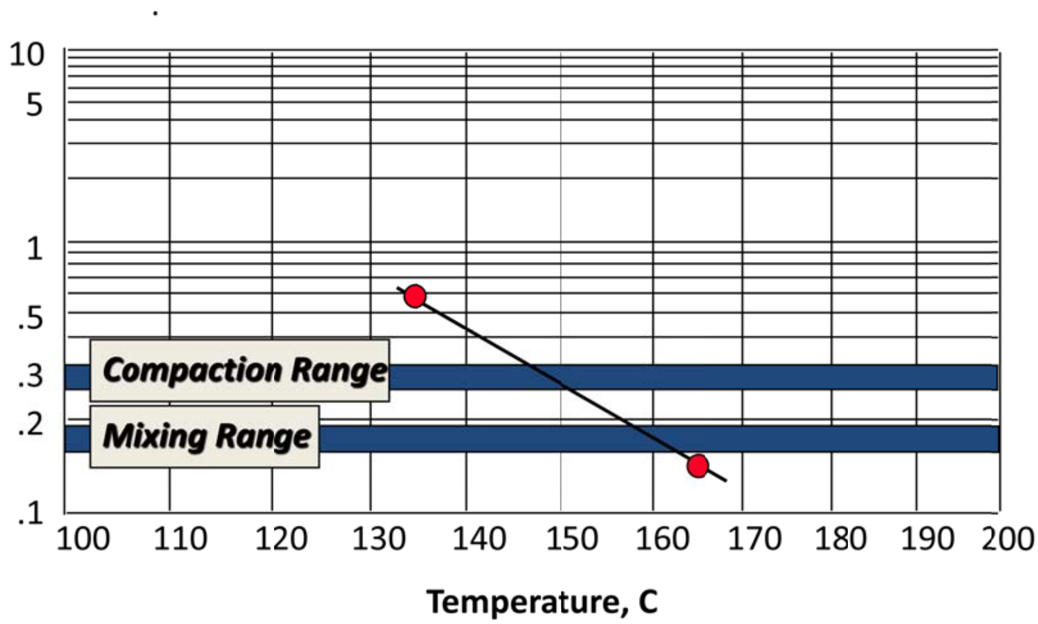


FIGURE 3-1 Mixing / Compaction Temp.

- the combined aggregate in an oven or hot plate and heat to a temperature 155 °C.
- Charged the mixing bowl with heated combined aggregate and dry mix thoroughly.
- Added the required asphalt weight to the aggregate in the mixing bowel started by 3.5 % from the total aggregate weight.

FIGURE 3-2 Added the required asphalt weight to the aggregate in the mixingbowel

- Mixed the aggregate and the asphalt cement thoroughly until consistency at the mixing temperature specified above (155°C).

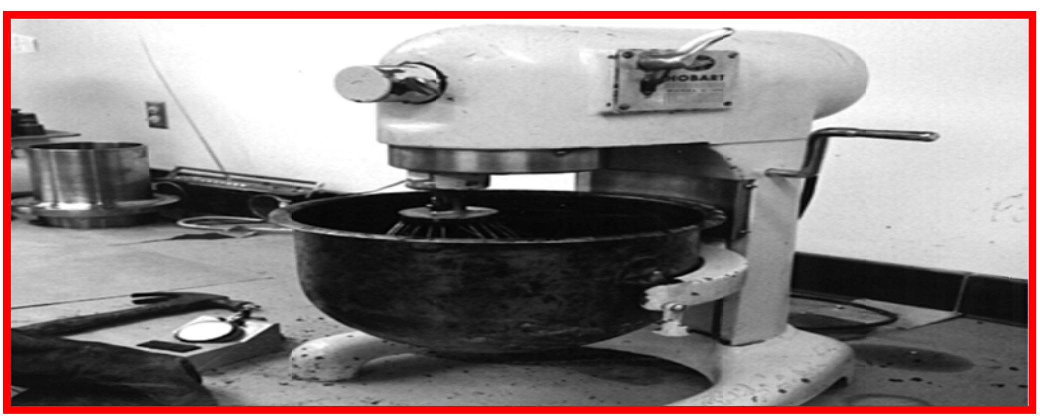


FIGURE 3-3 Mixing aggregate and the asphalt cement thoroughly until

Consistency

- Placed the mold the pre-heated and its assembly and place filter paper in its bottom, the place the mixture in to the mold with apply 15 tamps to the mixture around the mold perimeter and ten time over the interior using spatula, and smooth the surface.

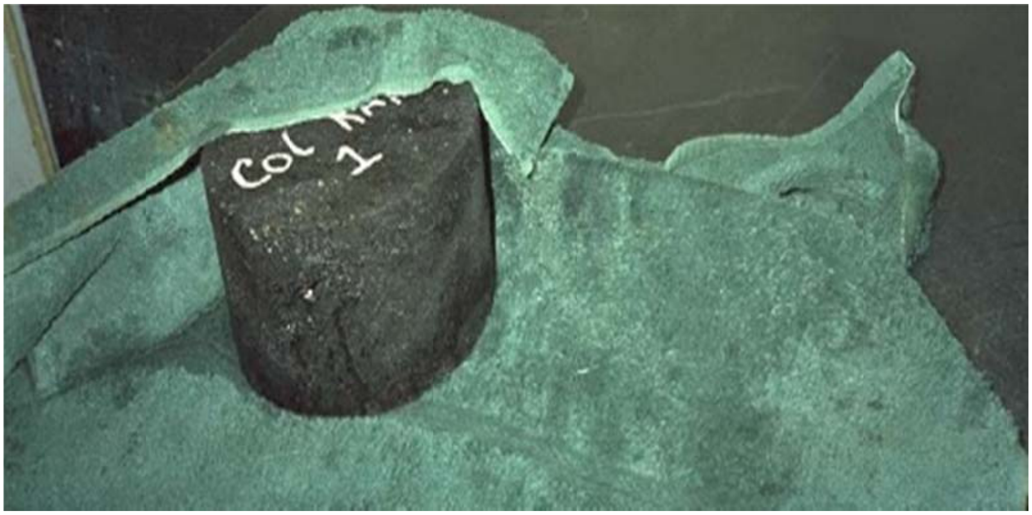
FIGURE 3-4 Pouring asphalt mix in the mold

- Placed another paper on top of the mixture , placed the mold in the compaction pedestal and compact the mixture with specified compaction effort according to level of traffic 75 number of blows each side.

FIGURE 3-5 The compaction pedestal

- Remove the collar and base plate and reverse the mold and apply to this side the same number of blows applied to the top.
- Mark the specimen and label it with asphalt content percent used, and leave it to cool for 24 hour to room temperature.
- Remove the compacted specimen from the mold using extrusion jack and place it in dry, smooth level surface until ready for testing.
- Repeat the last ten steps for each other 14 sample for each set of asphalt content (each set containing the same asphalt content is composed of 3 samples).

- Carried specific gravity test using saturated surface dry method for each of the 15 compacted specimen.



FIUGRE 3-6 Saturated surface dry S.G.

- Carried the maximum specific gravity test (Gmm) in separate two samples using certain asphalt content near the initial asphalt content calculated before.
- Carry the required calculation and density- void analysis.
- Carry the stability and flow test and correct the value of stability using standard table (3-1).

FIGURE 3-7 Measuring stability and flow

Equations used in the analysis

$$G_{sb} = \frac{(P_1 + P_2 + \dots + P_n)}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \dots + \frac{P_n}{G_n}}$$

$$Va = \frac{100 \times (G_{mm} - G_{mb})}{G_{mm}}$$

$$VMA = 100 - \frac{(G_{mb} \times P_s)}{G_{sb}}$$

$$VFB = \frac{100 \times (VMA - V_a)}{VMA}$$

$$G_{mm} = \frac{P_{mm}}{\frac{P_s}{G_{se}} + \frac{P_b}{G_b}}$$

$$P_{ba} = \frac{100 \times G_b (G_{se} - G_{sb})}{G_{se} \times G_{sb}}$$

$$P_{be} = P_b - (\frac{P_{ba} \times P_s}{100})$$

TABLE 3-7 Test Data For Design By Bailey Method**METHOD**

Method	Bailey Method	B.SG of AC	1.02	Project	Design Mix for
Source of Agg	Omdurman west	B S.G of AAgg	2.784	Compaction	75 Blows

Spec. No	AC of Mix	Weight of		Vol	Gmb	Gmm	Va	VMA	VFB	Stability			Flow
		in water	SSD							M.St	Facto	C.St	
1	3.3	725.0	1239.4	509	2.435	2.627	7.3	15.4	52.6	850	1.00	850	1.8
2	3.3	727.0	1241.0	509	2.438	2.627	7.2	15.3	53.0	880	1.00	880	3.0
3	3.3	722.0	1238.0	511	2.423	2.627	7.8	15.8	50.9	790	1.00	790	1.9
Avera				0	2.432		7.4	15.5	52.2			840	2.2
4	3.8	732.0	1242.2	508	2.444	2.606	6.2	15.5	60.1	1210	1.00	1120	1.7
5	3.8	738.0	1254.0	514	2.442	2.606	6.3	15.6	59.6	980	1.00	980	3.2
6	3.8	734.0	1253.0	515	2.435	2.606	6.5	15.8	58.7	1050	1.00	1050	4.0
Avera				0	2.440		6.4	15.7	59.5			1050	3.0
7	4.3	743.0	1251.3	506	2.473	2.585	4.3	15.0	71.1	1410	1.04	1466	3.2
8	4.3	737.0	1240.0	501	2.477	2.585	4.2	14.9	71.9	1050	1.04	1092	3.8
9	4.3	733.0	1238.0	501	2.471	2.585	4.4	15.1	70.7	1210	1.04	1258	2.7
Avera				0	2.474		4.3	15.0	71.2			1272	3.2
10	4.8	739.0	1244.7	504	2.470	2.564	3.7	15.5	76.3	1210	1.04	1258	4.0
11	4.8	739.0	1242.0	501	2.479	2.564	3.3	15.2	78.2	900	1.04	936	4.5
12	4.8	737.0	1241.5	503	2.471	2.564	3.6	15.5	76.5	1380	1.04	1435	3.0
Avera				0	2.473		3.5	15.4	77.0			1210	3.8
13	5.2	740.0	1246.1	506	2.464	2.543	3.1	16.1	80.7	780	1.04	811	3.8
14	5.2	754.0	1265.0	510	2.483	2.543	2.4	15.5	84.7	1060	1.00	1060	3.9
15	5.2	739.0	1248.4	508	2.457	2.543	3.4	16.3	79.4	1140	1.04	1186	4.9
Avera					2.468		2.9	16.0	81.6			1019	4.2

Five curves plotted using the asphalt content in the x-axis and the (Stability, Air void (Va), VMA VFA or VFB and Flow) in y-axis

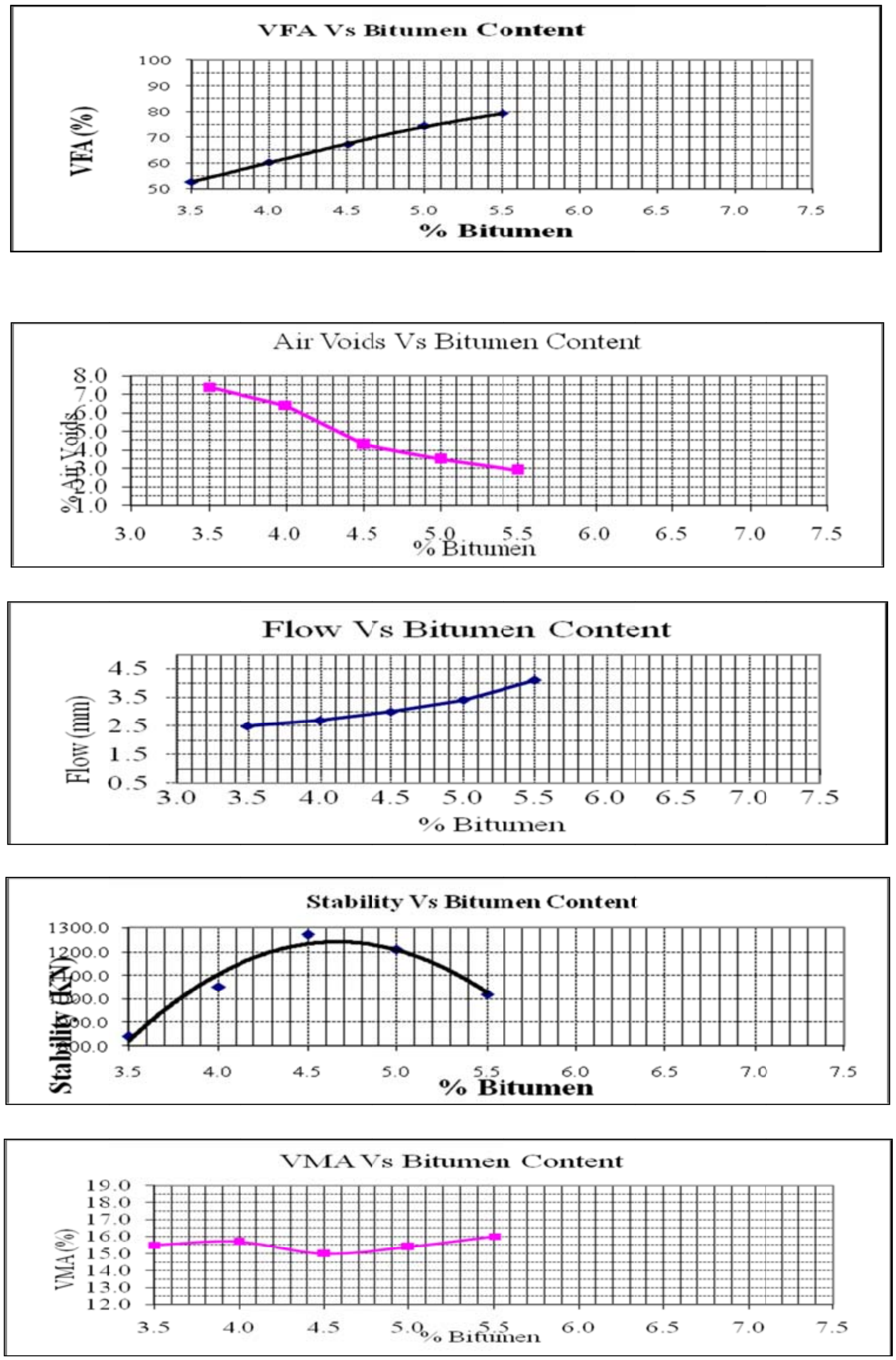


Figure 3-8 Optimum asphalt content study (Omdurman west Bailey method)

- The optimum asphalt content determined (OAC) from the air void curve using the mid of air void value (4%) and it was found 4.7 %.
- Used this OAC check whether the other specification requirement is satisfied or not and they were found as in table 3-8.

TABLE 3-8 asphalt mix properties (Bailey Method)

Mix properties	**Bailey Method**	**Ms-2 Specification**	**AASHTO Specification**
A/C of agg.	4.7	-	-
Air voids	4.0	3-5	3-5
VMA%	15.0	14	16-20
VFA%	70.0	65-75	70-85
Stability kn	1230	Min 800	Min800
Flow 0.25 mm	3.1	2-3.5	1-4

3-3-2 Application of Tradition Method for Designing HMA (OWS):

From table (3-2) Tradition Method (try and error) used to determine

percentages of aggregate blend and they were found as in the table(3-9). The result in table (3-9) used to calculate combined aggregate blend as in table (3-10).

TABLE 3-9 percentages of aggregates used for Tradition Methods- Omdurman west source

Aggregate type	Tradition Method
CA1	**29**
CA2	**28**
FA1	**39**
MF	**4**
Total	**100**

Table 3-10 aggregate blend using Tradition Method- Omdurman west source

Sieve	19.0	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Blend	**100**	**83.0**	**67.9**	**46.7**	**40.3**	**28.9**	**16.6**	**10.9**	**8.4**	**6.3**
Spec	100	95-66	88-52	70-37	52-26	40-18	30-13	23-8	16-6	4-10
Med	100	80.5	70.0	53.5	39.0	29.0	21.5	15.5	11.0	7.0

Preparation of test specimens using Tradition Method-OWS

Prepared three specimens for each combination of aggregate and asphalt content as in table (3-11).

TABLE 3-11 weight of aggregates used for prepared specimens-OS

Aggregate type	Percentage used by weight of aggregate	Weight required per mold
CA1	29	1200*0.29 = 348
CA2	28	1200*0.28 = 336
FA1	39	1200*0.39 = 468
MF	4	1200*0.04 = 48
Total	100	1200 g

- Preparation of aggregate: dried the aggregate to constant weight at 105°C.
- Determined mixing and compaction temperature from standard viscosity curve at 159centistokes and 300 centistokes respectively.
- Charged the mixing bowel with heated combined aggregate and dry mix thoroughly.
- Added the required asphalt weight to the aggregate in the mixing bowel started by 4.0 % from the total aggregate weight.
- Did the same previous steps as in (3-3-1) after the required asphalt weight was added to the aggregate to get following results:

TABLE 3-12 Test Data For Design By Tradition Method

Method		**Tradition**		**B.SG of A/C**		**1.02**			**Project**	**esign Mix for Research**			
Source of Agg		**Omdurman**		**B S.G of Agg**		**2.799**			**Compaction**	**75 Blows**			
VMA	**VFB**	**AC**	**Weight**	**Vol**	**Gmb**	**Gmm**	**Va**	**VMA**	**VFB**	**Stability**			**Flow**
of Mix	**in air**	**water**	**SSD**							**M.St**	**Factor**	**C.St**	
3.8	**1230.0**	**719.0**	**1236.2**	**511**	**2.419**	**2.595**	**6.8**	**16.9**	**59.8**	**800**	**1.00**	**800**	**3.0**
3.8	**1229.0**	**718.6**	**1235.7**	**510**	**2.421**	**2.595**	**6.7**	**16.8**	**60.1**	**780**	**1.00**	**780**	**2.0**
3.8	**1231.4**	**720.2**	**1237.1**	**511**	**2.420**	**2.595**	**6.7**	**16.8**	**59.9**	**920**	**1.00**	**920**	**1.9**
				0	**2.420**		**6.7**	**16.8**	**59.9**			**833**	**2.3**
4.3	**1240.0**	**726.1**	**1245.3**	**514**	**2.423**	**2.574**	**5.9**	**17.1**	**65.8**	**970**	**1.00**	**970**	**1.9**
4.3	**1249.0**	**732.0**	**1253.0**	**517**	**2.424**	**2.574**	**5.8**	**17.1**	**65.9**	**1060**	**1.00**	**1060**	**3.0**
4.3	**1245.6**	**735.0**	**1248.9**	**511**	**2.446**	**2.574**	**5.0**	**16.4**	**69.6**	**990**	**1.00**	**990**	**3.9**
				0	**2.431**	**2.574**	**5.6**	**16.9**	**67.1**			**1007**	**2.9**
4.8	**1243.5**	**731.0**	**1245.3**	**513**	**2.430**	**2.553**	**4.8**	**17.4**	**72.2**	**1250**	**1.00**	**1250**	**3.2**
4.8	**1231.5**	**725.0**	**1233.6**	**507**	**2.436**	**2.553**	**4.6**	**17.2**	**73.2**	**1310**	**1.04**	**1362**	**2.9**
4.8	**1232.7**	**728.0**	**1235.0**	**505**	**2.447**	**2.553**	**4.2**	**16.8**	**75.2**	**1105**	**1.04**	**1149**	**4.2**
				0	**2.437**		**4.5**	**17.1**	**73.5**			**1254**	**3.4**
5.3	**1236.0**	**726.0**	**1237.8**	**510**	**2.427**	**2.532**	**4.1**	**17.9**	**76.8**	**1050**	**1.00**	**1050**	**4.0**
5.3	**1232.0**	**725.0**	**1234.0**	**507**	**2.434**	**2.532**	**3.9**	**17.7**	**78.1**	**1220**	**1.04**	**1269**	**3.3**
5.3	**1233.4**	**727.0**	**1235.1**	**506**	**2.439**	**2.532**	**3.7**	**17.5**	**79.0**	**1220**	**1.04**	**1269**	**3.7**
				0	**2.433**		**3.9**	**17.7**	**78.0**		**1.0**	**1196**	**3.7**
5.8	**1240.0**	**726.0**	**1240.1**	**514**	**2.413**	**2.511**	**3.9**	**18.8**	**79.2**	**1000**	**1.00**	**1000**	**4.3**
5.8	**1260.0**	**744.0**	**1260.4**	**516**	**2.443**	**2.511**	**2.7**	**17.8**	**84.7**	**1050**	**1.00**	**1050**	**3.8**
5.8	**1254.0**	**740.0**	**1254.6**	**514**	**2.441**	**2.511**	**2.8**	**17.9**	**84.4**	**890**	**1.00**	**890**	**4.6**
					2.432		**3.1**	**18.1**	**82.7**			**980**	**4.2**

Five curves plotted using the asphalt content in the x-axis and the (Stability, Air void (Va), VMA VFA or VFB and Flow) in y-axis

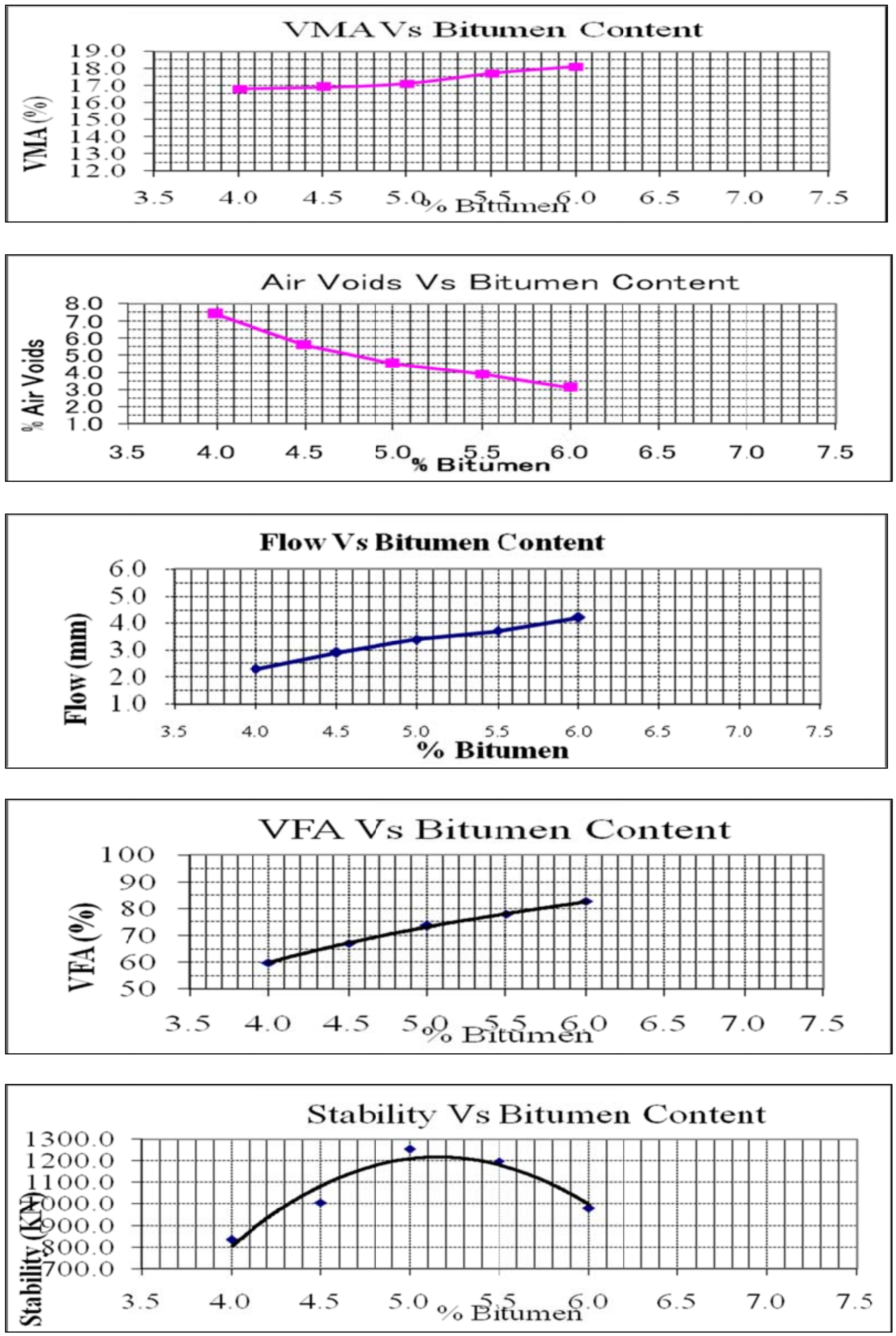


Figure 3-9 Optimum asphalt content study (Omdurman west Tradition method)

- The optimum asphalt content determined (OAC) from the air void curve using the mid of air void value (4%) and it was found 5.4 %.
- Used this OAC check whether the other specification requirement is satisfied or not and they were found as in table 3-13.

TABLE 3-13 asphalt mix properties (Tradition Method)

Mix properties	**Tradition Method**	**Ms-2 Specification**	**AASHTO Specification**
A/C of agg.	5.4	-	-
Air voids	4.0	3-5	3-5
VMA%	17.5	14	16-20
VFA%	77.0	65-75	70-85
Stability kn	1200	Min 800	Min800
Flow 0.25 mm	3.5	2-3.5	1-4

3-4 Designing HMA for aggregate samples from Jubal Toria:

There will be two aggregate blend design for hot mix asphalt, the first one was application of Bailey Method and the second was application of Tradition Method (try and error).

3-4-1Application of Bailey Method for Designing HMA(JTS):

The table 3-14 show that the sieve analysis (1) , specific gravity, loose density and rodded density for aggregates(2) , table 3-15 show the

suitability tests made to aggregate obtained from Jubal Toria source.

TABLE 3-14 aggregate sieve analysis and density from Jubal Toria source

sieve	**19.0**	**12.5**	**9.5**	**4.75**	**2.36**	**1.18**	**0.6**	**0.3**	**0.15**	**0.075**
CA1	97.6	46.1	9.6	1.8	1.7	1.5	1.4	1.3	1.0	0.9
CA2	100	100	96	6.4	1.8	1.6	1.5	1.4	1.2	1.0
FA1	100	100	100	92.3	86.5	68.2	54.6	21.0	10	5.4
MF	100	100	100	100	100	97.4	93.7	90.7	85.9	85.4
%ble	99.2	82.68	69.8	37.7	34.2	27.5	22.5	10.3	6.1	4.4
Spec	100	66-95	52-88	37-70	26-52	18-40	13-30	8.-23	6.-16	4.-10
	BulkSG		Apparent		Loose weght		Rodded		Absorption %	
CA1	2.804		2.882		1504		1795		0.9	
CA2	2.789		2.866		1401		1599		1.2	
FA1	2.676		2.769		_		1689		1.6	
MF	2.709									

TABLE 3-15 Suitability test for aggregate from- Jubal Toria source

TESTS	CA1	CA2	FA1
Flakiness Index	11.0 %	17.0 %	…
Sodium Sulphate Soundness	3.1%	1.1 %	2.6 %
Aggregate Crushing Value	14.0 %	14.0 %	…
Los Angels Abrasion	19.0 %	19.0 %	…
Coating & Stripping	Above 95%	Above 95%	…
Sand Equivalent	…	…	92 %

First determined the aggregate blend using Bailey Method the calculations and formulas as mentioned in chapter 2

Step 1: Determine unit weight of coarse aggregate

CA 1 = 1549.0 Kg/m3

CA2 = 1443.0 Kg/m3

Step 2: Determine unit weight contributed by each coarse aggregate to proportion by volume

CA 1= 775 Kg/m3

CA2 = 722 Kg/m3

Step 3: Determine the voids in each coarse aggregate according to chosen unit weight and contribution by volume

voids in CA1 = 22.4 %
voids in CA2 = 24.1 %
total voids = 46.5 %

Step4: Determine unit weight contributed by each fine aggregate to desired volume blend of fine aggregate volume

FA1 = 785 Kg/m3
FA2 = 0 Kg/m3
Sum = 785 kg/m3

Step5: Determine unit weight for total aggregate blend

Unit weight of blend= 2822 kg/m3

Step6: Determine the initial blend percentage by weight of each aggregate

CA1 = 33.9 %

CA2 = 31.6 %

FA1 = 34.4 %

FA2 = 0 %

Step7: Determine the percentage passing the 2.36mm sieve for coarse and percentage retained on the 2.36 mm sieve

CA1 = 1.7 %

CA2 = 1.8 %

FA1	=	13.5 %
FA2	=	100 %

Step 8: Determine the fine aggregate in each coarse stockpile according in the blend

CA1	=	0.5 %
CA2	=	0.6 %

Step 9: sum the percentage of the fine aggregate particles in all coarse

All CAs	=	1.1 %

Step 10: Determine the coarse aggregate in each fine stock pile

FA1	=	4.6 %
FA2	=	0.0 %

Step 11: sum the percentage of the coarse aggregate particles in all fine

All FAs	=	4.6 %

Step 12: Correct the initial blend percentage of each coarse adjusted Stockpile in blend

CA1	=	32.1 %
CA2	=	30.0 %

Step 13: Correct the initial blend percentage of each fine aggregate

adjusted stockpile in blend

FA1	=	37.9 %
FA2	=	0 %

Step14: Determine the amount of 0.075mm for each aggregate using adjusted stockpile percentages

CA1 = 0.3 %

CA2 = 0.3 %

FA1 = 2.0 %

FA2 = 0 %

Total = 2.6%

Step15: Determine the amount of mineral filler required

Percent of MF = 2.2 %

Step16: Determine the final blend percentage of fine aggregate

FA1 = 35.7 %

FA2 = 0 %

RESULT

CA = 32.1 %

CA2 = 30.0 %

FA1 = 35.7 %

MF = 2.2 %

Total = 100 %

The above result used to calculate combined aggregate blend see table (3-16).

TABLE3-16 aggregate blend using Bailey Method –Toria source

Sieve	19.0	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Blend	**99.2**	**82.7**	**69.8**	**37.7**	**34.2**	**27.5**	**22.5**	**10.3**	**6.1**	**4.4**
Spec	100	95-66	88-52	70-37	52-26	40-18	30-13	23-8	16-6	4-10
Med	100	80.5	70.0	53.5	39.0	29.0	21.5	15.5	11.0	7.0

Preparation of test specimens using Bailey Method-JTS

- Prepared three specimens for each combination of aggregate and asphalt content as in table (3-17).

TABLE 3-17 weight of aggregates used for prepared specimens-TS

Aggregate type	Percentage used by weight of aggregate	Weight required per mold
CA1	32.1	1200*0.321= 385.2
CA2	30	1200*0.3 = 360
FA1	35.7	1200*0.357 = 428.4
MF	2.2	1200*0.022 = 26.4
Total	100	1200 g

- Preparation of aggregate: dried the aggregate to constant weight at 105°C.
- Determine mixing and compaction temperature from standard viscosity curve at 160centistokes and 300 centistokes respectively.
- Charged the mixing bowel with heated combined aggregate and dry mix.
- Added the required asphalt weight to the aggregate in the mixing bowel started by 3.5 % from the total aggregate weight.
- Did the same previous steps as in (3-3-1)after the required asphalt weight was added to the aggregate to get following results:

TABLE 3-18 Test Data For Design By Bailey Method

Method	Bailey Method		B.SG of A/C	1.02		Project	Design Mix
Source of Agg	Jubal Toria		B SG of Agg	2.750		Compacti	75 Blows

Spec. No	AC of Mix	Weight of specimen			Vol	Gmb	Gmm	Va	VMA	VFB	Stability			Flow
		in air	water	SSD							M.St	Factor	C.St	
1	3.3	1231.0	725.0	1239.4	506	2.449	2.620	6.5	13.9	53.1	890	1.04	926	2.0
2	3.3	1233.0	727.0	1239.0	506	2.449	2.620	6.5	13.9	52.9	900	1.04	936	2.9
3	3.3	1230.3	722.0	1238.0	508	2.436	2.620	7.0	14.4	51.0	890	1.00	890	2.5
Avera					0	2.445		6.7	14.0	52.3			917	2.5
4	3.8	1237.6	732.0	1239.9	506	2.452	2.599	5.6	14.2	60.3	980	1.04	1120	3.0
5	3.8	1248.1	738.0	1251.2	510	2.453	2.599	5.6	14.2	60.4	970	1.00	970	3.0
6	3.8	1245.0	734.0	1251.9	511	2.450	2.599	5.7	14.3	59.9	1000	1.00	1000	2.0
Avera					0	2.452		5.7	14.2	60.2			1030	2.7
7	4.3	1245.9	737.0	1247.5	509	2.451	2.578	4.9	14.7	66.6	1250	1.00	1250	3.0
8	4.3	1234.4	731.0	1235.8	503	2.455	2.578	4.8	14.6	67.2	1120	1.04	1165	2.9
9	4.3	1232.5	730.0	1235.0	503	2.458	2.578	4.7	14.5	67.8	1290	1.04	1342	3.0
Avera					0	2.455		4.8	14.6	67.2			1252	3.0
10	4.8	1241.4	736.0	1242.7	505	2.459	2.557	3.8	14.9	74.2	1070	1.04	1113	3.5
11	4.8	1237.4	734.0	1238.3	503	2.460	2.557	3.8	14.8	74.4	1100	1.04	1144	3.8
12	4.8	1236.5	733.0	1238.0	504	2.459	2.557	3.8	14.9	74.2	1250	1.04	1300	3.0
Avera					0	2.459		3.8	14.9	74.3			1186	3.4
13	5.2	1245.8	738.0	1246.4	508	2.455	2.536	3.2	15.4	79.1	823	1.04	856	4.2
14	5.2	1263.6	750.0	1264.4	514	2.462	2.536	2.9	15.1	80.7	931	1.00	931	4.0
15	5.2	1246.0	737.0	1247.0	509	2.450	2.536	3.4	15.5	78.2	985	1.00	985	4.2
Avera						2.455		3.2	15.4	79.3	913.0		924	4.1

Five curvesplotted using the asphalt content in the x-axis and the (Stability,Air void (Va), VMA VFA or VFB andFlow) in y-axis

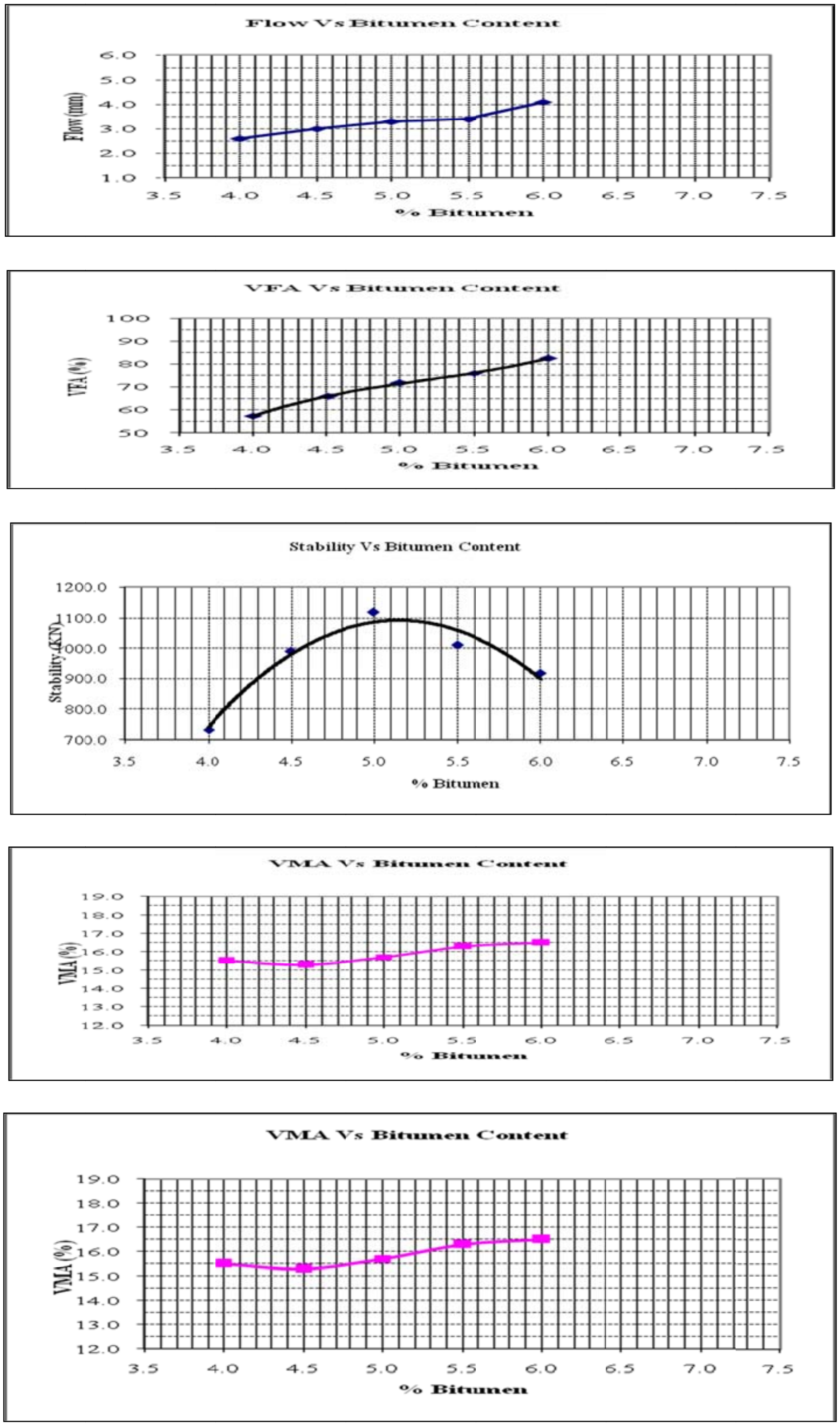


Figure 3-10 Optimum asphalt content study(Jubal Toria Bailey method)

- The optimum asphalt content determined (OAC) from the air void curve using the mid of air void value (4%) and it was found 5.0 %.
- Used this OAC check whether the other specification requirement is satisfied or not and they were found as in table 3-19:

TABLE 3-19asphalt mix properties (Bailey Method)

Mix properties	**Bailey Method**	**Ms-2 Specification**	**AASHTO Specification**
A/C of agg.	5.0	-	-
Air voids	4.0	3-5	3-5
VMA%	14.7	14	16-20
VFA%	72.0	65-75	70-85
Stability kn	1120	Min 800	Min800
Flow 0.25 mm	3.3	2-3.5	1-4

3-4-2Application of Tradition Method for Designing HMA(JTS):

From table3-14 Tradition Method (try and error) used to determine percentages of aggregate blend and they were found as in the table 3-20. The result in table (3-10) used to calculate combined aggregate blend as in table (3-21).

TABLE 3-20 percentages of aggregates used from Tradition Method

Aggregate type	Tradition Method
CA1	**30**
CA2	**28**
FA1	**38**
MF	**4**
Total	**100**

Table 3-21 aggregate blend using Tradition Method -JTS

Sieve	19.0	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Blend	**100**	**84.8**	**72.8**	**42.3**	**38.7**	**31.4**	**25.9**	**12.6**	**8.0**	**6.2**
Spec	100	95-66	88-52	70-37	52-26	40-18	30-13	23-8	16-6	4-10
Med	100	80.5	70.0	53.5	39.0	29.0	21.5	15.5	11.0	7.0

Preparation of test specimens using Tradition Method:

- Prepared three specimens for each combination of aggregate and asphalt content as in table (3-22).

TABLE 3-22 weight of aggregates used for prepared specimens-JTS

Aggregate type	Percentage used by weight of aggregate	Weight required per mold
CA1	30	1200*0.3= 360
CA2	28	1200*0.28 = 336
FA1	38	1200*0.38 = 456
MF	4	1200*0.04= 48
Total	100	1200 g

- Preparation of aggregate: dried the aggregate to constant weight at 105°C.
- Determine mixing and compaction temperature from standard viscosity curve at 155centistokes and 295 centistokes respectively.
- Charged the mixing bowel with heated combined aggregate and dry mix.
- Added the required asphalt weight to the aggregate in the mixing bowel started by 4.0 % from the total aggregate weight.
- Did the same previous steps as in (3-3-1)after the required asphalt weight was added to the aggregate to get following results:

TABLE 3-23 Test Data For Design By Tradition Method

Tradation Method	B.SG of A/C	1.02		Project	Design Mix for
Jubl TORIA	B.SG of Agg	2.746		Compaction	75 Blows

Weight of specimen			Vol	Gmb	Gmm	Va	VMA	VFB	Stability			Flow
in air	water	SSD							M.St	Factor	C.St	
1233.0	719.0	1239.4	514	2.411	2.583	6.6	15.5	57.2	780	1.00	780	2.3
1233.0	719.0	1239.0	514	2.411	2.583	6.7	15.6	57.1	670	1.00	670	3.0
1235.2	721.2	1240.1	514	2.413	2.583	6.6	15.5	57.4	750	1.00	750	2.5
			0	2.411	2.583	6.6	15.5	57.2			733	2.6
1237.6	726.7	1239.9	511	2.427	2.564	5.3	15.4	65.3	980	1.00	980	3.0
1248.1	733.0	1251.2	515	2.429	2.564	5.3	15.3	65.7	990	1.00	990	4.0
1249.2	734.5	1251.9	515	2.432	2.564	5.1	15.2	66.3	1000	1.00	1000	2.0
			0	2.429	2.564	5.2	15.3	65.8			990	3.0
1245.9	733.0	1246.7	513	2.431	2.545	4.5	15.7	71.4	1100	1.00	1100	3.0
1234.4	726.5	1235.8	508	2.433	2.545	4.4	15.6	71.9	1120	1.04	1165	3.1
1235.7	727.0	1237.0	509	2.432	2.545	4.5	15.7	71.6	1050	1.04	1092	3.7
			0	2.432	2.545	4.4	15.7	71.7			1119	3.3
1241.4	729.5	1242.7	512	2.428	2.526	3.9	16.3	76.1	1070	1.00	1070	3.0
1237.4	727.1	1238.3	510	2.427	2.526	3.9	16.3	75.9	970	1.00	970	3.8
1238.9	728.0	1240.0	511	2.427	2.526	3.9	16.3	76.0	990	1.00	990	3.3
			0	2.427	2.526	3.9	16.3	76.0		1.0	1010	3.4
1245.8	729.0	1246.4	517	2.412	2.507	3.8	17.3	78.0	823	1.00	823	3.8
1263.6	747.1	1264.4	517	2.448	2.507	2.4	16.0	85.3	931	1.00	931	3.8
1260.0	743.9	1260.9	516	2.443	2.507	2.5	16.2	84.3	985	1.00	985	4.2
				2.434	2.507	2.9	16.5	82.5	913.0		913	3.9

Five curves plotted using the asphalt content in the x-axis and the (Stability, Air void (Va), VMA VFA or VFB and Flow) in y-axis

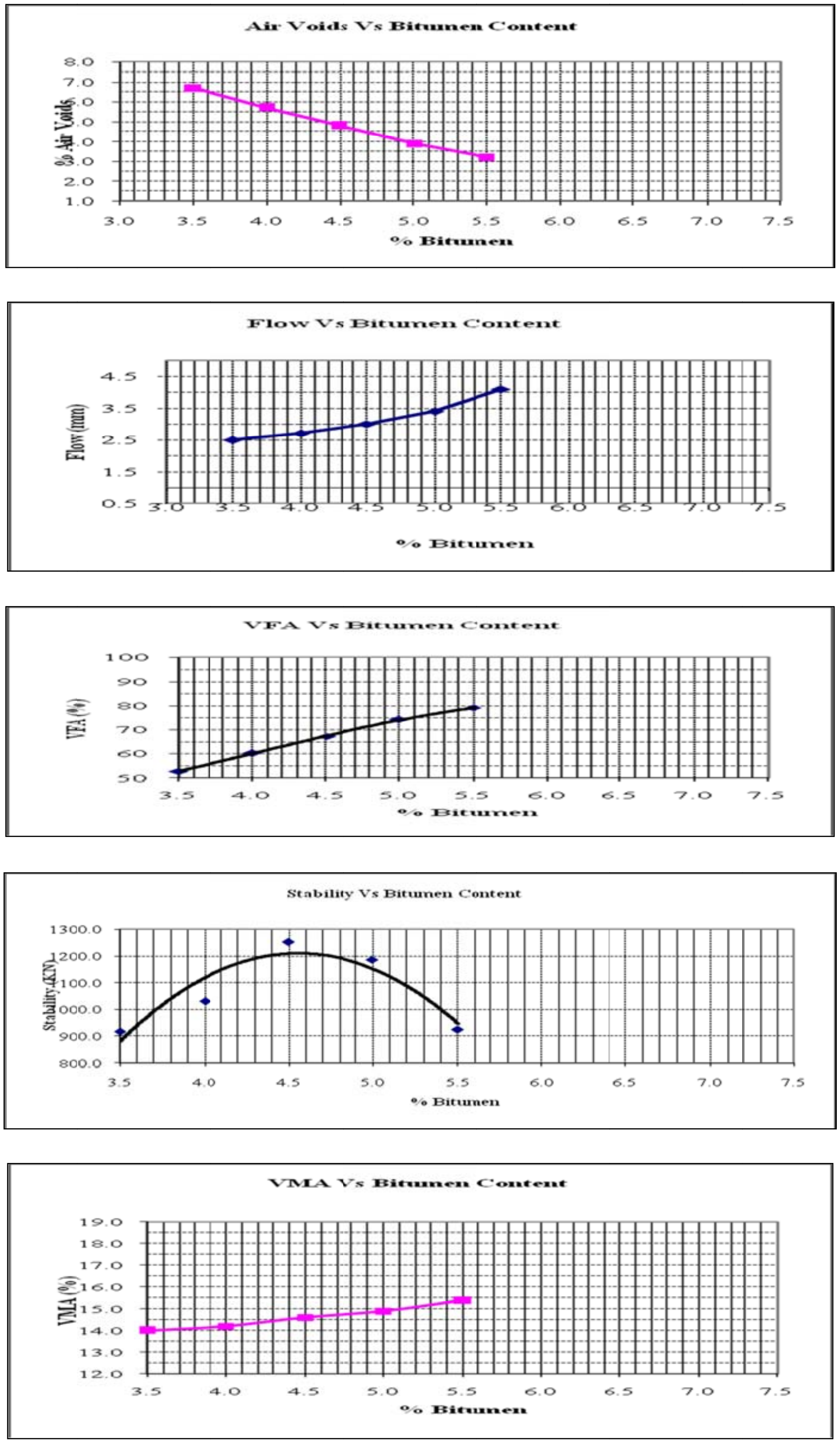


Figure 3-11 Optimum asphalt content study(JublToria Tradition method)

- The optimum asphalt content determined (OAC) from the air void curve using the mid of air void value (4%) and it was found 5.0 %.
- Used this OAC check whether the other specification requirement is satisfied or not and they were found as in table 3-24:

TABLE 3-24 asphalt mix properties (Tradition Method)

Mix properties	**Tradition Method**	**Ms-2 Specification**	**AASHTO Specification**
A/C of agg.	5.3	-	-
Air voids	4.0	3-5	3-5
VMA%	16.0	14	16-20
VFA%	74.0	65-75	70-85
Stability kn	1090	Min 800	Min800
Flow 0.25 mm	3.4	2-3.5	1-4

3-5 Designing HMA for aggregate samples from Alselate:

There will be two aggregate blend design for hot mix asphalt, the first one was application of Bailey Method and the second was application of Tradition Method (try and error).

3-5-1 Application of Bailey Method for Designing HMA (AS):

The table 3-25 show that the sieve analysis (1) , specific gravity, loose density and rodded desity for aggregates(2) , table 3-26 show the suitability tests made to aggregate obtained from Alselate.

TABLE 3-25 aggregate sieve analysis and density from Alselate source

seive	**19.0**	**12.5**	**9.5**	**4.75**	**2.36**	**1.18**	**0.6**	**0.3**	**0.15**	**0.075**
CA1	97.6	18.5	1.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
CA2	100	100	78.7	2.6	0.8	0.7	0.7	0.6	0.6	0.6
FA1	100	100	100	97.3	84.9	62.6	34.3	19.0	9.9	5.3
MF	100	100	100	100	100	97.4	93.7	90.7	85.9	85.4
%blen	99.3	75.7	64.5	41.0	35.6	26.9	15.8	9.8	6.2	4.4
Spec	100	66-	52-88	37-70	26-52	18-40	13-30	8.-23	6.-16	4.-10
	BulkSG		Apparent SG		Loose weight		Rodded weight		Absorption	
CA1	2.623		2.683		1346		1520		1.0	
CA2	2.578		2.660		1315		1507		0.75	
FA1	2.526		2.650		_		1635		1.6	
MF	2.709									

TABLE 3-26 Suitability test for aggregate from Alselate source

TESTS	CA1	CA2	FA1
Flakiness Index	19.0 %	23.0 %	…
Sodium Sulphate Soundness	9.6%	3.8 %	2.6 %
Aggregate Crushing Value	21.0 %	21.0 %	…
Los Angels Abrasion	24.0 %	24.0 %	…
Coating & Stripping	Above 95%	Above 95%	…
Sand Equivalent	…	…	92 %

First determined the aggregate blend using Bailey Method the calculations and formulas as mentioned in chapter 2.

Step 1: Determine unit weight of coarse aggregate

CA 1 = 1386 kg/m3
CA2 = 1354.45 kg/m3

Step 2: Determine unit weight contributed by each coarse aggregate to proportion

CA 1	=	693 kg/m3
CA2	=	677 kg/m3

Step 3 :Determine the voids in each coarse aggregate according to unit weight and contribution by volume

voids in CA1	23.6	%
voids in CA2	23.7	%
total voids	47.3	%

step4 :Determine unit weight contributed by each fine aggregate according to desired volume blend of fine aggregate

FA1		773 kg/m3
FA2		0.0 kg/m3
Sum	=	773 kg/m3

Step5: Determine unit weight for total aggregate blend

Unit weight of blend = 2144 kg/m3

Step6 :Determine the initial blend percentage by weight of each aggregate

CA1	=	32.3 %
CA2	=	31.6 %
FA1	=	36.1 %
FA2	=	0.0 %

Step7 :Determine the percentage passing the 2.36mm sieve for coarse and percentage retained on the 2.36 mm sieve

CA1	=	0.7 %
CA2	=	0.8 %

FA1	=	15.1
FA2	=	100

Step 8: Determine the fine aggregate in each coarse stockpile according to its percent in the blend

CA1	=	0.2 %
CA2	=	0.3 %

Step 9: sum the percentage of the fine aggregate particles in all coarse aggregate Stockpile

All CAs = 0.5 %

Step 10 :Determine the coarse aggregate in each fine stockpile

FA1	=	5.4 %
FA2	=	0.0 %

Step 11: Sum the percentage of the coarse aggregate particles in all fine aggregate stockpile

All FAs = 5.4 %

Step 12: Correct the initial blend percentage of each coarse aggregate Adjusted Stockpile percent in blend

CA1	=	29.8 %
CA2	=	29.2 %

Step 13: Correct the initial blend percentage of each fine aggregate adjusted stockpile percent in blend

FA1	=	41.0 %
FA2	=	0.0 %

Step14: Determine the amount of 0.075mm for each aggregate using the adjusted Stockpile percentages

CA1	=	0.2 %
CA2	=	0.2 %
FA1	=	2.1 %
FA2	=	0.0 %
Total	=	2.5 %

Step15: Determine the amount of mineral filler required

Percent of MF = 2.3 %

Step16: Determine the final blend percentage of fine aggregate

FA1	=	38.7 %
FA2	=	0.0 %

RESULT

CA1	=	29.8 %
CA2	=	29.2 %
FA1	=	38.7 %
MF	=	2.30 %
Total	=	100 %

The above result used to calculate combined aggregate blend see table (3-27).

TABLE 3-27 aggregate blend using Bailey Method – Alselate source

Sieve	19.0	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Blend	**99.3**	**75.7**	**64.5**	**41.0**	**35.6**	**26.9**	**15.5**	**9.8**	**6.2**	**4.4**
Spec	100	95-66	88-52	70-37	52-26	40-18	30-13	23-8	16-6	4-10
Med	100	80.5	70.0	53.5	39.0	29.0	21.5	15.5	11.0	7.0

Preparation of test specimens using Bailey Method:

- Prepared three specimens for each combination of aggregate and asphalt content as in table (3-28).

TABLE 3-28 weight of aggregates used for prepared specimens-AS

Aggregate type	Percentage used by weight of aggregate	Weight required per mold
CA1	29.8	1200*0.298= 357.6
CA2	29.2	1200*0.292 = 350.4
FA1	38.7	1200*0.387 = 464.4
MF	2.3	1200*0.023= 27.6
Total	100	1200 g

- Preparation of aggregate: dried the aggregate to constant weight at 105°C.
- Determine mixing and compaction temperature from standard viscosity curve at 155centistokes and 295 centistokes respectively.
- Charged the mixing bowel with heated combined aggregate and dry mix
- Added the required asphalt weight to the aggregate in the mixing bowel started by 3.5 % from the total aggregate weight.
- Did the same previous steps as in (3-3-1)after the required asphalt weight was added to the aggregate to get following results:

TABLE 3-29 Test Data For Design By Bailey Method

Method	Bailey Method	B.SG of A/C	1.02	Project	Design Mix (Researc
Source of Agg	Alselate	B SG of Agg	2.573	Compacti	75 Blows

Spec. No	A/C of Mix	Weight of specimen			Vol.	Gmb	Gmm	Va	VMA	VFB	Stability		
		air	water	SS							M.St	Factor	C.St
1	3.3	1223.3	673.0	1226.3	550	2.228	2.404	7.3	16.3	55.1	990	0.89	881
2	3.3	1237.4	681.0	1239.2	556	2.227	2.404	7.4	16.3	54.9	900	0.89	801
3	3.3	1235.7	680.0	1238.4	556	2.229	2.404	7.3	16.2	55.1	850	0.89	757
Average					0	2.228		7.3	16.3	55.0			813
4	3.8	1230.9	685.0	1232.0	546	2.257	2.387	5.5	15.6	65.1	1100	0.89	979
5	3.8	1229.7	678.0	1231.0	552	2.231	2.387	6.5	16.6	60.6	1210	0.89	1077
6	3.8	1230.0	681.0	1232.6	549	2.245	2.387	5.9	16.1	63.0	1280	0.89	1139
Average					0	2.244		6.0	16.1	62.9			1065
7	4.3	1244.4	697.0	1245.0	547	2.274	2.370	4.0	15.4	73.8	1450	0.89	1291
8	4.3	1236.6	693.0	1238.1	544	2.278	2.370	3.9	15.3	74.5	1250	0.89	1113
9	4.3	1232.5	691.0	1233.0	542	2.277	2.370	3.9	15.3	74.4	1360	0.89	1210
Average					0	2.276		4.0	15.3	74.2			1204
10	4.8	1254.3	702.0	1256.0	552	2.274	2.353	3.4	15.9	78.9	1250	0.89	1113
11	4.8	1235.8	692.0	1237.9	544	2.276	2.353	3.3	15.8	79.4	1370	0.93	1274
12	4.8	1234.0	691.0	1236.7	543	2.278	2.353	3.2	15.7	79.6	1270	0.93	1181
Average					0	2.276		3.3	15.8	79.3			1189
13	5.2	1245.4	698.0	1246.4	547	2.277	2.336	2.5	16.1	84.3	1050	0.89	935
14	5.2	1226.8	686.0	1227.4	541	2.270	2.336	2.8	16.4	82.6	900	0.93	837
15	5.2	1228.0	687.1	1228.9	541	2.272	2.336	2.7	16.3	83.2	1190	0.93	1107
Average						2.273		2.7	16.3	83.4	1046.7		959

Five curves plotted using the asphalt content in the x-axis and the (Stability, Air void (Va), VMA VFA or VFB and Flow) in y-axis

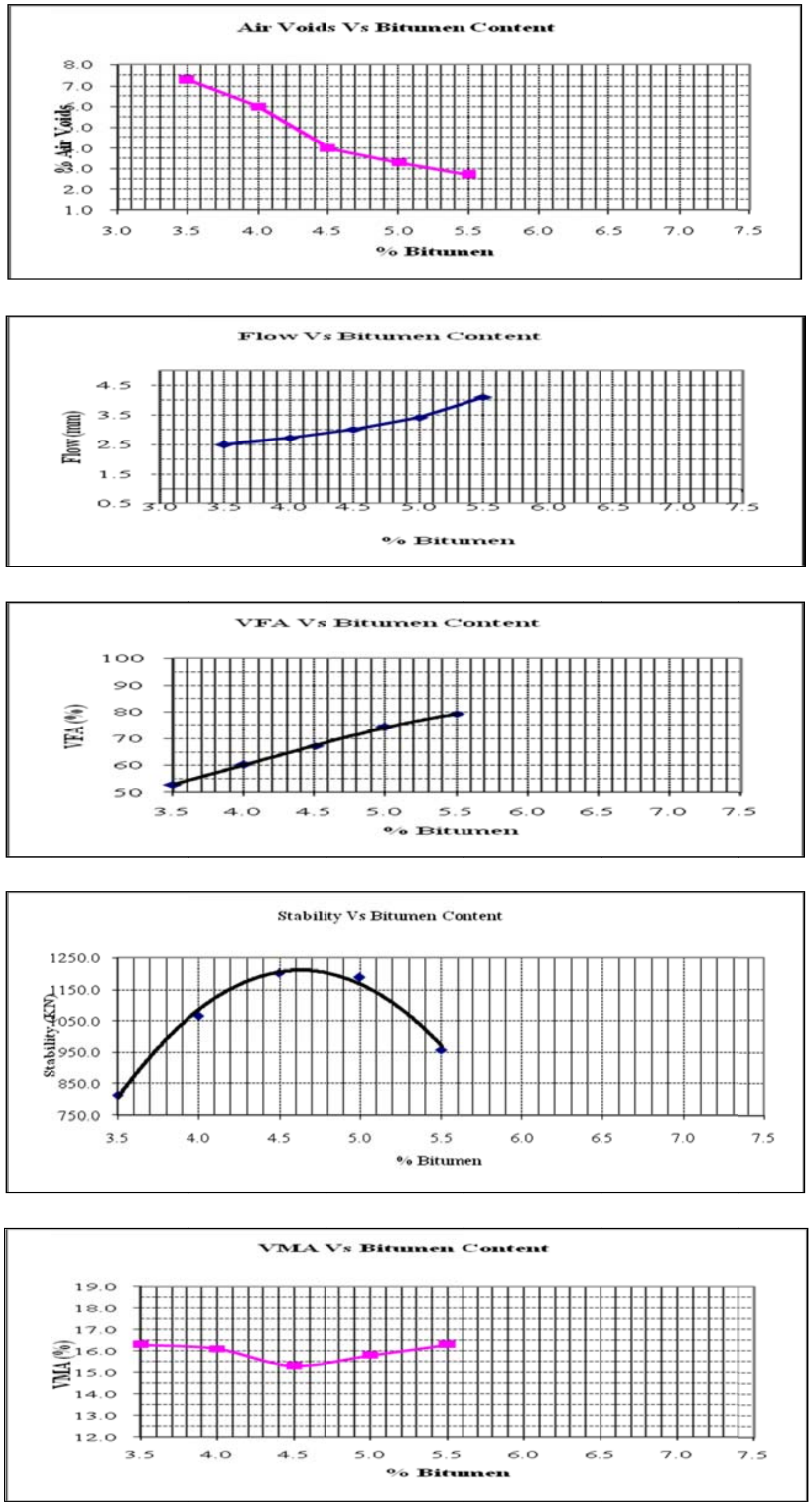


Figure 3-12 Optimum asphalt content study (Alselate Bailey method)

- The optimum asphalt content determined (OAC) from the air void curve using the mid of air void value (4%) and it was found 4.6 %.
- Used this OAC check whether the other specification requirement is satisfied or not and they were found as in table 3-30

TABLE 3-30 asphalt mix properties (Tradition Method)

Mix properties	Bailey Method	Ms-2 Specification	AASHTO Specification
A/C of agg.	4.6	-	-
Air voids	4.0	3-5	3-5
VMA%	15.2	14	16-20
VFA%	69.0	65-75	70-85
Stability kn	1200	Min 800	Min800
Flow 0.25 mm	3.0	2-3.5	1-4

3-5-2Application of Tradition Method for Designing HMA:

From table 3-25 Tradition Method (try and error) used to determine percentages of aggregate blend and they were found as in the table 3-31.

The result in table3-31 used to calculate combined aggregate blend as in table 3-32.

TABLE 3-31percentages of aggregates used for Tradition Method– Alselate source

Aggregate type	Tradition Method
CA1	**26**
CA2	**27**
FA1	**43**
MF	**4**
Total	**100**

Table 3-32 aggregate blend using Tradition Method – Alselate source

Sieve	19.0	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Blend	**99.4**	**78.8**	**68.7**	**46.7**	**40.9**	**31.2**	**18.8**	**12.1**	**8.0**	**6.0**
Spec	100	95-66	88-52	70-37	52-26	40-18	30-13	23-8	16-6	4-10
Med	100	80.5	70.0	53.5	39.0	29.0	21.5	15.5	11.0	7.0

Preparation of test specimens using Tradition Method-AS

- Prepared three specimens for each combination of aggregate and asphalt content as in table (3-33).
-

TABLE 3-33 weight of aggregates used for prepared specimens-AS

Aggregate type	Percentage used by weight of aggregate	Weight required per mold
CA1	26	1200*0.26= 312
CA2	27	1200*0.27 = 324
FA1	43	1200*0.43 = 516
MF	4	1200*0.04 = 48
Total	100	1200 g

- Preparation of aggregate: dried the aggregate to constant weight at 105°C.
- Determine mixing and compaction temperature from standard viscosity curve at 155centistokes and 295 centistokes respectively.
- Charged the mixing bowel with heated combined aggregate and dry mix
- Added the required asphalt weight to the aggregate in the mixing bowel started by 4.0 % from the total aggregate weight.

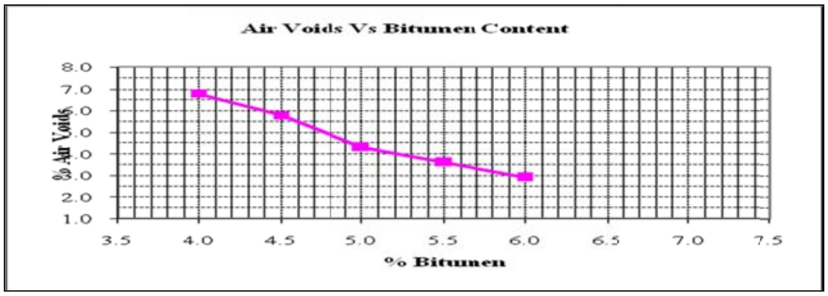
Did the same previous steps as (3-3-1)after the required asphalt weight was added to the aggregate to get following results:

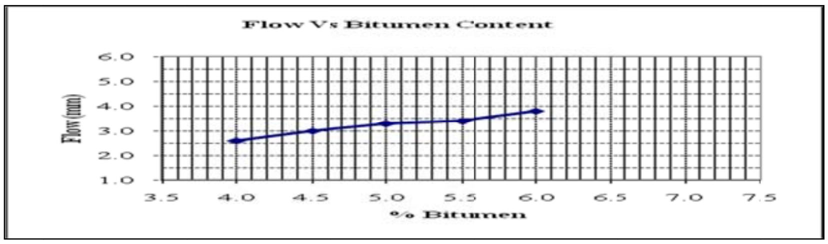
TABLE 3-34 Test Data For Design By Tradition

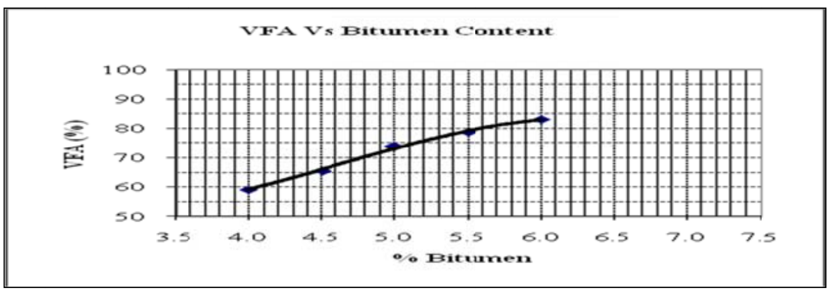
Method	Old Method	B.SG OF A/C	1.02	Project	Design Mix
Source of Agg	ALSELATE	B S.G of Agg	2.572	Compactio	75 Blows

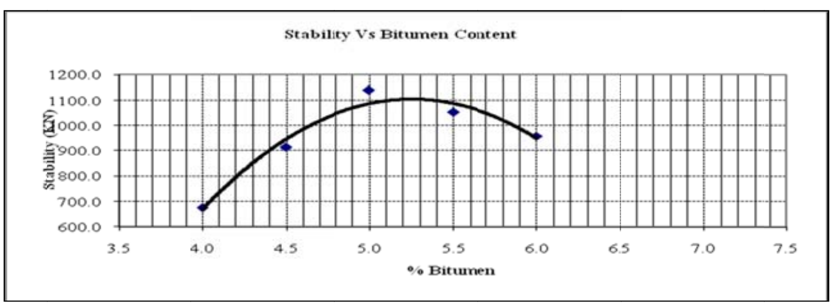
Spec. No	A/C of Mix	Weight of specimen			Vol	Gmb	Gmm	Va	VMA	VFB	Stability			Flow
		air	water	SSD							M.St	Factor	C.St	
1	3.8	1260.0	693.0	1264.	567	2.229	2.392	6.8	16.6	59.1	700	0.86	602	2.3
2	3.8	1238.3	681.0	1242.	557	2.229	2.392	6.8	16.6	59.0	850	0.89	757	3.0
3	3.8	1237.5	681.0	1241.	557	2.231	2.392	6.7	16.6	59.3	750	0.89	668	2.5
Averag					0	2.230	2.392	6.8	16.6	59.1			675	2.6
4	4.3	1240.4	687.0	1243.	553	2.246	2.375	5.4	16.4	67.0	1090	0.89	970	3.0
5	4.3	1221.3	670.0	1225.	551	2.222	2.375	6.4	17.3	62.8	990	0.89	881	4.0
6	4.3	1241.1	686.0	1245.	555	2.244	2.375	5.5	16.5	66.6	1000	0.89	890	2.0
Averag					0	2.237		5.8	16.7	65.5			914	3.0
7	4.8	1244.0	693.0	1246.	551	2.261	2.358	4.1	16.3	74.9	1260	0.89	1121	3.0
8	4.8	1231.7	684.0	1234.	548	2.253	2.358	4.5	16.6	73.2	1270	0.89	1130	3.1
9	4.8	1232.7	684.0	1236.	549	2.253	2.358	4.5	16.6	73.1	1310	0.89	1166	3.7
Averag					0	2.256		4.3	16.5	73.7			1139	3.3
10	5.3	1240.1	690.1	1242.	550	2.258	2.341	3.5	16.9	79.0	1350	0.89	1202	3.0
11	5.3	1256.0	699.0	1257.	557	2.257	2.341	3.6	16.9	78.7	970	0.89	863	3.8
12	5.3	1239.1	689.0	1241.	550	2.257	2.341	3.6	16.9	78.8	1230	0.89	1095	3.3
Averag					0	2.257		3.6	16.9	78.8			1053	3.4
13	5.8	1250.8	695.6	1251.	555	2.253	2.324	3.0	17.5	82.6	1360	0.89	1210	3.8
14	5.8	1244.0	692.2	1244.	552	2.255	2.324	3.0	17.4	82.9	980	0.89	872	3.8
15	5.8	1245.0	693.6	1245.	551	2.259	2.324	2.8	17.3	83.7	890	0.89	792	4.8
Averag						2.256		2.9	17.4	83.1	1078		958	4.1

Five curves plotted using the asphalt content in the x-axis and the (Stability, Air void (Va), VMA VFA or VFB and Flow) in y-axis









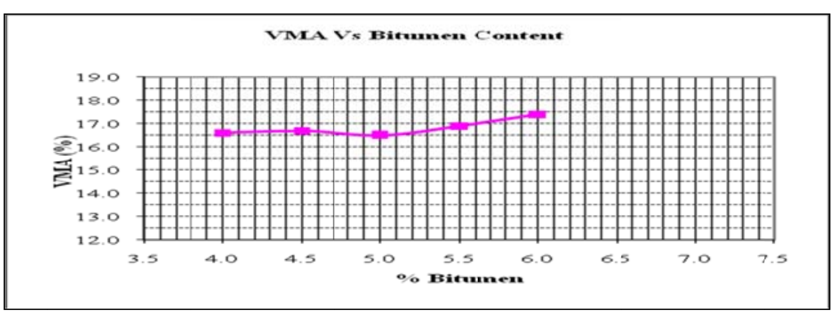


Figure 3-13 Optimum asphalt content study(Alselate Tradition method)

- The optimum asphalt content determined (OAC) from the air void curve using the mid of air void value (4%) and it was found 4.6 %.
- Used this OAC check whether the other specification requirement is satisfied or not and they were found as in table 3-35:

TABLE 3-35 asphalt mix properties (Tradition Method)

Mix properties	Tradition Method	Ms-2 Specification	AASHTO Specification
A/C of agg.	5.2	-	-
Air voids	4.0	3-5	3-5
VMA%	16.5	14	16-20
VFA%	75.0	65-75	70-85
Stability kn	1100	Min 800	Min800
Flow 0.25 mm	3.3	2-3.5	1-4

3-6 Result analysis:

From table 3-36 the aggregate blend using Bailey Method was coarser than using Tradition Method (Try & error) this resulted the following:

- Bailey Method Mix properties VMA and VFB satisfied the change was made in the VMA specification and air void percentage required in HMA mixture in 1995 [MS-2] in Marshall Method in table(3-37).
- Adequate asphalt binder and less sand that will minimize rutting.

Table 3-36 aggregate blend using Two Methods for all samples[6],[7]

Method	**Sieve**	**19.0**	**12.5**	**9.5**	**4.75**	**2.36**	**1.18**	**0.6**	**0.3**	**0.15**	**0.075**
Bailey	**OWS**	100	81.8	65.2	42.8	36.4	25.6	14.0	8.6	6.3	4.4
	JTS	99.2	82.7	69.8	37.7	34.2	27.5	22.5	10.3	6.1	4.4
	AS	99.3	75.7	64.5	41.0	35.6	26.9	15.5	9.8	6.2	4.4
Tradition (T&E)	**OWS**	100	83.0	67.9	46.7	40.3	28.9	16.6	10.9	8.4	6.3
	JTS	100	84.4	72.8	42.3	38.7	31.4	25.9	12.6	8.0	6.2
	AS	99.4	78.8	68.7	46.7	40.9	31.2	18.8	12.1	8.0	6.0
	Spec	**100**	**95-66**	**88-52**	**70-37**	**52-26**	**40-18**	**30-13**	**23-8**	**16-6**	**4-10**
	Med	100	80.5	70.0	53.5	39.0	29.0	21.5	15.5	11.0	7.0

TABLE 3-37 asphalt mix properties using two Method for all samples

Method	Mix properties	A/C of aggregate	Air voids	VMA%	VFA %	Stability kn	Flow 0.25 mm
Bailey	**OWS**	4.7	4.0	15.0	70.0	1230	3.1
	JTS	5.0	4.0	14.7	72.0	1120	3.3
	AS	4.6	4.0	15.2	69.0	1200	3.0
Tradition	**OWS**	5.4	4.0	17.5	77.0	1200	3.5
	JTS	5.3	4.0	16.0	74.0	1090	3.4
	AS	5.2	4.0	16.5	75.0	1100	3.3
Ms-2 Specification		**_**	**3 -5**	**15.0**	**65 - 75**	**Min 800**	2- 3.5
AASHTO Specification		**_**	**3 -5**	**16 - 20**	**70 - 85**	**Min 800**	1- 4

Chapter 4

Conclusion and Recommendations

4.1 Conclusions

Explain the Bailey Method and it can be used to choose aggregate blend combination.

Sample ,test and analyze samples of aggregates obtain from three different sources in Khartoum state.

The following results are found, based on the findings of this thesis:

- A aggregate blend combination by using Bailey Method analysis process was coarser than using tradition method (trial and error).
- Coarse blend provide low VMA value.
- Low VMA provides rut-resistant mixture, adequate asphalt binder and good durability.

Marshal properties using Bailey Method to determine aggregate blend more satisfy to specification than tradition method.

4-2 Recommendations

The concepts outlined in this study provide the foundation for a mixture comprehensive design procedure. This procedure would allow the structure to be designed to create coarse aggregate interlock providing aggregate skeleton to resist deformation.

The resulting aggregate blend packing characteristics can be evaluated with the aggregate ratios to understand the void structure in the mixture.

However, there are crucial elements in

a mix design procedure that were not possible to study in this thesis.

Further study is required in the following:

- The performance of mixtures, measured by mechanical property tests, designed using the concepts given in this study should be evaluated.

-An evaluation of mixtures with more than one coarse and fine aggregate should be performed to illustrate the effect of changing aggregate shape and surface texture on the volumetric properties and performance of the asphalt mixtures.

-With continued research, the concepts provided in this study will become the state of the art in asphalt mixture design; establishing the next mixture design method, "The Bailey Method for Asphalt Mix Design."

The following recommendations are made, based on the findings of this thesis:

- A modified Bailey Method analysis process should be incorporated into the mix design process as an additional tool to develop and select trial blends for the design of dense-graded mixes.

- Additional sieves should be included (No.16, No.50, No.100) during aggregate quality control testing and included in the Quality Level analysis.

- Standard spreadsheets should be developed for rapidly computing the ratios.

- Ratio criteria should be provided for information initially and eventually adopted as design criteria.

- Contractor Mix Design Training (CMDT) should incorporate some form of Bailey Method analysis for the coming training season.

- Provide more suitable equipment for more practicing to this method.

- Encourage more researches in Bailey Method and give chance for application in the field.

Bailey method provides much needed assistance to the designer to ensure the mixes are designed to provide required volumetric properties and better performance.

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