بسم الله الرحمن الرحيم

Sudan University of Science and Technology
College of Graduate Studies

Field and Laboratory Investigation of the Influence of Fine Aggregate Angularity on Rutting of Flexible Pavement

A Case study - Khartoum State

دراسة حقلية مختبرية عن اثر الشكل الزاوى للركام الناعم في التخدد فى الرصف المرن - دراسة حالة فى ولاية الخرطوم

A Thesis Submitted in Partial Fulfillment for MSc degree in Civil Engineering (Highway and Transportation Engineering)

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Dedication

To my late brother Hythem, my parents and my family for their understanding and unlimited patience without their support this work would have not been possible

Abstract

The primary purpose of this study is to identify the causes of rutting in highway pavements in the form of channelization particularly on wheel tracks resulting from high traffic repetitions and environmental effects. The rutting reduces the required performance due to poor hot mix asphalt (HMA) components and construction to mention a few. The study focused on the impact of fine aggregate angularity (FAA) to increase Asphalt layer stability.

AASHTO testing method (T 304) was applied at the expense of uncompacted void content as a measure to determine the fine aggregate angularity index. Through the selection of samples of fine aggregate natural and crushed used in the production of hot mixt asphalt in Khartoum State by adopting Asphalt Institute requirements as described in Superpave design method, in Relation between Angularity and Traffic volume (ESAL) .

This study applied Marshall Design method in the evaluation of properties of asphalt mixture voids, stability and other indicators to assess the results in producing accepted mixture with good performance. The study also included data collection on producing crushed aggregate, quarry sources and suitability for hot mix asphalt within Khartoum state to study the cause of rutting in the Ring road and Elsteen Street as case study in order to link the angularity and texture with the both process of crushing aggregate and various type crushers available.

Data analysis has shown the high FAA value increase the stability. For the proper matching between all mixes properties, the mix should not be design to optimize one particular property mixes. Also the finding from this study indicate that regarding the existing HMA in the Ring road the fine aggregate angularity with blended natural and crushed aggregate is suitable for the current ESAL according to Asphalt Institute requirements.

التجريد

الغرض الاساسى من البحث هو دراسة ظاهرة التخدد والتى تظهر فى شكل اخاديد وهبوط فى مسار الايطارات، والناتج من زيادة الاحمال و حركة المرور وكذلك نتيجة لضعف الخلطة الاسفلتية او لسوء احدى مكوناتها والتى تقلل من الاداء المطلوب على الطرق . وقد تركزت الدراسة فى اثر الشكل الزاوى للركام الناعم فى زيادة احتمال حدوث التخدد باعتماد طريقة الاشتو للاختبارات مواد النقل والطرق (T 304) فى حساب محتوى الفراغات للركام غير المدموك كمقياس لتحديد مؤشر الشكل الزاوى للركام الناعم وذلك من خلال اختيار عينات من الركام الناعم الطبيعى والمصنع المستخدم فى انتاج الخلطات الاسفلتية فى ولاية الخرطوم لدراسة الحالة فى كل من الطريق الدائرى وشارع الستين وذلك باعتماد متطبات معهد الاسفلت الامريكى الموصوفة فى طريقة السوبربيف لربط قيمة الشكل الزاوى والملمس بحجم المرور على الطرق الاسفلتية .

لتقييم النتائج تم الاعتماد على طريقة مارشال لدراسة خواص الخلطة الاسفلتية كنسبة الفراغات والثبات والانسياب والمؤشرات لاخرى لتصميم خلطة قادرة على الاداء الجيد. تشمل الدراسة كذلك جمع معلومات عن طرق انتاج الركام الناعم من خلال جمع معلومات عن الكسارات المستخدمة ومقالع الحجر المتوفرة فى حدود ولاية الخرطوم ومدى ملائمتها لانتاج الخلطة الاسفلتية الساخنة وكذلك لربط الشكل الزاوى للركام المنتج بعملية انتاج الحجر من خلال الانوع المختلفة الكسارات الموجوده.

من خلال عملية تحليل البيانات الخاصة بالاختبارات المعملية التى اجريت تلاحظ ان زيادة معدل الرقم الزاوى للركام الناعم تزيد من ثبات الخلطة ومقاومتها للتخدد فلموامة جميع خواص الخلطة يجب عدم الاعتماد على خاصية واحدة . وايضا من مخرجات البحث فى ان الشكل الزاوى للركام الناعم والمتكون من الحجر الطبيعى والمكسورالمستخدم فى الطريق الدائرى مناسب حسب حجم المرور الحالى وذلك حسب متطلبات معهد الاسفلت الامريكى

ACKNOWLEDGEMENTS

I would like to thank those individuals who were instrumental in the completion of this research. Specially, I would like to thank my supervisor, Professor Dr. Galal A. Ali for willingly sharing his knowledge, guidance, encouragement and patience His support and enthusiasm is greatly appreciated.

My special thanks are also extended to Arab Center for Engineering Studies.

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ABBREVIATIONS

CBR	California Bearing Ratio
AASHTO	American Association Of State Highway And Transportation Material
FHWA	Federal Highway Administration
NHA	Sudanese National Highway Authority
FAA	Fine Aggregate Angularity
HMA	Hot Mix Asphalt
C S	Crushed Stone
G_a	Apparent Specific Gravity
G_e	Effective Specific Gravity
G_{mb}	Bulk Specific Gravity of Compacted Mixture
G_{sb}	Bulk Specific Gravity of Aggregate
G_{se}	Effective Specific Gravity of Aggregate
G_{mm}	Maximum Specific Gravity of Mixture (Zero Air Void)
Pb	Percent of Bitumen
Av	Percent of Air Void
VMA	Void in Mineral Aggregate
VFB	Void Filled with Asphalt
BBR	Proving Ring Reading
ESAL	Equivalent Single Axel Load
N. sand	Natural Sand
N. Filler	Natural Filler
NP	Non Plastic
STI	Shape Texture Index
VSI	Vertical Shaft Impactor
HSI	Horizontal Shaft Impactor
NAA	National Aggregate Association
SAG	Semi- Autogenously Grinding Mill

CHAPTER ONE

INTRODUCTORY BACKGROUND AND LITERATURE REVIEW

1.1 Introduction

Pavement rutting is the accumulation of permanent deformation in all or a portion of the layers in a pavement structure that results in distorted pavement surface .The overall objective of this study was to develop recommendations for more rut resistant asphalt concrete mixtures .Also accomplish project objectives a plan of study that include analysis of rutting data from Khartoum ring road and Elsteen street

The main purpose of road construction is to reduce congestion in the center of the capital and to facilitate the passage of trucks coming from Port Sudan to the other States without access to the center of Khartoum. From the Initial condition survey of the surface failure shown the rutting failure in some portions of the road

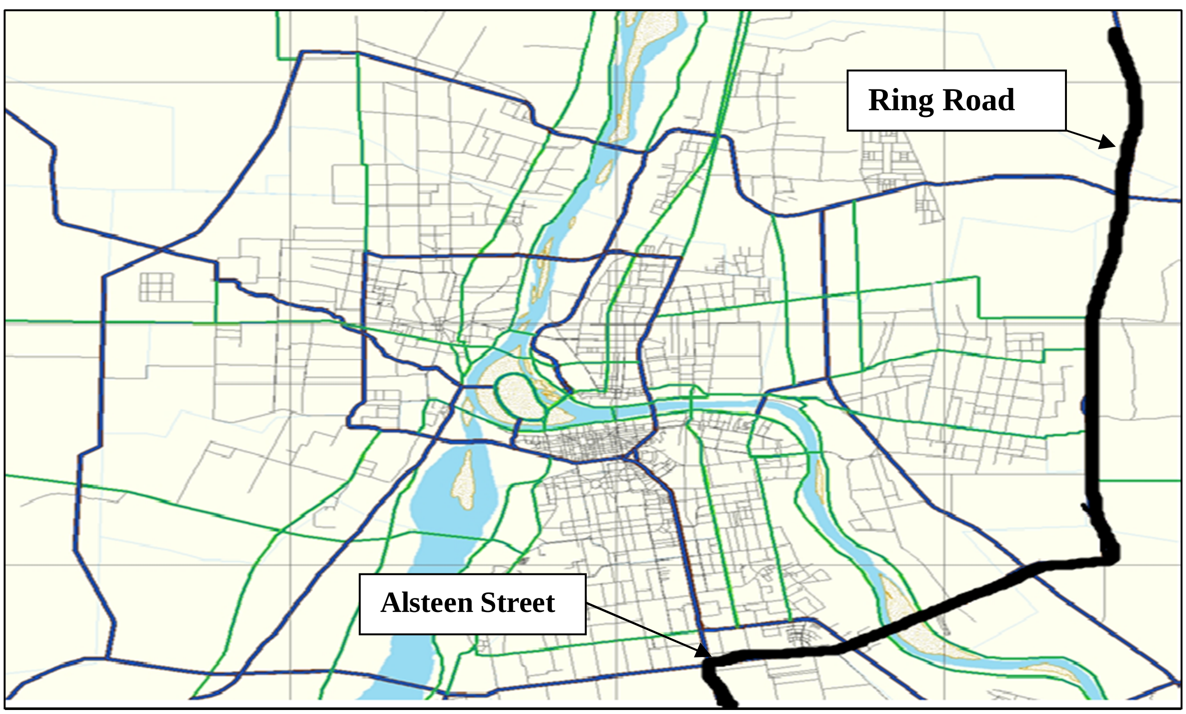


Figure 1.1: Ring Road & Alsteen Street in Khartoum State

The rutting is defined as a permanent deformation of the pavement surface that develops in the wheel paths under traffic due to the permanent deformation in the HMA layer the main reason is the following:

- High traffic volume
- Poor construction quality control
- Decreased quality of mix components

Super pave mix design attempted to increase the sheer strength by requiring course aggregate with some fractured faces and manufacture sand with angularity measured by the fine aggregate angularity (FAA) test .The stability need to resistance the permanent deformation has many contributing factor, which can summarized as:

- Friction

The variable that can consider in friction is surface roughness of particles, inter granular contact pressure due to compaction and loading and asphalt amount

- Cohesion

Variable that can consider is rheological properties of the asphalt, aggregate gradation and surface area, aggregate density and adhesion between asphalt and aggregate

- Inertia (resistance of deformation)

The variable can consider is magnitude of load, rate and duration of loading and mass of paving mixture.

Since the approximately 90% of the total volume of mixture consist of aggregate the performance of HMA mixtures is greatly affected and influenced by the properties of the aggregate blend specially the shape and texture.

From the primary survey for crushed aggregate production in Khartoum, state from the available sources we can consider the average production is range between 40 and 30 % is fine aggregate moreover all the plant has large quantity of fine crushed sand as stoke hence they using the about two third rom fine aggregate in normal asphalt concrete with one third as natural sand

1.2 Problem Definition

Over the past ten years; road traffic (both passenger and freight) has grown significantly and loading is progressively getting worse due to the introduction of newer and more powerful trucks with heavier in Sudan. Moreover Khartoum state is capital with all highway roads crossing in consequently; premature rutting in the form of shear flow in flexible pavements has been observed during high ambient temperatures. Highway Authority in Khartoum state has been facing serious threats like, frequent pavement failures, poor riding quality and high maintenance cost.

In the ring road designed as free way to link the highway from the main Sudan port in the red sea coast with other highway to Aljazeera state and White Nile state as shown in the map in figure (1.1) high rutting in the wheel bath has been observed as shown in figure (1.2)

Figure 1.2: Rutting in Wheel Pass in Khartoum Ring Road

1.3 Research Objectives

The research described in this report was conducted and analyzed to achieve the following objectives:

- To evaluate the influence of fine aggregate particle angularity and texture on permanent deformation characteristics of HMA mixtures.

- To characterize and quantify aggregate shape and texture with performance related fine aggregate tests.
- To develop relationships between physical properties of fine aggregates and the permanent deformation characteristics of HMA mixtures by using Marshall design method.
- To estimate acceptable range of using natural fine aggregate in HMA in Khartoum.

1.4 Literature Review

Much research has been conducted concerning the effects of aggregate properties and characteristics on the quality and performance of HMA mixtures. Moreover several methods have been proposed for fine aggregate evaluation.

A review of this research has been conducted and summarized into general categories that best relates fine aggregate properties to the performance of HMA mixtures in the below mention categories.

1.4.1 Rutting Related to the FAA by Using Superpave Method

- *Chih-Jen Lee, Thomas D. White Terry R. West* “Effect of Fine Aggregate Angularity on Asphalt Mixture Performance” The objectives of this research were to address effects of fine aggregate angularity (FAA) on asphalt mixture rutting performance. Six fine aggregates were selected for this study and eighteen mixtures were designed using the Superpave volumetric mix design incorporated in Phase II mixtures were used to increase the mastic stiffness, change the VMA and decrease the resistance to compaction, respectively. However With lower asphalt content and denser mineral aggregate structure, the rutting performance was also improved
- *Anthony D. Stakston, ,Hussain U. Bahia* the title of the study “The Effect of Fine Aggregate Angularity, Asphalt Content and Performance Graded Asphalts on Hot Mix Asphalt Performance The following are the major conclusions of this research do not support the assumption that higher values of FAA would always result in better performing mixtures. In

addition, findings of this study show the effect of FAA to be highly dependent on the source of the aggregates. It is, therefore, difficult to suggest a limit on FAA independent of the source that would improve quality of asphalt mixtures. 2.) The findings indicate that mixtures with fine aggregates of high FAA values are more difficult to compact in the SGC than those with low FAA values.

1.4.2 Rutting Related to the FAA by Using Marshall air Voids

- *E.R. Brown, Stephen A. Cross* the title of the study is "A study of in-place rutting of asphalt pavements" The results of this study show that mixes can be produced to support today's traffic. The pavements evaluated, which had rutted under traffic in most cases appeared to have rutted due to low air voids (in recompacted samples and/or in the field). Only two of the pavements investigated had rutting sufficiently high to require rehabilitation.

One of the best indicators of rutting is low air voids in the laboratory compacted asphalt mixture. Satisfactory laboratory compaction effort (providing density approximately equal to that under traffic) must be utilized when compacting these samples.

A maximum flow of 1- 6 is often specified for mix design and construction control and that appears to be a reasonable number from the data presented in this study. Mixes having flow values above 1- 6 tended to have higher amounts of rutting.

1.4.3 Rutting Related to the FAA by Using Marshall Stability

- *Moore and Welke* conducted numerous asphalt mix designs to determine the effect of fine aggregate. They stated that the asphalt concrete mixture gradation and aggregate angularity were very significant in increasing the stability of mixtures. They reported that as the mixture gradation approached the Fuller curve for maximum density, the Marshalll stability increased. They also stated that the more angular the fine aggregate, the higher the stability. The study concluded that rounded fine aggregates (natural sands) produced lower stabilities than crushed fine aggregates.

- *Wedding and Gaynor* evaluated the effect of particle shape in dense graded asphalt concrete mixtures. The percentages of crushed and uncrushed coarse aggregates (plus No. 4) and the types of fine aggregate (minus No. 4) which included natural and washed concrete sands varied in the mixtures. A major finding from the analysis of the result the increasing of Marshalll Stability by increasing the percentage of crushed aggregate.
- *Kandhal and Wegner* conducted a study to determine the effect of crushed aggregate on properties of asphalt concrete for the Pennsylvania Department of Transportation. They found that replacing natural sand with crushed sand improved the Marshall stability and reduced permanent deformation. The authors also concluded that replacing uncrushed coarse aggregate with crushed coarse material did not significantly improve the asphalt mix properties.
- *Ahlrich* conducted a laboratory study to determine the influence of various amounts of natural sands on the engineering properties of asphalt concrete mixtures and to set quantitative limits of natural sand to prevent the use of unstable mixtures and reduce rutting potential. The study indicated that the use of natural sand materials decreased the stability and strength characteristics of asphalt concrete mixtures and that replacing natural sand materials with crushed sand materials increased the resistance to permanent deformation. The author found that the amount of natural sand did affect the results of the indirect tensile, resilient modulus and unconfined creep-rebound tests. The indirect tensile results indicated a reduction in mixture strength as the percentage of natural sand increased. The resilient modulus test results were very inconsistent and provided no discernable trend.
- *Herrin and Goetz* conducted a laboratory evaluation to determine the effect of aggregate shape on the stability of asphalt concrete mixtures. This laboratory study involved crushed and uncrushed gravel, crushed limestone for the coarse aggregate (plus No. 4), and natural sand and crushed limestone

sand for the fine aggregate (minus No. 4). In their tests, the strength of the mixture, regardless of the type of coarse aggregate, increased substantially when the fine aggregate changed from rounded sand to crushed limestone. A major finding was that the strength of the asphalt mixture affected more by a change in fine aggregate shape than a change in the coarse aggregate shape.

- Lottman and Goetz evaluated the effect of crushed gravel fine aggregate on the strength of asphalt mixtures. The authors found that the strength of asphalt mixtures increased when mixtures contained crushed gravel fine aggregate instead of natural sand fine aggregates. They stated that the increase in strength attributed to the angularity and the roughness of the crushed fine aggregate. The authors recommended that some amount of crushed fine aggregate could be used with natural sands in asphalt mixtures to produce sufficient stability for high quality pavements.

1.4.4 Rutting Related to the FAA Using Static and Repeated Load Triaxial Test Devices

- *Krutz and Sebaaly* evaluated the effects of aggregate gradation on permanent deformation of HMA mixtures for the Nevada Department of Transportation. This research study evaluated four aggregate gradations using two different aggregate sources and two asphalt binders. Each gradation falls inside the current FAA specification for 1 in. maximum aggregates, and they have the same shapes that follow the upper (fine), middle, and lower (coarse) limits. The HMA specimens were tested with static and repeated load triaxial test devices to determine the permanent deformation properties of each HMA mixture. The authors concluded that the type and source of the aggregate had an effect on how the HMA mixture performed. They stated that the "best" aggregate gradation may be dependent on the type and source of aggregate. The data consistently showed for all the HMA mixtures that the course (bottom band) aggregate gradation performed the worst and that the finer gradations (middle and top band) produced better performing mixtures.

- *Button and Perdomo* conducted a study to evaluate the effects of natural sands on permanent deformation and to quantify the influence on resistance to plastic deformation when natural sand replaced with crushed fine aggregate. The study showed that total deformation and rate of deformation increased as the percentage of natural sand increased. The shape and texture of the fine aggregate were major factors controlling plastic deformation in asphalt concrete mixtures. The authors recommended replacing natural sand material with manufactured sand to increase the resistance of the asphalt concrete pavement to permanent deformation.

1.4.5 Study of the Relation Between the Rutting and the (STI) Value

- *Jiminez* evaluated the Shape-Texture Index (STI) test as a method to measure shape and texture of sands. This test procedure (modified Rex and Peck) measured the flow rate (time) of minus No. 8 aggregate to determine the shape and texture characteristics (i.e., the flow time increases as the angularity and roughness of the aggregate increase). The author stated that this test procedure was economical and easy to perform and produced results that correlated very well with sand shape and texture properties.

1.4.6 Rutting Related to the Aggregate Gradation Index

- *Randolph C. Ahlrich* Study based on the Influence of aggregate gradation and particle shape /texture on permanent deformation of hot mix asphalt pavement.

Based on the conclusions derived from the results of this research study, that Current aggregate specifications could be improved by implementing performance related aggregate properties determined by the Particle Index test and the NAA and modified NAA particle shape and texture tests. Initial preliminary guidance and criteria could be implemented based on values determined in this study, but final criteria should be establish based on additional research involving a variety of aggregate types and sources.

1.4.7 Rutting Related to the Method of Quality Control

- *Richard C. Menninger* the study about the important to develop test methods and specifications for constituent materials and for combinations of materials that related to pavement performance.

The key is developing evaluation procedures, which will give an accurate indication of the long-term performance of a mixture when it produced, placed, and compacted properly. An important corollary is the employment of reliable procedures for verification of mix performance as it is produce through the hot mix plant, and the use of quick quality control tests, which will verify that the desired mixture is being produce in a consistent manner.

1.4.8 Rutting Related to the Course Aggregate Crushed Face by Using Marshall Method

- *Yeggoni, Button and Zollinger* conducted a research study to evaluate the influence of coarse aggregate shape and texture on permanent deformation characteristics of HMA mixtures. The study also characterized the coarse aggregate physical properties and correlated these aggregate properties to the permanent deformation characteristics of HMA mixtures. The authors concluded that the coarse aggregate fraction did influence the performance of HMA mixtures (i.e., an increase in the percentage of crushed coarse aggregate resulted in an increased Hveem stability, Marshall Stability, and resistance to permanent deformation). The researchers also found a direct correlation between rutting potential of HMA mixtures and the shape of coarse aggregate particles.
- *Kalcheff and Tunnicliff* conducted a laboratory study to determine the effects of crushed aggregate size and shape on properties of asphalt concrete mixtures. They specifically evaluated the effect of coarse aggregate gradations, shape effects of fine aggregates, and effects of high mineral filler content. The laboratory specimens were produced with Marshall and Hveem

methods using aggregate blends composed of natural and manufactured sands. The optimum asphalt content was approximately the same for natural sand mixtures and manufactured sand mixtures if the sands had similar particle shape. The optimum asphalt content was higher if the manufactured sand had particles that are more angular. The authors found that asphalt concrete mixtures containing crushed fine aggregate were more resistant to permanent deformation from repeated loadings than comparable mixtures containing natural sand. The behavior of the asphalt concrete mixture improved when manufactured sands replaced natural sands.

- *Prithvi S. Kandhal, Maqbool A. Khatri, John B. Motter* the study Based on the results from the phases of this study using several natural and manufactured coarse and fine aggregates, the following conclusions can be drawn.

There is a significant relationship between the 2-face crushed count and particle shape and texture index of gravel coarse aggregate as measured by ASTM D3398. As the 2-face crushed count increases, the particle shape and texture of the coarse aggregate also increases. The results suggest that there is a sharp increase in the particle shape and texture index when the percentage of two faces crushed particles in the blend exceed 80 percent. The effect seems to be more pronounce for larger size coarse aggregate.

- *William Robert Vanrik* the study conduct on the Asphalt mixture design to concept to develop aggregate interlock The following are specific conclusions of this research:

The results of this study improve the state-of-the-art in asphalt mix design and production by providing a method to characterize HMA mixture voids (Air Voids, VMA, and VFA) and compaction characteristics through the fundamental principles of particle packing.

- *McLeod and Davidson* conducted an extensive laboratory study to determine the relationship between Particle Index and asphalt concrete mixtures. The authors concluded that aggregates with rounded particles and smooth surface textures have a Particle Index of six or seven or less, while aggregates with highly crushed angular particles have a Particle Index of 15 to

20 or more. This study produced a distinct relationship between Particle Index and Marshall Stability. They also concluded that the Particle Index of fine aggregate has a greater influence than the particle index of coarse aggregate on Marshall Stability.

- *Prithri S. Kendal ,john B,motter* Study based on the particle shape and texture index values obtained for the various natural and manufactured sands tested using ASTM D3398 and NAA's proposed methods A and B, the following

A particle index value of 14 seems to be dividing the natural and manufactured sands when using ASTM D3398. This value can probably be used for specification purposes when ASTM D3398 is used. All manufactured sands except one exhibit higher particle index values and all natural sands have lower particle index values.

CHAPTER TWO

FINE AGGREGATE ANGULARITY

2.1 Introduction

When the fine aggregate angularity plays a major role in the potential for rutting of an asphalt pavement performance of asphalt concrete mixes; true prediction and accurate estimation of probable behavior of mixes need to be investigated. In addition to the shear stress created by repeated wheel load applications exceeds the shear strength of the mix.

In this chapter Study the possible cause of rutting in HMA and the method of measuring the fine aggregate angularity as factor to study the influence resistance of sheer stresses to find relation between marshal stability as indicator for rutting resistance in hot mix asphalt.

2.2 Possible Causes of Rutting

2.3.1 Traffic induced

The lateral movement under traffic (rutting) can cause from traffic this type of rutting is very clear in Algaili – Khartoum Highway immediately after the link from Atbara to Port Sudan completed the rutting occurred in the Atbara -Khartoum section from the additional traffic load.

2.3.2 Insufficient Compaction.

The result of compaction degree done in this study for the existing base (1) and base (2) and sub base and embankment layers in the ring road shown in table (4.1) in the result of compaction degree in the base layer in the ring road the most of the section with Cause of rutting the compaction degree in average is equal to 90 % less than the required in the project specifications the results shown very clear that the rutting happen only in the portion with insufficient compaction.

Table 2.1: The Existing Compaction Degree in the Rutting Section

Change	Layer	0+650	4+400	7+600	Ave.	Project specification
Compaction Degree %	Base 1	87	86	88	87	98
Compaction Degree %	Base 2	87	90	97	86	98
Compaction Degree %	Emb.	87	83	77	83	90

2.3.3 Improper Mix design or manufacture

The high bitumen content more than the optimum content also can cause of rutting in addition of high content of fine material (mineral filler) in addition of reducing the void content which is very important to keep the asphalt layer extend during the hot climate without displacement in the asphalt surface layer.

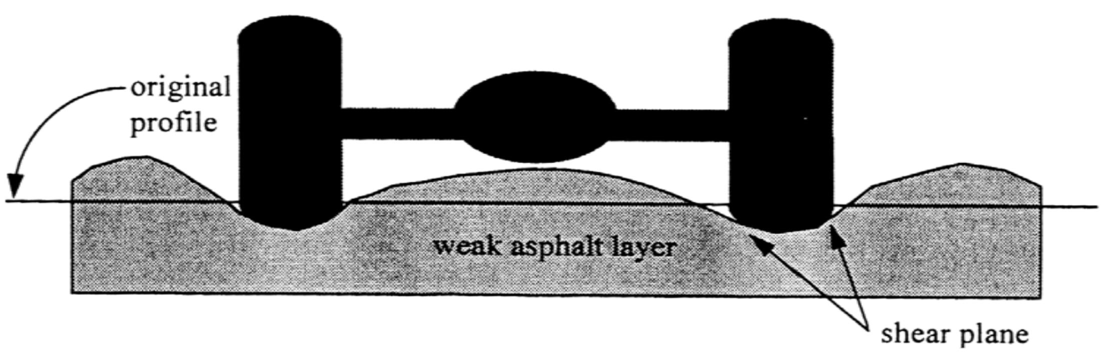


Figure 2.1: The Rutting in Hot Mix Asphalt (AI Superpave)

2.3 Fine Aggregate Angularity

2.3.1 Definition

Fine aggregate angularity can be defined as "The percent air voids present in loosely compacted aggregates smaller than 2.36 mm" (Asphalt Institute SP-2, 2003). Fractured faces are indicated by the void content measured as un-compacted void contents of fine aggregates (AASHTO T304). Greater the void contents more will be the fractured faces. High degree of internal friction and high shear strength for rutting resistance can be achieved by specifying this property. Particle shape, surface texture and grading influence fine aggregate angularity.

Aggregates shapes were measured using flakiness and elongated index gauges.

2.3.2 Test Method

This determination of the loose uncompacted of void content of sample of fine aggregate. when measured on any aggregate of known grading Void content provides an indication of that aggregate's angularity sphericity ,and surface texture compared with other fine aggregate test in same grading . When Void content is measured on as received fine aggregate grading, it can be indicator of the effect of fine aggregate on the workability of a mixture in which it may be used.

Three procedures are including for the measuring of void content.

- Standard grading sample (method A) this method uses standard aggregate grading that obtained by combining individual sieve fraction from typical fine aggregate sieve analysis .

- Individual size fraction (method B) this method uses each of the three fine size fractions: total of 190 gm. Can be select from the following :

  44 gm. from Retained in 2.36 mm (No. 8) passing 1.18mm (No. 16)

  57 gm. From Retained in 1.18 mm (No. 16) passing 600 µm (No. 30)
  72 gm. from Retained in 600 µm (No. 30) passing 300 µm (No. 50)

  17 gm. from Retained in 300 µm (No. 50) passing 150 µm (No. 100)

- As received Grading (Method C) this method Uses that portion of the fine aggregate finer than a 4.75 (No. 4)

In this method, the prepared sample is allowed to free-fall through a standard funnel of a specified diameter from a specified height into a small cylinder of known volume (nominal 100 mL).

The material is then leveled with the top of the calibrated cylinder and weighed. Because the volume and weight of the cylinder are known, the weight of the sample contained in the cylinder may be calculated. Using the Bulk Dry Specific Gravity (as determined by AASHTO T 84), the volume of the material in the cylinder is calculated. By subtracting the calculated volume of material from the calibrated volume of the test cylinder, the volume of voids may be calculated.

2.3.3 Summary of Test Result

A sample of sand is prepared in accordance with one of three methods. Method A, a standard gradation, is the most common used. The sample is allowed to free-fall from a funnel into a cylinder of known volume. Using the Bulk Dry Specific Gravity of the sample as determined by AASHTO T 84, the percent of void space in the cylinder is calculated. This value is known as the Fine Aggregate Angularity Value or FAA.

2.3.4 Apparatus

- Cylindrical measure, approximately 1.56 in. (39 mm) in diameter, 3.44 in. (86 mm) deep with a capacity of approximately 100 ml.
- Funnel, conforming to Figure (2.3) in AASHTO T 304.
- Funnel Stand, conforming to Figure (2.3) in AASHTO T 304.
- Glass Plate, for calibrating cylindrical measure.
- Pan, large enough to contain funnel stand and to catch overflow material. The pan shall not be warped so as to prevent rocking of the apparatus during testing.
- Metal spatula, with a straight edge approximately 4.0 in. (100 mm) long and 0.8 in. (20 mm) wide.
- Balance, accurate and readable to 0.1 grams.

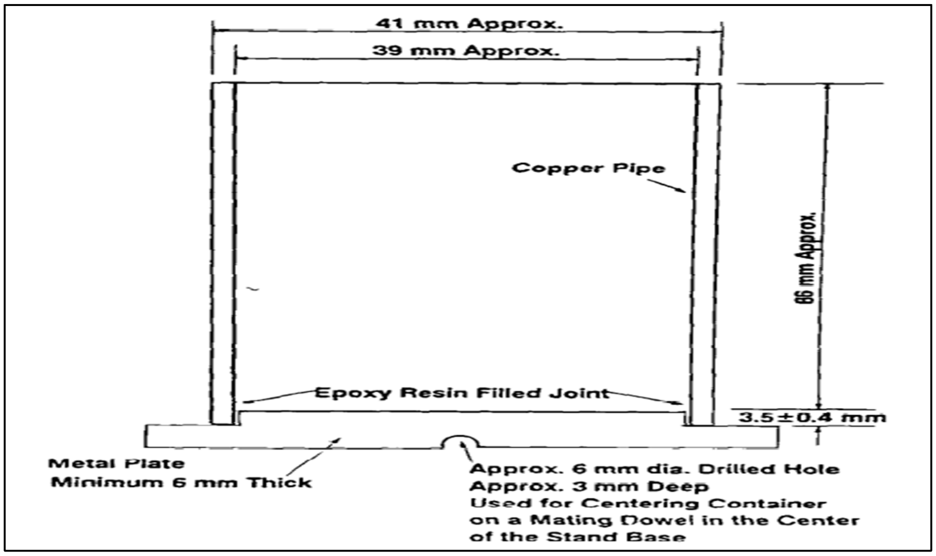


Figure 2.2: The Cylindrical Measure (AASHTO T04)

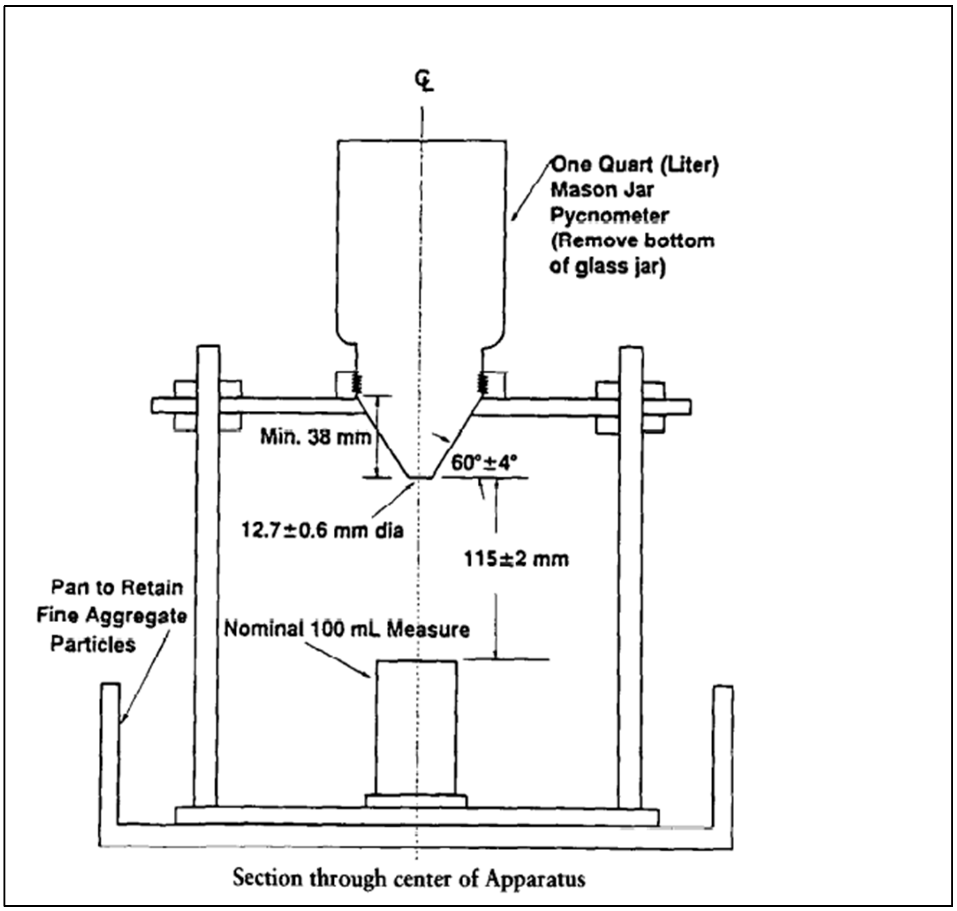


Figure 2.3: Suitable Funnel Stand Apparatus with Cylindrical Measure in Place (AASHTO T04)

2.3.5 Calculations

Calculate the uncompacted voids content as follows:

$$U = \frac{V - \left(\frac{F}{G}\right)}{V} 100$$

Where:

V = Volume of calibrated cylinder in mL (cubic centimeters)

F = Net Weight of Sample in cylinder (gross weight minus weight of empty cylinder)

G = Bulk Dry Specific Gravity as determined by AASHTO T 84

U = Uncompacted Voids in Percent (reported to nearest 0.1%)

Figure 2-4: Nominal 100 Cm3 Calibrated Cylinder Measure

Figure 2.5: Funnel Stand Apparatus

2.4 The Relation between the FAA and Sheer Strength

For fine aggregate with a given gradation, the void content determined from this test provides an indication of the aggregate's angularity, sphericity, and surface texture relative to other fine aggregates with the same gradation.

Let us consider a stockpile with crushed (angular) aggregate and one with rounded aggregates.

If both stockpiles are of equivalent mass, the crushed aggregate would form a steeper (greater angle of repose), more stable stockpile compared to the one with rounded aggregates. This is due to the greater degree of aggregate-interlock in the crushed aggregate stockpile.

This theory states that the shear strength of an aggregate mix (τ) is dependent on cohesion of the aggregates (c), the normal stress experienced by the aggregates (σ), and the internal friction of the aggregates (φ) as shown in the equation (2.1)

$$\tau = c + \sigma \tan \varphi \quad \text{……………………………..(2.1)}$$

By themselves, aggregates have relatively little cohesion. Therefore the source of shear strength in an aggregate mix comes primarily from the angle of internal friction. This angle of internal friction is higher for aggregates with good aggregate interlock.

Rounded aggregates, such as natural gravel and sands, are more workable and require less effort to compact. However, HMA mixtures comprised of rounded aggregates may continue to density under traffic loading and lead to rutting. Angular aggregates, on the other hand, are harder to compact due to the aggregate-interlock, which gives the mix greater shear strength.

These mixes tend to be more stable and resistant to rutting. Realizing this, many owner agencies have a minimum coarse and fine aggregate angularity requirement.

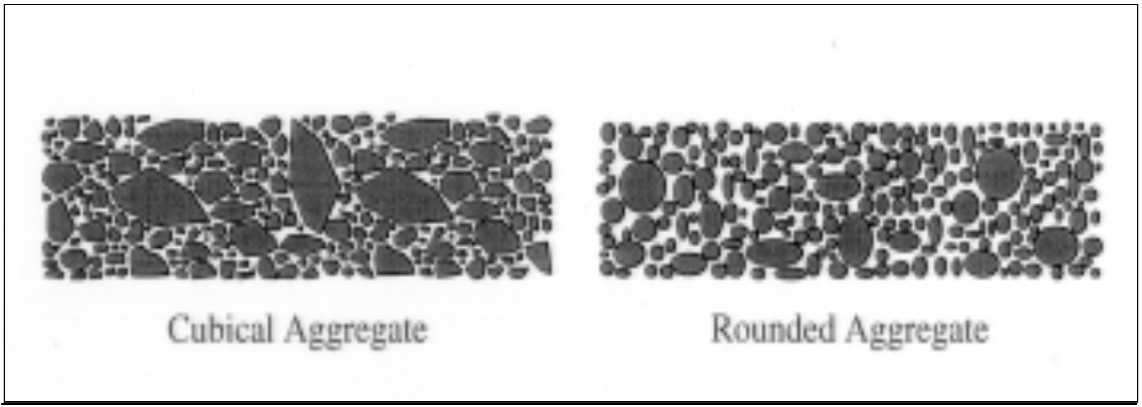


Figure 2.6: The Shape of Cubical and Rounded Aggregate in HMA

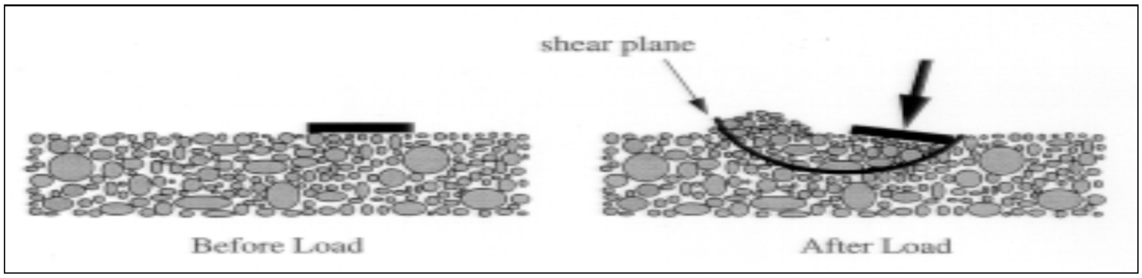


Figure 2.7: The Influence of Loading in the Asphalt Layer

2.5 Asphalt Mixture Requirements

Superpave procedures include specifications and recommendations for material properties of both the asphalt cement, fine and coarse aggregates used in hot mix asphalt (HMA).

Aggregate properties specified include fine and coarse aggregate angularity, flat and elongated particles (for coarse aggregate) and sand equivalency (for fine aggregate).

Superpave has defined limits on the angularity of fine aggregates used in HMA using the National Aggregate Association (NAA) test, Method A (also exists as AASHTO TP 33).

The purpose of these limits is to increase the mix's ability to resist excessive permanent deformation or rutting under traffic loading.

The previous Superpave limits were dependent on how much traffic the pavement is designed for (Equivalent Single Axle Loads, ESALS) and the depth from the surface of this layer that the mixture is designed for.
Table (2-2) shows the original Superpave requirements for Fine Aggregate Angularity (FAA).

Table 2.2: Superpave Fine Aggregate Angularity Requirements

Traffic	Original Superpave Specification		Wisconsin Dot Specification
ESALS (millions)	<100 mm	>100mm	AASHTO T304, Method A
<0.3	-	-	40
< 1	40	-	40
< 3	40	40	43
< 10	40	40	45
< 30	45	45	45
>= 30 <100	45	45	45
< 100	45	45	-
AMS			45

In 2000, new updated FAA limits were implemented in which the table was Simplified by remove the Depth categorization and adding more traffic categories.
This new version was adopted in Wisconsin in the 2000 edition of the State of Wisconsin Supplemental Specifications.

Table 2.3: Wisdom Fine Aggregate Angularity Requirements

Traffic ESALS (millions)	Fine Aggregate Angularity
< 0.3	40
0.3 - < 1	40
1 - < 3	43
3 - < 10	45
10 - < 30	45
> = 30	45
SMA	45

CHAPTER THREE

CRUSHED AGGREGATE PRODUCTION AND TYPE OF CRUSHER PLANTS

3.1 Introduction

The main objective of this study to find the influence of aggregate angularity in rutting on hot mix asphalt as known the angularity can be improved and adjusted during crushing process by using he suitable crusher type which can use in the quarry sources to achieve the best shape and angularity . This chapter concentrates on presenting the date collection about the crusher plant and sources and type of available quarry for the aggregate in addition to the sources of natural fine aggregate.

3.2 Production of Crushed Aggregate

Production of aggregate operations use crushers, commonly classified by the degree to which they fragment the starting material, with primary and secondary crushers handling course materials, and tertiary and quaternary crushers reducing ore particles to finer gradations.

Each crusher is designed to work with a certain maximum size of raw material, and often delivers its output to a screening machine which sorts and directs the product for further processing. Typically, crushing stages are followed by milling stages if the materials need to be further reduced. Additionally rock breakers are typically located next to a crusher to reduce oversize material too large for a crusher.

Crushers are used to reduce particle size enough so that the material can be processed into finer particles in a grinder. A typical processing line at a mine might consist of a crusher followed by a SAG mill followed by a ball mill.

In this context, the SAG mill and ball mill are considered grinders rather than crushers. In operation, the raw material (of various sizes) is usually delivered to the primary crusher's hopper by dump trucks, excavators or wheeled front-end loaders.

A feeder device such as an apron feeder, conveyor or vibrating grid controls the rate at which this material enters the crusher, and often contains a preliminary screening device which allows smaller material to bypass the crusher itself, thus improving efficiency.

Primary crushing reduces the large pieces to a size which can be handled by the downstream machinery. Some crushers are mobile and can crush rocks as large as 60 inches. Primarily used in-pit at the mine face these units are able to move with the large in feed machines (mainly shovels) to increase the tonnage produced.

In a mobile road operation, these crushed rocks are directly combined with concrete and asphalt which are then deposited on to a road surface.

This removes the need for hauling over-sized material to a stationary crusher and then back to the road surface.

3.3 Type of Crusher Plants:

The most of the crusher plant in Khartoum state is cone crusher which more suitable with available quarry sources in addition to high productivity. The main problem with cone crusher is shape of aggregate as mention blow the cone crusher need quantity in feeding when the cone is full of material the shape of aggregate will be more suitable. Table (3-1) shows the suitability of each type of crushers related to type of quarries.

- **A Jaw Crusher**

A jaw crusher uses compressive force for breaking of particle. This mechanical pressure is achieved by the two jaws of the crusher of which one is fixed while the other reciprocates. A jaw or toggle crusher consists of a set of vertical jaws, one jaw is kept stationary and is called as fixed jaw while the other jaw, called as swing jaw, moves back and forth relative to it, by a cam or pitman mechanism, acting like a class II lever or a nutcracker. The volume or cavity between the two jaws is called as the crushing chamber. The movement of the swing jaw can be quite small, since complete crushing is not performed in one stroke. The inertia required to crush the material is provided by a weighted flywheel that moves a shaft creating an eccentric motion that causes the closing of the gap.

Jaw crushers are heavy duty machines and hence need to be robustly constructed. The outer frame is generally made of cast iron or steel. The jaws themselves are usually constructed from cast steel. They are fitted with replaceable liners which are made of manganese steel, or Ni-hard (a Ni-Cr alloyed cast iron).

- **Gyratory Crusher**

A gyratory crusher is similar in basic concept to a jaw crusher, consisting of a concave surface and a conical head; both surfaces are typically lined with manganese steel surfaces. The inner cone has a slight circular movement, but does not rotate; the movement is generated by an eccentric arrangement.

A gyratory crusher is one of the main types of primary crushers in a mine or ore processing plant. Gyratory crushers are designated in size either by the gape and mantle diameter or by the size of the receiving opening.

Gyratory crushers can be used for primary or secondary crushing. The crushing action is caused by the closing of the gap between the mantle line (movable) mounted on the central vertical spindle and the concave liners (fixed) mounted on the main frame of the crusher.

- **Cone Crusher**

A cone crusher is similar in operation to a gyratory crusher, with less steepness in the crushing chamber and more of a parallel zone between crushing zones.

A cone crusher breaks rock by squeezing the rock between an eccentrically gyrating spindle, which is covered by a wear resistant mantle, and the enclosing concave hopper, covered by a manganese concave or a bowl liner.

A cone crusher is suitable for crushing a variety of mid-hard and above mid-hard ores and rocks. It has the advantage of reliable construction, high productivity, easy adjustment and lower operational costs. The spring release system of a cone crusher acts an overload protection that allows tramp to pass through the crushing chamber without damage to the crusher.

- **Impact Crusher**

Impact crushers involve the use of impact rather than pressure to crush material. The material is contained within a cage, with openings on the bottom, end, or side of the desired size to allow pulverized material to escape. There are two types of impact crushers one of most type of this crusher are (HSI) and (VSI)

- **Horizontal Shaft Impactor**

Horizontal shaft impactor crushers break rock by impacting the rock with hammers that are fixed upon the outer edge of a spinning rotor. HSI machines are sold in Stationary, trailer mounted and crawler mounted configurations. HSI's are used in recycling, hard rock and soft materials. In earlier years the practical use of HSI crushers is limited to soft materials and nonabrasive materials, such as limestone, phosphate, gypsum, weathered shales, however improvements in metallurgy has changed the application of these machines.

- **Vertical Shaft Impactor (VSI)**

VSI crushers use a different approach involving a high speed rotor with wear resistant tips and a crushing chamber designed to 'throw' the rock against.

The VSI crushers utilize velocity rather than surface force as the predominant force to break rockApplying surface force (pressure) results in unpredictable and typically non-cubical resulting particles.

Utilizing velocity rather than surface force allows the breaking force to be applied evenly both across the surface of the rock as well as through the mass of the rock. Rock, regardless of size, has natural fissures (faults) throughout its structure.

- **Mineral Sizes**

The basic concept of the mineral sizer is the use of two rotors with large teeth, on small diameter shafts, driven at a low speed by a direct high torque drive system. This design produces three major principles which all interact when breaking materials using sizer technology. The unique principles are the three-stage breaking action, the rotating screen effect, and the deep scroll tooth pattern.

Table 3.1: The Type of Crusher Plant with Suitable Type of Quarries

Type	**Hardness**	**Abrasion limit**	**Moisture content**	**Reduction ratio**	**Main use**
Compound crusher	Medium hard to very hard	Abrasive	Dry or wet, not sticky	3/1 to 5/1	Mine, Building Materials
Cone crushers	Medium hard to very hard	Abrasive	Dry or wet, not sticky	3/1 to 5/1	Quarried materials, Sand & gravel
Gyratory crushers	Soft to very hard	Abrasive	Dry to slightly wet, not sticky	4/1 to 7/1	Heavy mining, Quarried materials
Horizontal shaft impactors	Soft to medium hard	Slightly abrasive	Dry or wet, not sticky	10/1 to 25/1	Quarried materials, sand & gravel, recycling
Jaw crushers	Soft to very hard	No limit	Dry to slightly wet, not sticky	3/1 to 5/1	Heavy mining, Quarried materials, sand & gravel, recycling
Mineral sizer	Hard to soft	Abrasive	Dry or wet and sticky	2/1 to 5/1	Heavy mining
Vertical shaft impactors (autogenous)	Soft to very hard	No limit	Dry or wet, not sticky	2/1 to 5/1	Quarried materials, sand & gravel
Vertical shaft impactors (shoe and anvil)	Medium hard to very hard	Slightly abrasive	Dry or wet, not sticky	6/1 to 8/1	Sand & gravel, recycling

3.4 The Influence of Crusher Type in the Fine Aggregate Shape and Angularity

The main factor in production of fine aggregate:

- The stable flow during the crushing process
  The crusher plant need stable flow of stone to make the aggregate cubic and with good angularity when the crusher full of stone all the flacked and elongated stone well be crushed to the round and cubic shape .
- The best shape can product with impact crusher while the Cone crusher can be use when the aggregate need for other construction need
- The type of quarry source

The suitability crusher type more important in well shaped aggregate and good production need test the strength of quarry to use the suitable crusher

The fine aggregate product in different crushing plants in Khartoum, state with vary range of angularity .

CHAPTER FOUR

SOURCES OF HOT MIX ASPALT MATERIALS

4.1 Introduction

As in normal hot mix asphalt its composition of crushed aggregate, bitumen, natural sand, Filler and bitumen in this chapter we study the different type of sources and we can concentrate in crushed aggregate sources that used in Khartoum state.

4.2 Crushed Aggregate Types and Sources

Classification recent reports prepared by the Geological Research Authority of the Sudan (GRAS) and other workers in Khartoum State showed that there is a shortage in construction material (mainly crushed aggregate) due to the rapid development in Khartoum State. Tackling this issue by focusing mainly on searching for building material is the main objective of this study, putting in consideration all the economic and quality factors. The geological map mention in figure (4.1) had shown the sources of quarry that used in production of crushed stone. J.toria is the main source with many Construction companies plants the other sources in Alselate area.

4.2.1. J.Toria, Omdurman (Crushed Basalt)

Many crusher plants fixed in J.toria area table (3.1) shown the plants type with production per day in tons the variation of production value may be restricted by availability of the quarry because the J.toria is considered for many recent years is unique source of crushed aggregate used in construction in Khartoum state and in the other states with lack of material in many states like white Nile and Aljazeera state.

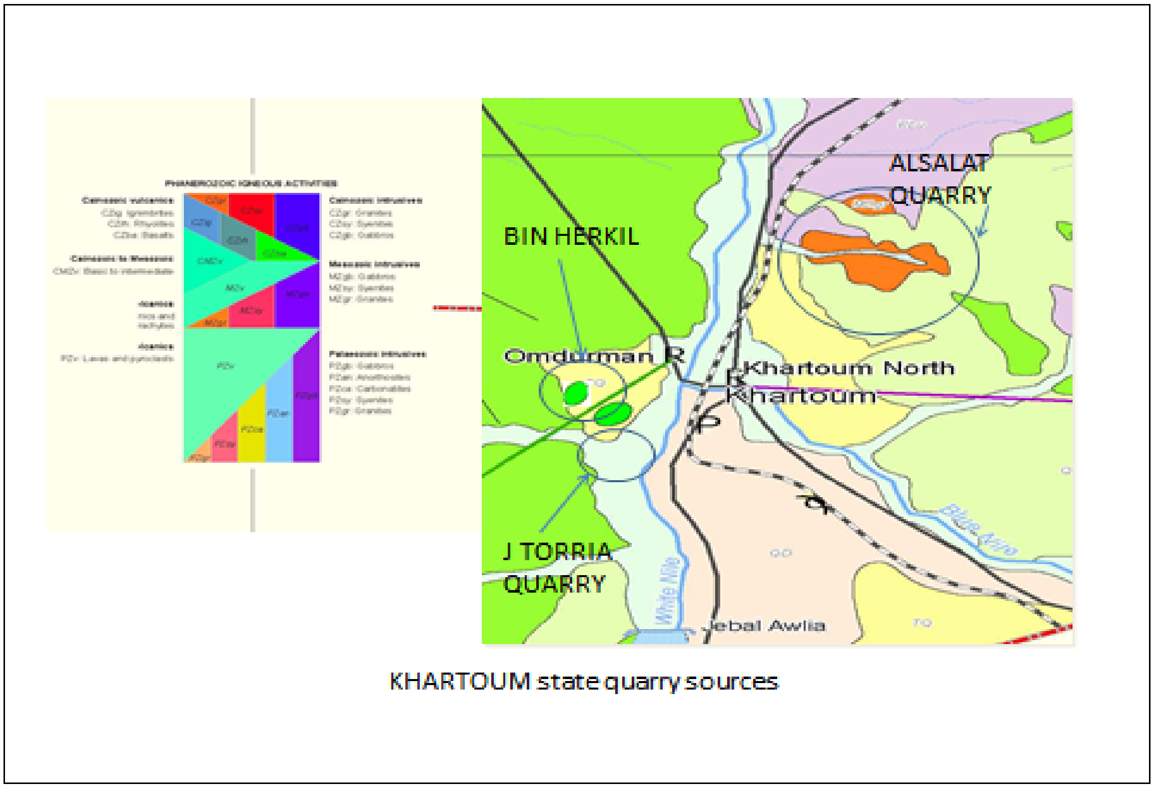


Figure 4.1 Main Quarry Sources in Khartoum State

Table 4.1: J.Toria Crusher Plans Production

#	Plant	Type	Productivity(ton /day)	Fine Agg. (%)
1	MAM	Impact crusher	200	30
2	ADAA	Impact crusher	250	30
3	REBIDA	Impact crusher	150	30
4	BETRODALTA	Impact crusher	200	30
5	ALRAGI	Cone crusher	300	30
6	KH.NATIONAL	Cone crusher	200	30
7	INJAZ	Cone crusher	200	30
8	TAYBA	Cone crusher	200	30
9	ALSHRIAN	Cone crusher	350	30
10	National	Cone crusher	150	30

4.2.2. Alalate, Khartoum North (Crushed Basalt)

The second sources of quarry in alsalte area north east Khartoum state the crusher plant throughout in large area and some plant need to haulage the quarry from 3-2 km from the plant location regarding to lake of quarry from the table (4-2) shown the plant production and the percentage of fine aggregate from the total crushed aggregate.

Table 4.2: Alsalate in Khartoum North (Syenite, Granite)

#	Plant	Type	Productivity (ton /day)	Fine agg.(%)
1	ALKOBANI	Cone crusher	250	20
2	TANA	Cone crusher	150	20
3	ALSADIG	Impact crusher	150	20
4	HIGLEIG	Cone crusher	350	30

4.2.3. South West Khartoum State

The third source of crushed aggregate in south west Khartoum state in Omdurman area only one company start in 2005 use that source with accepted quality but low quality than J.toria quarry table (4.3) shown the production and percentage of fine aggregate from total crushed aggregate

Table 4.3: West Omdurman Plants Using (Basalt)

#	Plant	Type	Productivity (ton /day)	Fine agg.(%)
1	RIDA for development (1)	Cone crusher	350	32
2	RIDAfor development(2)	Cone crusher	350	32

4.3 Sources of Natural Fine Aggregate

Sand is a naturally occurring granular materials composed of finely divided rock and mineral particles. The composition of sand is highly variable, depending on the local rock sources and conditions, The second most common type of sand is calcium carbonate, for example aragonite, which has mostly been created, over the past half billion years, by various forms of life, like coral and shellfish. It is, for example, the primary form of sand apparent in areas where reefs have dominated the ecosystem for millions of years like the Caribbean

4.4 Sources of Sand in Khartoum

There is many type of natural sand with different gradation from many sources normally the sand add with range of 10 to 20 percentage in hot mix asphalt The main purpose of using natural sand in hot mix asphalt to reduce the cost of HMA production.

In Omdurman we have many type of sand but the main source use in the available asphalt plant in J.toria from wady mandara about 30 km haulage distance.

- Well graded Medium sand
- Sand equivalent value about 85%
- Non plastic

IN Khartoum north there are about three asphalt plants the main source for this plant is Wad Asaad the sand from that source is

- Fine sand well gradient
- Sand equivalent value about 78%
- Non plastic
- 4- haulage distance 12 km

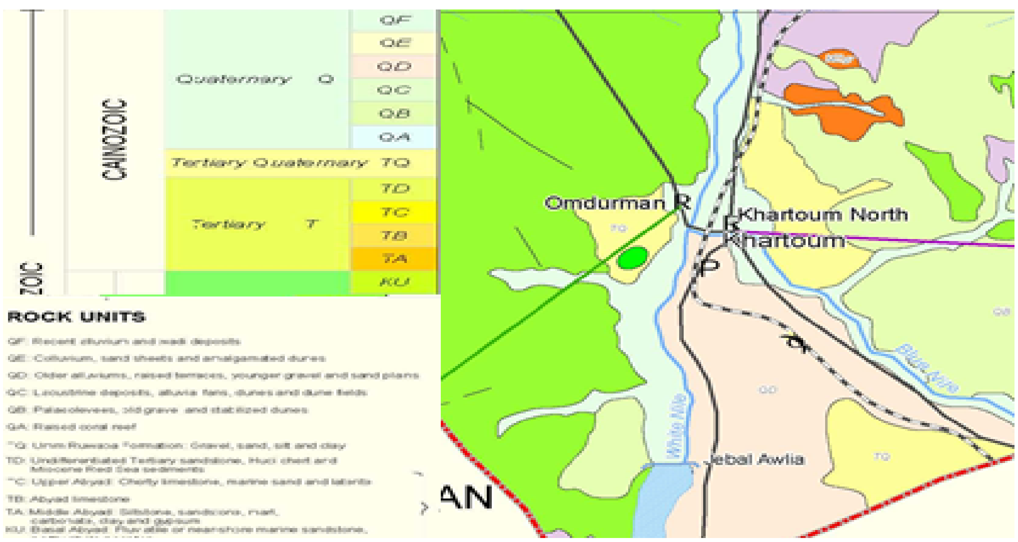
4.5 Sources of Mineral Filler

Mineral filler the material passing 0.075 mm (No. 200) sieve (have a significant effect on the performance of asphalt paving mixtures in terms of permanent deformation, fatigue cracking, and moisture susceptibility.

However, researchers have employed different characterization tests for evaluating the mineral filler materials. Mineral filler can influence the performance of HMA mixtures as follows. Depending on the particle size, fines can act as filler or as an extender of asphalt cement binder

In the latter case and over-rich HMA mix result leading to flushing and/or rutting. In many cases, the amount of asphalt cement used must be reduce to prevent a loss of stability or a bleeding pavement

Some filler have a considerable effect on the asphalt cement making it act as a much stiffer. Some fines make the HMA mixtures susceptible to moisture induced damage HMA mixtures as related to the properties of filler/asphalt combinations



Natural Aggregate sources

Figure 4.2: Sources of Natural Fine Aggregate in Khartoum State

Mineral filler normally use in hot mix asphalt in Khartoum state within 5 % before all construction company using mineral filler available in Algregreeb borrow pit in Aljazeera state middle of the country.

In the recent years regarding of widely development of road construction many highways under construction on all country using that source we facing lake of natural filler .And during the recent year’s many asphalt plants now using grinded calcium carbonate stone to be used as filler. Some plant using natural filler from Atabra area in Nile state in northern Sudan

4.6 Bituminous Materials

The costly part of hot mix asphalt in construction cost in Khartoum state the bituminous material with purchase from out site Sudan with lake of foreign currency. The cost of one ton of bitumen about 1000 USD mainly export from Egypt, Saudi Arabia and Iran

Recently the ministry of urban planning and infrastructure starting to provide the bitumen to the contractor to avoid the impact of the inflation to the contract of road construction value but it’s also affected the quality control and quality assurance procedure.

CHAPTER FIVE
LABORATORY TESTING

5.1 Introduction

The main object of the study to fine the relation between fine aggregate angularity and Possible Causes of rutting by measuring the stability indicator for the shear resistance and the flow as indicator to strain as permanent deformation on wheel track happen on HMA due the load repetition

The samples brought from the available sources and the most of the HMA contractors companies

Al the test done with same components of the HMA accept the fine aggregate to keep all the parameters constant to show the effect of the fine aggregate in the Marshall properties

5.2 Sampling of Fine Aggregate

Five samples of the normally used fine aggregate from available source that used production of HMA:

5.3.1 Crushed Aggregate:

- First sample brought to the laboratory from the crusher plants in J.toria in Omdurman the best fine aggregate products in J.toria crusher plant
- The second sample brought to the laboratory from Alslate quarry source only three crushing plant are available we select the Alsadig crusher plant (the contractor for the ring road)
- Third sample brought to the laboratory from 20 km west Omdurman. quarry source only one crusher plant available in that location as mention in the figure (3.1)

5.3.2 Natural Aggregate

- The fourth sample brought to the laboratory from J.mandara 25 km south Omdurman
- The fifths samples brought to the laboratory from wad Asad pit in Alslate area.

5.3 Classification Testing

The main test for the aggregate need for suitability test done for samples from the different source to compare between engineering properties to show if there were any variations between the sources

5.3.1 Source Properties

Toughness (Los Angeles Abrasion Test) (AASHTO T96)
Soundness (AASHTO T104)
Deleterious materials (Clay Lumps & Friable Particles) (AASHTO T112)

5.3.2 Consensus Properties

Toughness (Los Angeles Abrasion Test) (AASHTO T96)
Soundness (AASHTO T104)
Deleterious materials (Clay Lumps & Friable Particles) (AASHTO T112)

Table 5.1 Course Aggregate Tests Result

#	**test**	**Khartoum Specification**	**Sample sources**		
			J.TORIA	ALSALATE	West Omdurman
1	Los Angles (%)	Less than 40	15	38	23
2	Absorption (%)	Less than 2.0	1.5	2.1	1.6
3	Flakiness (%)	Less than 25	12	56	34
4	Elongation (%)	Less than 25	17	45	22
5	Soundness (%)	Less than 2.0	0.33	0.97	0.45

5.4 Natural Aggregates Tests:

There were many sources of natural fine aggregate (sand) available in Khartoum state the sample brought to the laboratory from the sources that used in production of HMA the main source for the natural fine aggregate for all the asphalt plant in Omdurman from J. mandara area

For the asphalt, plant in Khartoum north is the natural sand from wady Alslate in wad as ad area

Table 5.2: Natural Fine Aggregate Test Results

#	test	Khartoum state Specification	Sample	
			Mandara	Wad asad
1	Sand equivalent (%)		90	83
2	Plasticity	NP	NP	NP
3	Angularity (U_R)		39.1	38.1

5.5 The Bituminous Materials

Sample of Iranian asphalt had been used in this study the sampling brought from one of J.toria asphalt plants we note that this asphalt supplied by the Khartoum state government. Because the costly part of asphalt, mixture is bituminous material (1000 USD/ ton).

To solve this problem the Khartoum state government starts to supply the bitumen and discount the cost of bitumen from the total cost of asphalt layer, but this had effect the quality control activities and now many contractors clam the quality of bitumen the below mention table shown the result of bitumen sample had been used in this study.

Table 5.3: Bitumen Test Result

#	Test	Result	Khartoum state sp.
1	Penetration (mm)	64	60 -79
2	Flash point (C°)	608	-
3	Fire point (C°)	626	-
4	Softening point (C°)	48	35 -55
5	Ductility	105	More than 100

Figure 5.1 Sampling of Bitumen in J.Toria Plants

5.6 Mineral Filler:

All the asphalt plants now using grinded calcium carbonate powder during this period all the plant replace natural filler from Algragreb area. The sample that used in this study brought to the laboratory from J. Toria

Table 5.4 Mineral Filler Test Results

Sieve size (mm)	Sample Gradation	Specification
No.30(0.600)	100	100
No 50(0.300)	100	95-100
No.200(0.075)	90	70-100
Plasticity	NP	Less than 4%

5.7 Fines Aggregate Angularity Results:

To study the effect of fine sand angularly the five samples of sand were prepared in accordance with Method (A), standard gradation, is the most common used. The sample is allowed to free-fall from a funnel into a cylinder of known volume. Using the bulk dry Specific Gravity of the sample as determined by AASHTO T 84, the percent of void space in the cylinder is calculated. This value is known as the Fine Aggregate Angularity Value (FAA).

Table 5.5: Uncompacted Void Content of Fine Aggregate)

Un Compacted void content of fine Aggregate AASHTO Designation :T304-08						
Sample No.	Sample Description	Sample Source	Bulk Dry S.G.	Vol. of cy. meas. (mL)	Net mass (F)	U_R (%)
A	C.S.	J.toria	2.65	100	159.4	39.8
B	C.S.	Al salate Cobani	2.64	100	147.9	44.0
C	C.S.	W. Omdurman	2.63	100	145.97	44.5
D	Natural sand	Mandara	2.65	100	164	38.1
E	Natural sand	Salate (wad asd)	2.655	100	161.75	39.1

Figure 5.2: The Prepared Samples for Angularity Test

5.8 Fine Aggregate Gradation

Table (5.6) and figure (5.3) shows in each sample gradation analysis, and the gradations curves. From the results the sample brought from j.Toria (Petrodalta) crushing plant is better than the other samples. Also from visual inspection the crushed fine sand from Petrodalta crushing plant more cubic than the other two crushed fine aggregate which particles looking more flecked and elongated.

Table 5.6: Fine Aggregate Gradations

sieve size (mm)	passing percentage				
	J. toria	Alslate	west Omdurman	Mandara	wadasad
9.5	100	100	100	100	100
4.75	100	98	99	100	100
2.36	91	72	64	99	100
1.18	66	46	17	96	99
0.6	45	26	6	78	96
0.3	28	13	3	42	74
0.15	16	7	2	12	33
0.075	7	2	1	3	15

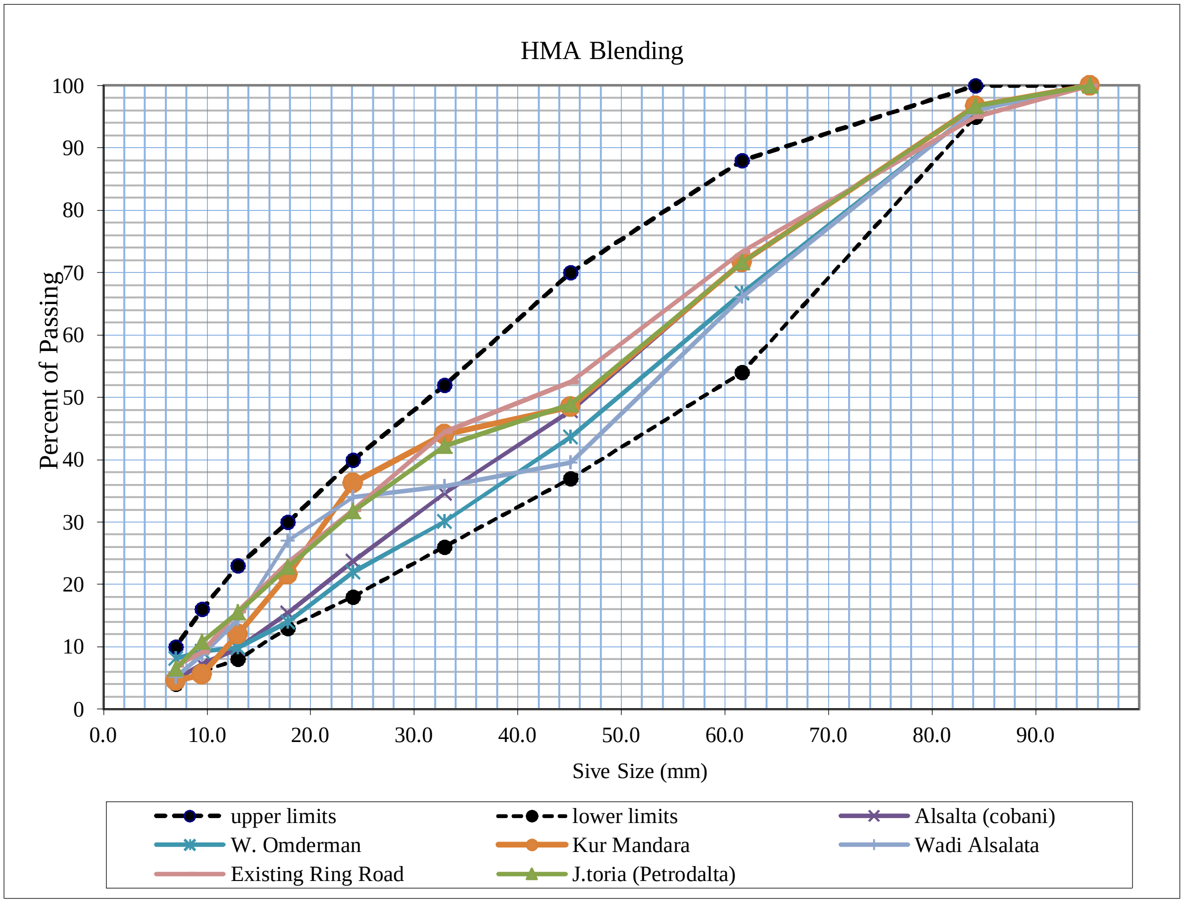


Figure 5.3: Fine Aggregate Gradation Curves

5.9 Marshall Tests

Sample from the best source of course aggregate with sample of best mineral filler and sample bitumen had been selected to be used with all five sample of fine aggregate to fine the impact of the FAA on the mix properties

- Marshall stability
- The flow
- The stiffness
- Air void
- Void in mineral aggregate
- Void filled with asphalt

The mix combination selected according to ministry of physical planning specification by using J.toria crushed aggregate with fine aggregate from same source to fine the effect of fine aggregate same percentage of bitumen had been used in five-trail mix.

All other parameter fixed with only change in fines aggregate angularity. The material blended with different percentage to achieve the grading requirements

Each sample used in to blend with same course aggregate and same for design in addition to test Maximum specific gravity test done for each sample to calculate mix properties, AV, VMA and the other properties.

In all the trail mix with different type of fine aggregate the optimum asphalt content vary from (4.8 %to 5.2%) , to get clear effect of the angularity the seven sample done with average asphalt content around to 5.0 % from the total mix

The first three samples blended with crushed fine aggregate and the other two samples blended with fine aggregate (crushed plus natural)

5.10 Proposed Blending

- Asphalt institute requirements with local gradations requirement used to select the best HMA gradation to be used in aggregate gradation.

- The five sample had different value of angularity with variation in gradations analysis therefore to study the effect of fine aggregate angularity the five sample had been mixed with different percentage to keep the gradation within the gradation limits in addition to avoid in effect of gradation

- First sample prepared with J.toria Betrodalta crusher plant with value of angularity value Equal to 40 % .the best gradation from the five samples can be obtained by using the crushed sand from Betrodalta as mention in chapter two the best shape of course and fine aggregate can be obtained from the impactor crusher.

- Second trial mix blended with fine crushed aggteragte from Alslate Area in Khartoum north (Alkobani crusher plant) with course aggregates from Betrodalta crusher plant in J.toria Appendix (A) shown the blended gradation.

- The third sample blended with west Omdurman Fine Crushed Aggregate Appendix (A) shown the blending need to be improved by adding the missing fraction especially from (sieve size 0.425 mm to 2.0 mm).

- Natural fine aggregate used in the blending of the fourth sample with crushed course aggregate from Betrodalta the Gradation of the blended material within the upper and lower limits as shown in Appendix (A) but need improvement by adding the more fine material .this size normally available in crushed fine aggregate moreover the sand from Kur Mandara more courser than the other fine natural aggregate. in this sample the filler is increased to improve the gradation curve but normally the manufacture filler is more fine than the natural filler this is the reason that the filler cannot improved the gradation without the crushed fine aggregate.

- The fifth sample blended with Alslate Natural fine aggregate the sample brought to the laboratory from wad asad area about 15 Km north the Khartoum state. Appendix (A) shown that the gradation much more better than the blending with mandara fine aggregate the main reason that sources and type the fine Aggregate from wad Asad consider more fine but still the size from (0.3 mm to 2.0mm was missing the gradation need to add some amount of this size which it available with crushed fine aggregate.
- Two samples blended with both crushed and natural fine aggregate with different percentage one done with same mix composition as done in the ring road .The second one done with more Natural sand percentage as shown in Appendix (A).

CHAPTER SIX

DATA ANALYSIS AND RESULTS

6.1 Introduction

This chapter mainly focused on the statistical estimation by using scatter gram to find the relations between the FAA and the different Marshall properties the stability, flow, AV, VMA, VFB, density and the stiffens are measured with different FAA values .The final goal of this study is establishing method or criteria for the suitability of FAA value that can improve all the HMA properties with a balance among all of the desired properties.

6.2 Summary of Test Results

Table 6.1 shows the summary of Marshall Test results with various FAA values from the different sources

Table 6.1: Summary of the Test Results

Sample No.	Sample Description	Sample Source	UR (%)	Density	AV
A	C.S.	J.toria	39.8	2.421	4.7
B	C.S.	Alslate	44.0	2.342	5.1
C	C.S.	W.om.	44.7	2.329	9.2
D	N. sand	J.mandara	38.1	2.440	3.7
E	N. sand	wad asad	39.1	2.423	6.5

Table 6.1: Summary of the Test Results (Con.)

Sample No.	Sample Description	VMA	VFB	Stability	Flow	Stiffness
A	C.S.	12.8	62.9	9.8	3.3	2.9
B	C.S.	15.5	67.3	11.4	4.6	2.5
C	C.S.	16.1	43.3	10.6	5.5	1.9
D	N. sand	12.0	71.6	7.1	2.1	3.3
E	N. sand	12.6	48.5	8.0	2.8	2.9

6.3 Effect of FAA on HMA Bulk Density:

AASHTO standard mention that the uncompacted void content provides an indication of that aggregate angularity and surface texture, the plot below the clear relation between the FAA and density of HMA. The increase of U_R% value makes the decrease of bulk density in HMA as shown in figure (6-1) with $R^2 = 0.9921$

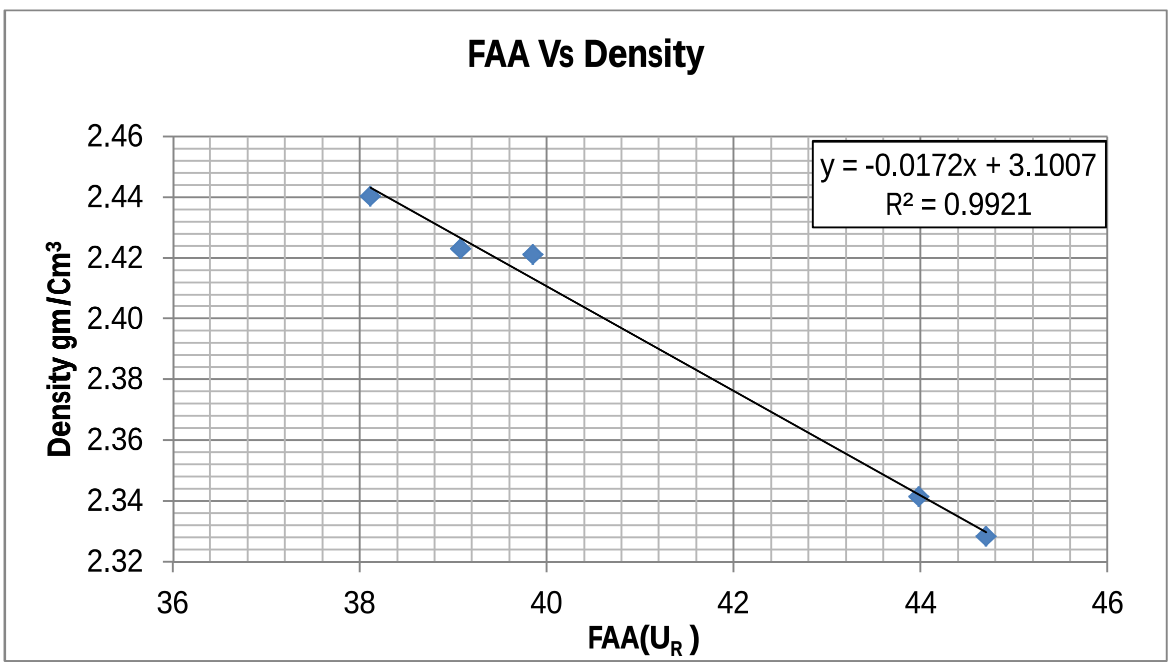


Figure 6.1: The Relation between the FAA (U_R) and Bulk Density

6.4 Effect FAA on HMA Bulk Air Void

High void content are frequently associated with mixes found to have high permeability by permitting circulation of air and water through the pavement ,may leads to premature hardening of the asphalt raveling of aggregate or possibly stripping of the asphalt off the aggregate even though stabilities are satisfactory.

The R^2 Equal to 0.4127 as shown in figure (6.2) for the Relation between the FAA and the air void may be this relation is effect by the bitumen content from the basic principle we can consider the increase of FAA can increase the air Void and may be more tests need to get best more fitting trend line

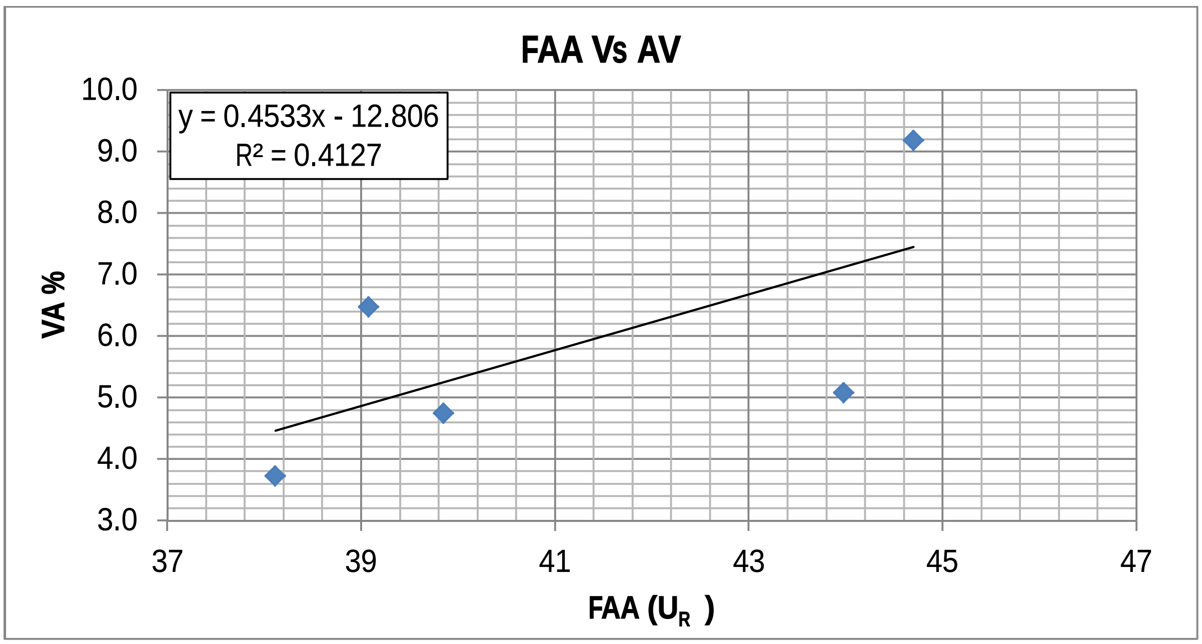


Figure 6.2: The Relation between the FAA (U_R) and Air Void

6.5 Effect of FAA on HMA Void in Mineral Aggregates

The most difficult mix design property to achieve is a minimum amount of voids in the mineral aggregates.

The goal is to furnish enough space for the asphalt cement so it can provide adequate adhesion to bind the aggregates particles but without bleeding when temperature rise and asphalt expand.

The chart of the relation between the FAA and the void in mineral aggregate shows that the VMA value is increase with the increase of void content as mention in figure (6.3) with R^2 value equal to 0.996

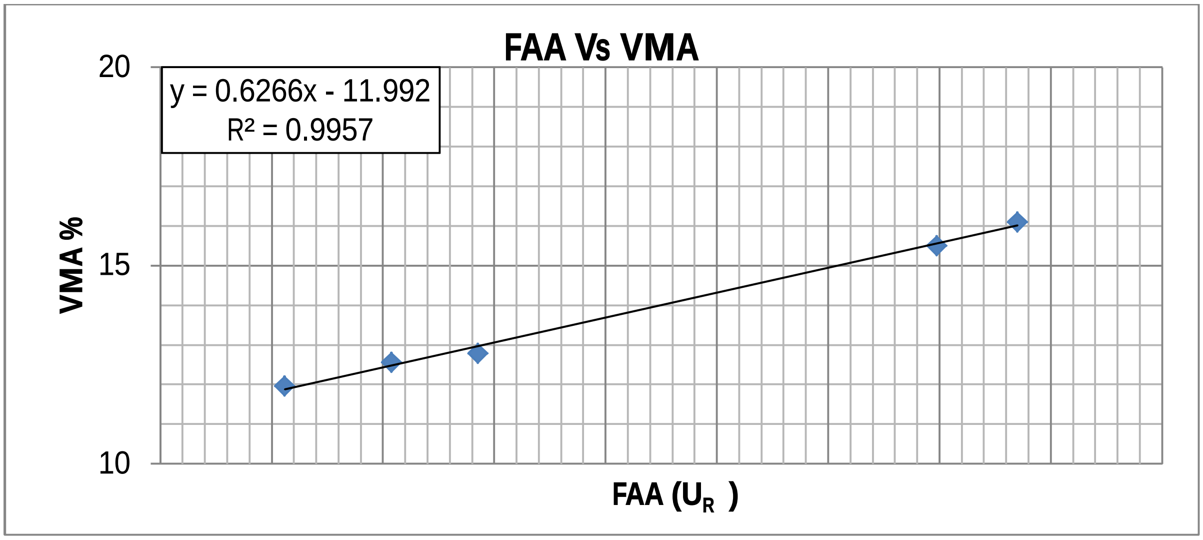


Figure 6.3: The Relation between the FAA (U_R) and VMA

6.6 Effect of FAA on HMA Void Filled with Asphalt (VFA)

The VFA criteria provide an additional factor of safety in the design and construction process in the term of performance

As mention in the asphalt institute (ms_2) that the VFA criteria helps to avoid those mixes that would be susceptible to rutting in heavy traffic situations.

To avoid the effect of asphalt content which had strong relation with VFA in term of find the relation between the FAA and the void filled with asphalt, the plotting in figure (6.4) shows there acceptable relation between the FAA and VFA in addition to the R^2 value is equal to 0.84 shows there is no strong relation

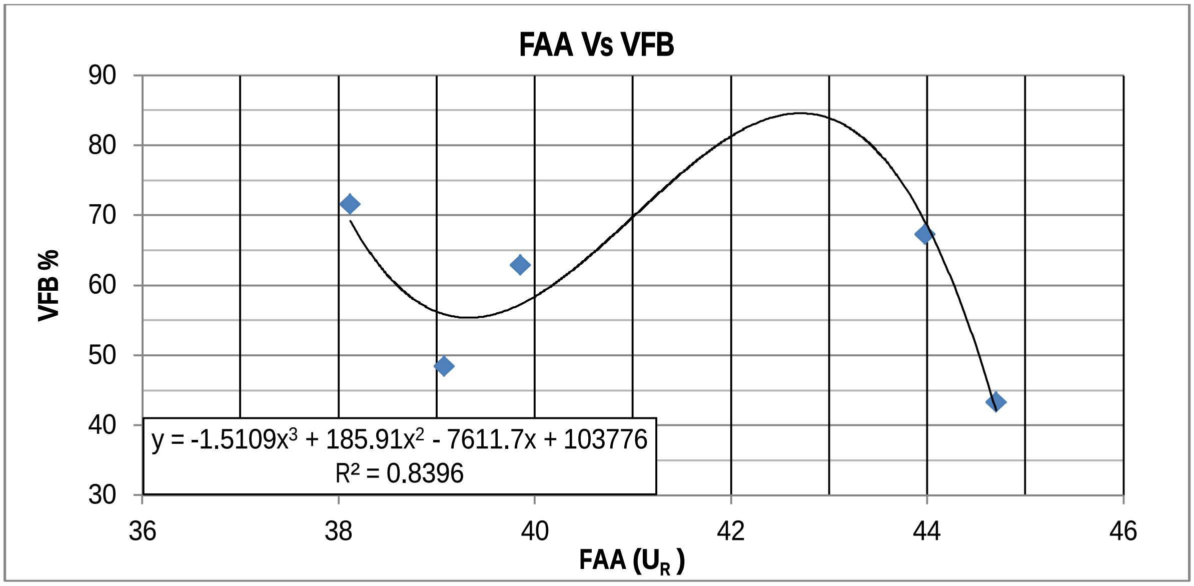


Figure 6.4: The Relation between the FAA (U_R) and VFB

6.7 Effect of FAA in Marshall Stability

Strong reason between the FAA and stability shown as mention in figure (6.5) the FAA, with R^2 value equal to 0.82 as acceptable indication for fine aggregate angularity, more angularity will increase the Marshall stability

All the trail shown satisfactory value of stability and on the other hand we need to match the values of FAA with other mix properties like the voids content to find good performance with high durability.

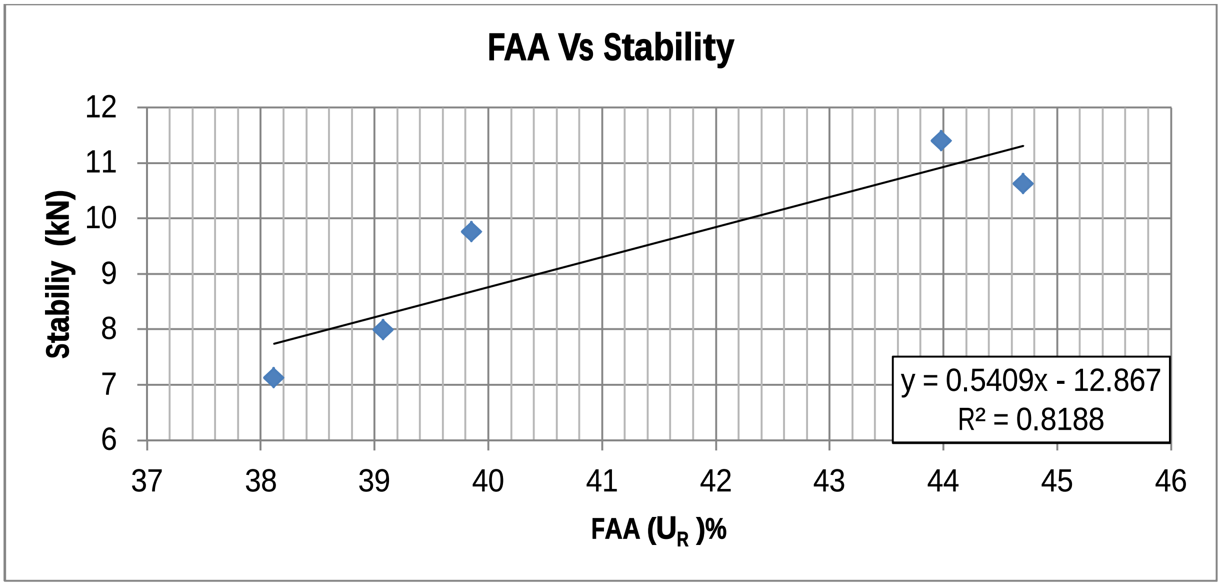


Figure 6.5*:* The Relation between the FAA (U_R) with Marshall Stability

6.8 Effect of FAA on Marshall Flow

Due to heavy traffic movement in addition to deferent between day and night temperatures we need to take into account the flow factor as major factor show the flexibility of hot mix asphalt.

figure (6.6) with R^2 value equal to 0.96 shows the increase of FAA value will increase the flow value, the main reason is the density of HMA mix the high density will decrease the flow value and make the HMA mix more rigid and resist the mix to flow.

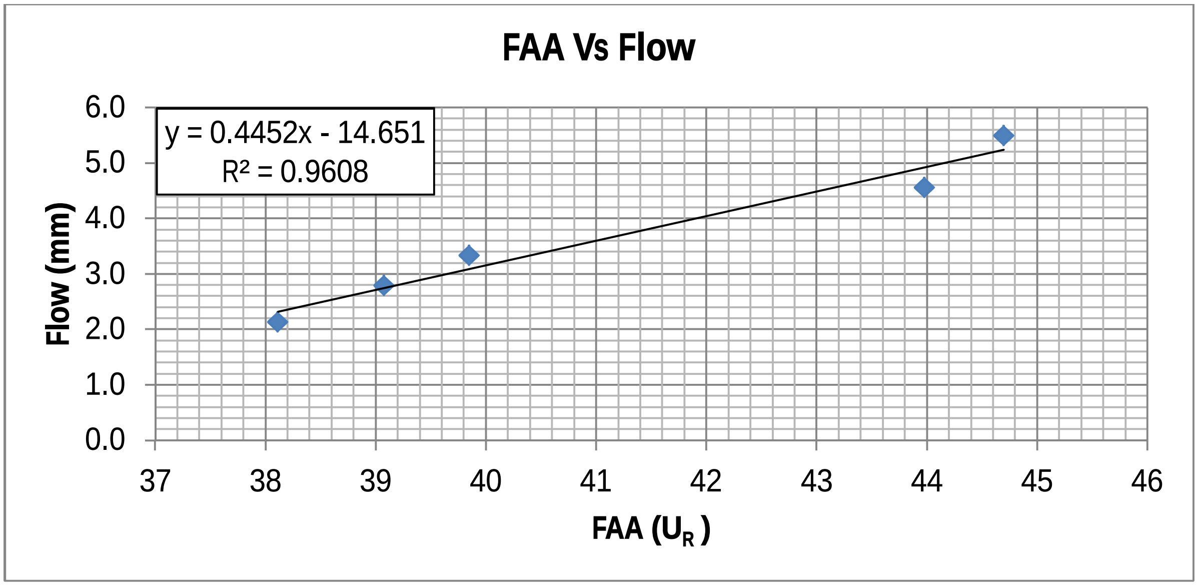


Figure 6-6*:* The Relation between the U_R with Marshall Flow

6.9 Blended Sample

The last two samples were done with blending of crushed and natural fine aggregate, with blending of crushed and natural aggregate

- 15% Natural +20 % crushed
- 15% Natural +30 % crushed

The first one same with existing HMA in the ring road from the extraction of existing HMA in the ring road the angularityalreadywithin 43 and according to super pave requirements with existing traffic about $3*10^6$ the requirements as showed in table (2.2) and in table (2.3) WISDOT Fine Aggregate Angularity Requirements must be U_R value more than 43 %

In addition to take the durability and long performance of HMA mix in account, as mention above all the other sample give satisfactory value of stability with high value of air void

The gradations of the two blended sample looking better than the other samples which it had been done with only one type of fine aggregate either crushed or natural.

CHAPTER SEVEN

SUMMARY, CONCLUSIONS AND RCOMMENDATIONS

7.1 Summary

Since the overall objective of this study was to develop recommendations for more rut resistant asphalt concrete mixtures and to accomplish project objectives a plan of study the include field investigation, sampling of existing asphalt layer , collecting sampling of material from the available sources and testing of material and data analysis .

Tests results of the collected sample around the area of study shows the HMA properties were affected by the vary FAA values. The stability was improved with increase of FAA values.

Ultimate pavement performance related to the durability impermeability, strength, stability, stiffness, flexibility, fatigue resistance and workability can achieve with proper matching between all the mix properties. The mix should not be designed to optimize a particular property.

Mixes with normally high stability are often desirable balance pavement with such mixes tend to be less durable and may crack prematurely under heavy volume of traffic. This situation is especially critical where the base and subgrade material beneath the pavement are weak and permit moderate to relatively high deflection under the actual traffic

7.2 Conclusions

The objective of the hot mix asphalt is to determine the combination of asphalt cement and the aggregate that will provide long term performance. This can be achieved through compromising among all HMA properties. Analysis of varies mixes led to the flowing outcomes:

- The FAA values increased the stability of the HMA as well as increasing the air void
- With gradation improvement Marshall Parameters AV, VMA, VFB and the stability improved.
- The FAA value of the extraction samples from existing asphalt layer in the Ring road shows it's suitable with current ESAL according to Asphalt Institute requirements.

- The cause of rutting in some portion of the ring road cause from the construction methodology as shown in field density test for the base 1 and base 2 layers the average density is about 90%. less than the required in the specifications

7.3 Recommendations

1. Additional amount of natural sand (15 % – 20%) will make the gradation better compering to only using crushed sand and the gradation improved by adding the missing fraction.
2. With bad production of crushed fine aggregate the value of FAA increases without improvement of rutting resistant. This can be noted from some samples of crushed fine aggregate. The shape of the samples showed the particles are more flecked and elongated. This may make the value of FAA high without improvement of HMA mix properties.
3. The fine aggregate angularity must be taken into account when considering as such, it is recommended that FAA be included in the specifications for the suitability of HMA as recommended in Asphalt institute design method (Superpave).
4. More samples need to be test to improve the R value for the relation between the FAA vs. air void and FAA vs. Void filled with between.
5. Although the effect of FAA on density, stability, VMA and the flow of the HMA mixture was defective and significant high value of R^2 this was not the case with the AV and VFB requiring the following additional recommendation number 6
6. In some of the correlation results the value of the correlation coefficient (R^2) were observed to be low. This might be due to limited sampling variations and few number of test points it is thus recommended to increase sampling sources, testing more samples.

   It is anticipate that such recommendation will improve the mix design correlation models.

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Appendix (A)

Material blending & blending chart

Table (A-1) blending with J.toria (Petrodalta) crushed fine aggregate

Sieve size	#	1 "	3/4 "	3/8 "	No. 4	No. 8	No.16	No. 30	No. 50	No. 100	No. 200
	mm	25	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
C.S 3/4	petrodlta	100	87	1	1	1	0	0	0	0	0
C.S 3/8	Petrodlta	100	100	88	12	2	1	0	0	0	0
C.S 3/16	Petrodla	100	100	100	100	91	66	45	28	16	7
N.sand											
N. filler		100	100	100	100	100	100	100	91	88	79
HMA Blending with Crushed fine aggregate (Petrodalta)											
Sieve size	%	1 "	3/4 "	3/8 "	No. 4	No. 8	No.16	No. 30	No. 50	No. 100	No. 200
		25	19	10	5	2	1.18	0.6	0.3	0.15	0.075
C.S 3/4	25	25	22	0	0	0	0	0	0	0	0
C.S 3/8	30	30	30	26	4	1	0.3	0	0	0	0
C.S 3/16	40	40	40	40	40	36	26.4	17.8	11	6.4	2.6
N.sand	0	0	0	0	0	0	0	0	0	0	0
N. filler	5	5	5	5	5	5	5	5	5	4	4
blending	**100**	**100**	**97**	**72**	**49**	**42**	**32**	**23**	**16**	**11**	**7**
mid point		100	100	80	68	50	30	15	6	6	6
upper		**100**	**100**	**88**	**70**	**52**	**40**	**30**	**23**	**16**	**10**
lower		**100**	**95**	**54**	**37**	**26**	**18**	**13**	**8**	**6**	**4**

Table (A-2) blending with Alsalte (Alkobani) crushed fine Aggregate

Sieve size	#	1 "	3/4 "	3/8 "	No. 4	No. 8	No.16	No. 30	No. 50	No. 100	No. 200
	mm	25	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
C.S.3/4	J.toria	100	87	1	1	1	0	0	0	0	0
C.S.3/8	J.toria	100	100	88	12	2	1	0	0	0	0
C.S.3/16	Alsalate	100	100	100	97.5	72	46	26	13	7	2
N. sand		0	0	0	0	0	0	0	0	0	0
N. filler	J.toria	100	100	100	100	100	100	100	91	88	78.5
HMA Blending with Crushed fine aggregate (Alsalte)											
C.S.3/4	25	25	22	0	0	0	0	0	0	0	0
C.S.3/8	30	30	30	26	4	1	0	0	0	0	0
C.S.3/16	40	40	40	40	39	29	18	10	5	3	1
N. Sand	0	0	0	0	0	0	0	0	0	0	0
N. filler	5	5	5	5	5	5	5	5	5	4	4
blending	100	100	97	72	48	35	24	15	10	7	5
mid point		100	98	71	54	39	29	22	16	11	7
upper		100	100	88	70	52	40	30	23	16	10
lower		100	95	54	37	26	18	13	8	6	4

Table (A-3) blending with West Omdurman (Benherkil) crushed fine aggregate

Sieve size	#	1 "	3/4 "	3/8 "	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200
	mm	25	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
C.S.3/4	J.toria	100	87	1	1	1	0	0	0	0	0
C.S.3/8	J.toria	100	100	88	12	2	1	0	0	0	0
C.S.3/16	w. Omdurman	100	100	100	99	64	16.5	5.5	2.5	1.5	1
N.sand		0	0	0	0	0	0	0	0	0	0
N.filler		100	100	100	100	100	100	100	91	88	78.5
HMA Blending with Crushed fine aggregate (west Omdurman)											
C.S.3/4	30	30	26.1	0.3	0.3	0.3	0	0	0	0	0
C.S.3/8	30	30	30	26.4	3.6	0.6	0.3	0	0	0	0
C.S.3/16	30	30	30	30	29.7	19	5	2	1	0	0
N.sand	0	0	0	0	0	0	0	0	0	0	0
N.filler	10	10	10	10	10	10	10	10	9	9	8
blending	100	100	96	67	44	30	15	12	10	9	8
mid point		100	97.5	71	53.5	39	29	21.5	15.5	11	7
upper		100	100	88	70	52	40	30	23	16	10
lower		100	95	54	37	26	18	13	8	6	4

Table (A-4) (blending with Omdurman (mandara) Natural fine Aggregate

Sieve size	#	1 "	3/4 "	3/8 "	No. 4	No. 8	No.16	No. 30	No. 50	No. 100	No. 200
	mm	25	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
C.S 3/4	J.toria	100	87	1	1	1	0	0	0	0	0
C.S 3/8	J.toria	100	100	88	12	2	1	0	0	0	0
C.S 3/16											
N. sand	mandara	100	100	100	99	95.5	77.5	41.5	12	3	0.5
N. filler		100	100	100	100	100	100	100	91	88	78.5
HMA Blending with N. fine aggregate (mandara)											
C.S 3/4	25	25	21.75	0.25	0.25	0.25	0	0	0	0	0
C.S 3/8	30	30	30	26.4	3.6	0.6	0.3	0	0	0	0
C.S 3/16	0	0	0	0	0	0	0	0	0	0	0
N. sand	40	40	40	40	39.6	38.2	31	16.6	4.8	1.2	0.2
N. filler	5	5	5	5	5	5	5	5	5	4	4
blending	**100**	**100**	**97**	**72**	**48**	**44**	**36**	**22**	**9**	**5.6**	**4.1**
mid-point		100	100	80	67.5	50	30	15	5.5	5.5	5.5
upper		**100**	**100**	**88**	**70**	**52**	**40**	**30**	**23**	**16**	**10**
lower		**100**	**95**	**54**	**37**	**26**	**18**	**13**	**8**	**6**	**4**

Table (A-5) blending with Alsalte (wad asad)Natural fine Aggregate

Sieve size	#	1 "	3/4 "	3/8 "	No. 4	No. 8	No.16	No. 30	No. 50	No. 100	No. 200
	mm	25	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
C.S. 3/4	J.toria	100	87	1	1	1	0	0	0	0	0
C.S. 3/8	J.toria	100	100	88	12	2	1	0	0	0	0
C.S. 3/16											
N. sand	salate	100	100	100	100	99	95.5	73.5	33	14.5	4
N. filler		100	100	100	100	100	100	100	91	88	79
HMA Blending with N. fine aggregate (wad asad)											
C.S. 3/4	30	30	26.1	0.3	0.3	0.3	0	0	0	0	0
C.S. 3/8	35	35	35	30.8	4.2	0.7	0.35	0	0	0	0
C.S. 3/16	0	0	0	0	0	0	0	0	0	0	0
N. sand	30	30	30	30	30	30	29	22	10	4	1
N. filler	5	5	5	5	5	5	5	5	5	4	4
blending	100	100	96	66	40	36	34	27	14	8.8	5.1
mid point		100	100	80	67.5	50	30	15	5.5	5.5	5.5
upper		100	100	88	70	52	40	30	23	16	10
lower		100	95	54	37	26	18	13	8	6	4

Table (A-6) blending with crushed 20% and Natural 15%fine aggregate

Sieve size	#	1 "	3/4 "	3/8 "	No. 4	No. 8	No.16	No. 30	No. 50	No. 100	No. 200
	mm	25	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
C.S. 3/4	J.toria	100	87	1	1	1	0	0	0	0	0
C.S. 3/8	J.toria	100	100	88	12	2	1	0	0	0	0
C.S. 3/16	J. toria	100	100	100	100	91	66	44.5	27.5	16	6.5
N. sand	salate	100	100	100	100	99	95.5	73.5	33	14.5	4
N. filler		100	100	100	100	100	100	100	91	88	79
HMA Blending with N. fine aggregate (wad asad)											
C.S. 3/4	30	30	26.1	0.3	0.3	0.3	0	0	0	0	0
C.S. 3/8	30	30	30	26.4	3.6	0.6	0.3	0	0	0	0
C.S. 3/16	20	20	20	20	20	18.2	13.2	8.9	5.5	3.2	1.3
N. sand	15	15	15	15	15	15	14	11	5	2	1
N. filler	5	5	5	5	5	5	5	5	5	4	4
blending	100	100	96	67	44	39	33	25	15	9.8	5.8
mid point		100	100	80	67.5	50	30	15	5.5	5.5	5.5
upper		100	100	88	70	52	40	30	23	16	10
lower		100	95	54	37	26	18	13	8	6	4

Table (A-7)blending with crushed 30% and Natural 15%fine aggregate

Sieve size	#	1 "	3/4 "	3/8 "	No. 4	No. 8	No.16	No. 30	No. 50	No. 100	No. 200
	mm	25	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
C.S. 3/4	J.toria	100	87	1	1	1	0	0	0	0	0
C.S. 3/8	J.toria	100	100	88	12	2	1	0	0	0	0
C.S. 3/16	J. toria	100	100	100	97.5	72	46	26	13	7	2
N. sand	salate	100	100	100	100	99	95.5	73.5	33	14.5	4
N. filler		100	100	100	100	100	100	100	91	88	79
HMA Blending with N. fine aggregate (wad asad)											
C.S. 3/4	25	25	21.75	0.25	0.25	0.25	0	0	0	0	0
C.S. 3/8	25	25	25	22	3	0.5	0.25	0	0	0	0
C.S. 3/16	30	30	30	30	29.25	21.6	13.8	7.8	3.9	2.1	0.6
N. sand	15	15	15	15	15	15	14	11	5	2	1
N. filler	5	5	5	5	5	5	5	5	5	4	4
blending	100	100	97	72	53	42	33	24	13	8.7	5.1
mid point		100	100	80	67.5	50	30	15	5.5	5.5	5.5
upper		100	100	88	70	52	40	30	23	16	10
lower		100	95	54	37	26	18	13	8	6	4

Appendix (B)

Marshall Data Sheet Calculation

Table B.1: *Blending* with J.Toria (Petrodalta) Crushed Fine Aggregate

Marshal Data Sheet

<table>
<tr><td colspan="2">Material Description</td><td>C.S.</td><td>C.S.</td><td>C.S.</td><td>Natural</td><td>filler</td></tr>
<tr><td colspan="2">Material size (mm)</td><td>20-10</td><td>10--5</td><td>5--0</td><td>5---0</td><td>filler</td></tr>
<tr><td colspan="2">%Used by wt. of Aggregate(P)</td><td>25.0</td><td>30.0</td><td>40.0</td><td>0.0</td><td>5.0</td></tr>
<tr><td colspan="2">Bulk Specific Gravity of Aggregate(G)</td><td>2.749</td><td>2.534</td><td>2.654</td><td>2.645</td><td>2.616</td></tr>
<tr><td colspan="2">Apparent Specific Gravity of Aggregate(G_a)</td><td>2.797</td><td>2.906</td><td>2.934</td><td>2.934</td><td>2.905</td></tr>
<tr><td colspan="2">mixture G_{mm} ASTM D 2041</td><td colspan="5">2.542</td></tr>
<tr><td colspan="2">(G_{sb})</td><td colspan="5">2.637</td></tr>
<tr><td colspan="2">Specific Gravity of Asphalt(G_b)</td><td colspan="5">1.024</td></tr>
<tr><td colspan="3">%AC by wt. of Aggregate</td><td>5.3</td><td>5.3</td><td>5.3</td><td>5.3</td></tr>
<tr><td colspan="3">%AC by wt. of mix</td><td>5.00</td><td>5.00</td><td>5.00</td><td>5.0</td></tr>
<tr><td colspan="3">Wt. of specimen in air</td><td>1229</td><td>1228</td><td>1223</td><td>1226.7</td></tr>
<tr><td colspan="3">Wt. of specimen in water</td><td>721.8</td><td>717.6</td><td>720.7</td><td>720.0</td></tr>
<tr><td colspan="3">Volume of specimen</td><td>507</td><td>510</td><td>502</td><td>506.6</td></tr>
<tr><td colspan="3">Bulk Specific Gravity for mix (G_{mb})</td><td>2.423</td><td>2.406</td><td>2.435</td><td>2.4</td></tr>
<tr><td colspan="3">maximum Specific Gravity for mix (G_{mm})</td><td>2.542</td><td>2.542</td><td>2.542</td><td>2.5</td></tr>
<tr><td colspan="3">Air void (%)</td><td>4.7</td><td>5.4</td><td>4.2</td><td>4.7</td></tr>
<tr><td colspan="3">Void in mineral aggregate (VMA)</td><td>12.7</td><td>13.3</td><td>12.3</td><td>12.8</td></tr>
<tr><td colspan="3">Void filled with Asphalt (VFA)</td><td>63.2</td><td>59.9</td><td>65.7</td><td>62.9</td></tr>
<tr><td rowspan="3">Stability</td><td colspan="2">PRR</td><td>45</td><td>40</td><td>38</td><td>41.0</td></tr>
<tr><td colspan="2">Force (KN)</td><td>10.44</td><td>9.28</td><td>8.82</td><td>9.5</td></tr>
<tr><td colspan="2">ADJESTED (KN)</td><td>11</td><td>9</td><td>9</td><td>9.8</td></tr>
<tr><td rowspan="2">Flow</td><td colspan="2">Gauge Reading</td><td>33</td><td>35</td><td>32</td><td>33.3</td></tr>
<tr><td colspan="2">(mm)</td><td>3.3</td><td>3.5</td><td>3.2</td><td>3.3</td></tr>
<tr><td colspan="3">Stiffness (KN/mm)</td><td>3.3</td><td>2.7</td><td>2.9</td><td>2.9</td></tr>
</table>

Table B.2: Blending with Alsalte Area (Kobani) Crushed Fine Aggregate

Marshal Data Sheet

Material Description	C.S.	C.S.	C.S.	Natural	filler
Material size (mm)	20-10	10--5	5--0	5---0	filler
%Used by wt. of Aggregate(P)	25.0	30.0	40.0	0.0	5.0
Bulk Specific Gravity of Aggregate(G)	2.749	2.534	2.643	2.645	2.616
(G_a)	2.797	2.906	2.934	2.934	2.905
mixture G_{mm}ASTM D 2041	2.467				
(G_{sb})	2.633				
Specific Gravity of Asphalt(G_b)	1.020				

Specification

Trail No		1	2	3	Ave.
%AC by wt. of Aggregate		5.3	5.3	5.3	5.3
%AC by wt. of mix		5.00	5.00	5.00	5.0
Wt. of specimen in air		1220.8	1127.0	1240.0	1195.9
Wt. of specimen in water		700.0	643.0	712.9	685.3
Volume of specimen		521	484	527	510.6
Bulk Specific Gravity for mix (G_{mb})		2.344	2.329	2.352	2.3
maximum Specific Gravity for mix (G_{mm})		2.467	2.467	2.467	2.5
Air void (%)		5.0	5.6	4.6	5.1
Void in mineral aggregate (VMA)		15.4	16.0	15.1	15.5
Void filled with Asphalt (VFA)		67.7	64.9	69.3	67.3
Stability	PRR	45	50	50	48.3
	Force (KN)	10.4	11.6	11.6	11.2
	ADJESTED (KN)	10	13	11	11.4
Flow	Gauge Reading	46	44	47	45.7
	(mm)	4.6	4.4	4.7	4.6
Stiffness (KN/mm)		2.3	2.9	2.4	2.5

Table B.3 Blending with West Omdurman (Benkerkil) Crushed Fine Aggregate

Marshal Data Sheet

Material Description		C.S	C.S	C.S	Natural	filler
Material size (mm)		20-10	10--5	5--0	5---0	filler
%Used by wt. of Aggregate(P)		30.0	30.0	30.0	0.0	10.0
Bulk Specific Gravity of Aggregate(G)		2.749	2.534	2.643	2.645	2.616
(G_a		2.797	2.906	2.934	2.934	2.905
G_{mm} ASTM D 2041		2.564				
Bulk Specific Gravity for the Total Aggregate(G_{sb})		2.637				
Specific Gravity of Asphalt(G_b)		1.020				
Trail No			1	2	3	Ave.
%AC by wt. of Aggregate			5.3	5.3	5.3	5.3
%AC by wt. of mix			5.00	5.00	5.00	5.0
Wt. of specimen in air			1232.0	1234.0	1249.0	1238.3
Wt. of specimen in water			712.0	706.0	701.0	706.3
Volume of specimen			520	528	548	532.0
Bulk Specific Gravity for mix (G_{mb})			2.369	2.337	2.279	2.329
maximum Specific Gravity for mix (G_{mm})			2.564	2.564	2.564	2.6
Air void (%)			7.6	8.8	11.1	9.2
Void in mineral aggregate (VMA)			14.6	15.8	17.9	16.1
Void filled with Asphalt (VFA)			48.1	44.0	37.9	43.3
Stability	PRR		45	50	50	48.3
	Force (KN)		10.44	11.6	11.6	11.2
	ADJESTED (KN)		10	11	10	10.6
Flow	Gauge Reading		56	51	58	55.0
	(mm)		5.6	5.1	5.8	5.5
Stiffness (KN/mm)			1.9	2.2	1.8	1.9

Table (B-4) Blending With Omdurman (Kur Mandara) Natural Fine Aggregate

Marshal Data Sheet

Material Description		C.S.	C.S.	C.S.	Natural	C.C
Material size (mm)		20-10	10--5	5--0	5---0	filler
%Used by wt. of Aggregate(P)		25.0	30.0	0.0	40.0	5.0
Bulk Specific Gravity of Aggregate(G)		2.749	2.534	2.643	2.645	2.616
(G_a)		2.797	2.906	2.934	2.934	2.905
G_{mm} ASTM D 2041		2.535				
(G_{sb})		2.634				
Specific Gravity of Asphalt(G_b)		1.020				
Trail No			1	2	3	Ave.
%AC by wt. of Aggregate			5.3	5.3	5.3	5.3
%AC by wt. of mix			5.00	5.00	5.00	5.0
Wt. of specimen in air			1212.0	1227.3	1214.0	1217.8
Wt. of specimen in water			710.0	713.0	732.4	718.5
Volume of specimen			502	514	482	499.3
Bulk Specific Gravity for mix (G_{mb})			2.414	2.386	2.521	2.4
maximum Specific Gravity for mix (G_{mm})			2.535	2.535	2.535	2.5
Air void (%)			4.8	5.9	0.6	3.7
Void in mineral aggregate (VMA)			12.9	13.9	9.1	12.0
Void filled with Asphalt (VFA)			63.2	57.9	93.8	71.6
Stability	PRR		29	29	29	29.0
	Force (KN)		6.7	6.7	6.7	6.7
	ADJESTED (KN)		7	7	8	7.1
Flow	Gauge Reading		21	22	21	21.3
	(mm)		2.1	2.2	2.1	2.1
Stiffness (KN/mm)			3.3	3.1	3.7	3.3

Table B.5: Blending with Alsalate (Wad Asad) Natural Fine Aggregate

Marshal Data Sheet

Material Description	C.S.	C.S.	C.S.	Natural	filler
Material size (mm)	20-10	10--5	5--0	5---0	filler
%Used by wt. of Aggregate(P)	30.0	35.0	0.0	30.0	5.0
Bulk Specific Gravity of Aggregate(G)	2.749	2.534	2.643	2.645	2.616
Apparent Specific Gravity of Aggregate(G_a)	2.797	2.906	2.934	2.934	2.905
mixture G_{mm}ASTM D 2041	2.591				
(G_{sb})	2.633				
Specific Gravity of Asphalt(G_b)	1.020				

Trail No		1	2	3	Ave.
%AC by wt. of Aggregate		5.3	5.3	5.3	5.3
%AC by wt. of mix		5.00	5.00	5.00	5.0
Wt. of specimen in air		1233.2	1235.1	1237.4	1235.2
Wt. of specimen in water		725.0	723.0	728.4	725.5
Volume of specimen		508	512	509	509.8
Bulk Specific Gravity for mix (G_{mb})		2.427	2.412	2.431	2.423
maximum Specific Gravity for mix (G_{mm})		2.591	2.591	2.591	2.591
Air void (%)		6.3	6.9	6.2	6.5
Void in mineral aggregate (VMA)		12.4	13.0	12.3	12.6
Void filled with Asphalt (VFA)		49.0	46.7	49.8	48.5
Stability	PRR	36	34	32	34.0
	Force (KN)	8.4	7.9	7.4	7.9
	Adjusted (KN)	9	8	7	8.0
Flow	Gauge Reading (Div.)	29	28	27	28.0
	In (mm)	2.9	2.8	2.7	2.8
Stiffness (KN/mm)		3.0	2.8	2.7	2.9

Table B.6: Blending with both Crushed and Natural Aggregate (20% Jabal Toria & Natural Sand 15 %)

Marshal Data Sheet

Material Description			C.S.	C.S.	C.S.	Natural	filler
Material size (mm)			20-10	10--5	5--0	5---0	filler
%Used by wt. of Aggregate(P)			30.0	30.0	20.0	15.0	5.0
Bulk Specific Gravity of Aggregate(G)			2.749	2.534	2.643	2.645	2.616
(G_a)			2.797	2.906	2.934	2.934	2.905
G_{mm} ASTM D 2041			2.421				
(G_{sb})			2.638				
Specific Gravity of Asphalt(G_b)			1.020				
Trail No				1	2	3	Ave.
%AC by wt.. of Aggregate				5.3	5.3	5.3	5.3
%AC by wt. of mix				5.00	5.00	5.00	5.0
Wt. of specimen in air				1255.1	1249.5	1251.7	1252.1
Wt. of specimen in water				716.30	712.20	712.40	713.6
Volume of specimens				539	537	539	538.5
Bulk Specific Gravity for mix (G_{mb})				2.329	2.326	2.321	2.325
maximum Specific Gravity for mix (G_{mm})				2.421	2.421	2.421	2.421
Air void (%)				3.78	3.94	4.13	4.0
Void in mineral aggregate (VMA)				16.1	16.3	16.4	16.3
Void filled with Asphalt (VFA)				76.5	75.8	74.9	75.7
Stability	PRR			55	53	49	52.3
	Force (KN)			12.76	12.30	11.37	12.1
	Adjusted (KN)			12	11	11	11.3
Flow	Gauge Reading			22	28	30	26.7
	(mm)			2.2	2.8	3.0	2.7
Stiffness (KN/mm)				5.4	4.1	3.5	4.3

Table B.7: Blending with both Crushed and Natural Aggregate (30% Jabal Toria & Natural Sand 15 %)

Marshal Data Sheet

Material Description		C.S.	C.S.	C.S.	Natural	filler
Material size (mm)		20-10	10--5	5--0	5---0	filler
%Used by wt. of Aggregate(P)		25.0	25.0	30.0	15.0	5.0
Bulk Specific Gravity of Aggregate(G)		2.749	2.534	2.643	2.645	2.616
(G_a)		2.797	2.906	2.934	2.934	2.905
mixture G_{mm} ASTM D 2041		2.422				
(G_{sb})		2.639				
Specific Gravity of Asphalt(G_b)		1.020				
Trail No			1	2	3	Ave.
%AC by wt. of Aggregate			5.3	5.3	5.3	5.3
%AC by wt. of mix			5.00	5.00	5.00	5.0
Wt. of specimen in air			1276	1270	1280	1275
Wt. of specimen in water			718	716	720	718
Volume of specimen			558	554	560	557.4
Bulk Specific Gravity for mix (G_{mb})			2.286	2.292	2.285	2.288
(G_{mm})			2.422	2.422	2.422	2.422
Air void (%)			5.62	5.35	5.68	5.5
Void in mineral aggregate (VMA)			17.7	17.5	17.8	17.6
Void filled with Asphalt (VFA)			68.3	69.4	68.0	68.6
Stability	PRR		47	42	39	42.7
	Force (KN)		10.90	9.74	9.05	9.9
	Adjusted (KN)		10	9	8	8.8
Flow	Gauge Reading		22	28	30	26.7
	(mm)		2.2	2.8	3.0	2.7
Stiffness (KN/mm)			4.4	3.1	2.7	3.4

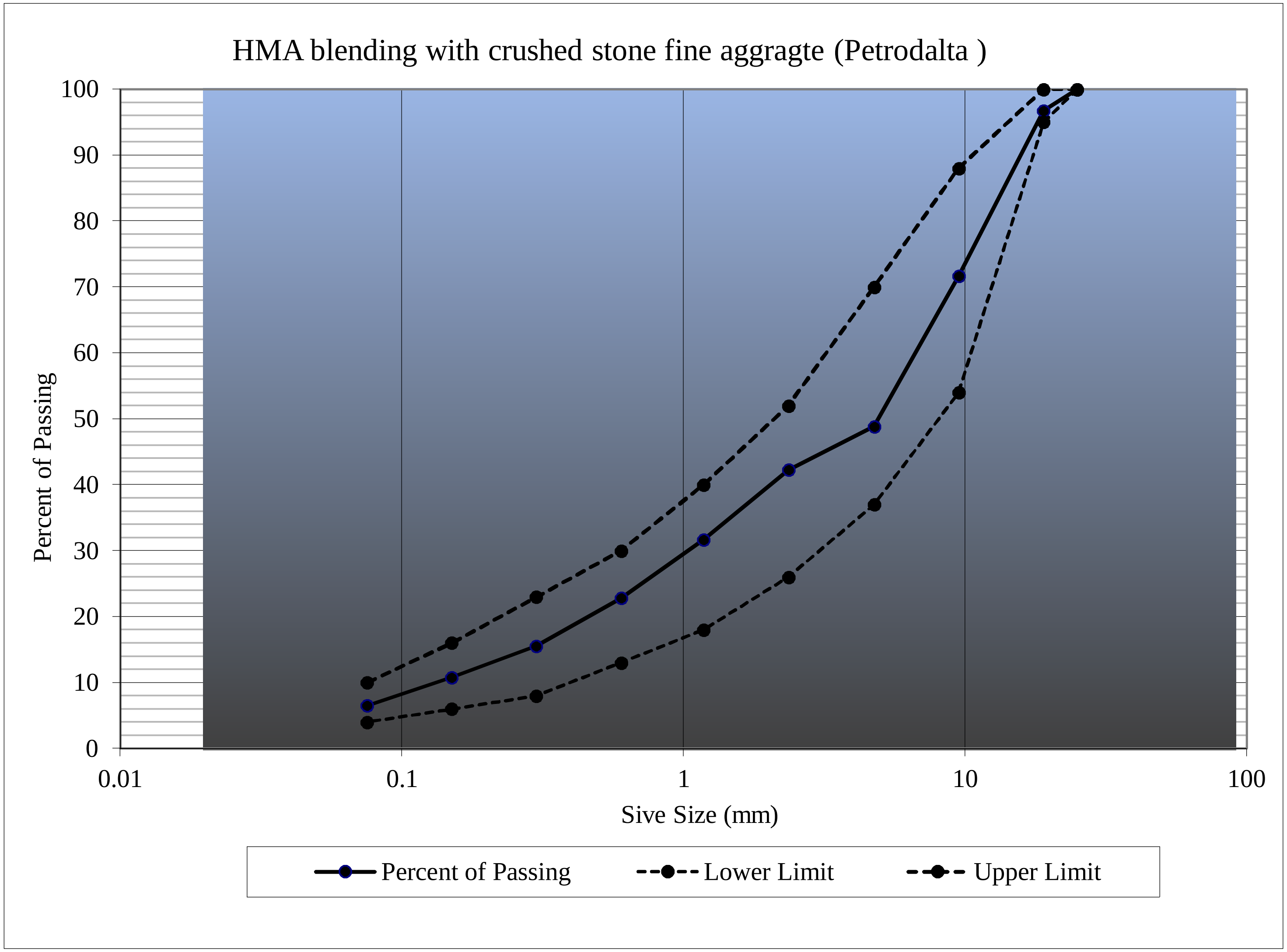
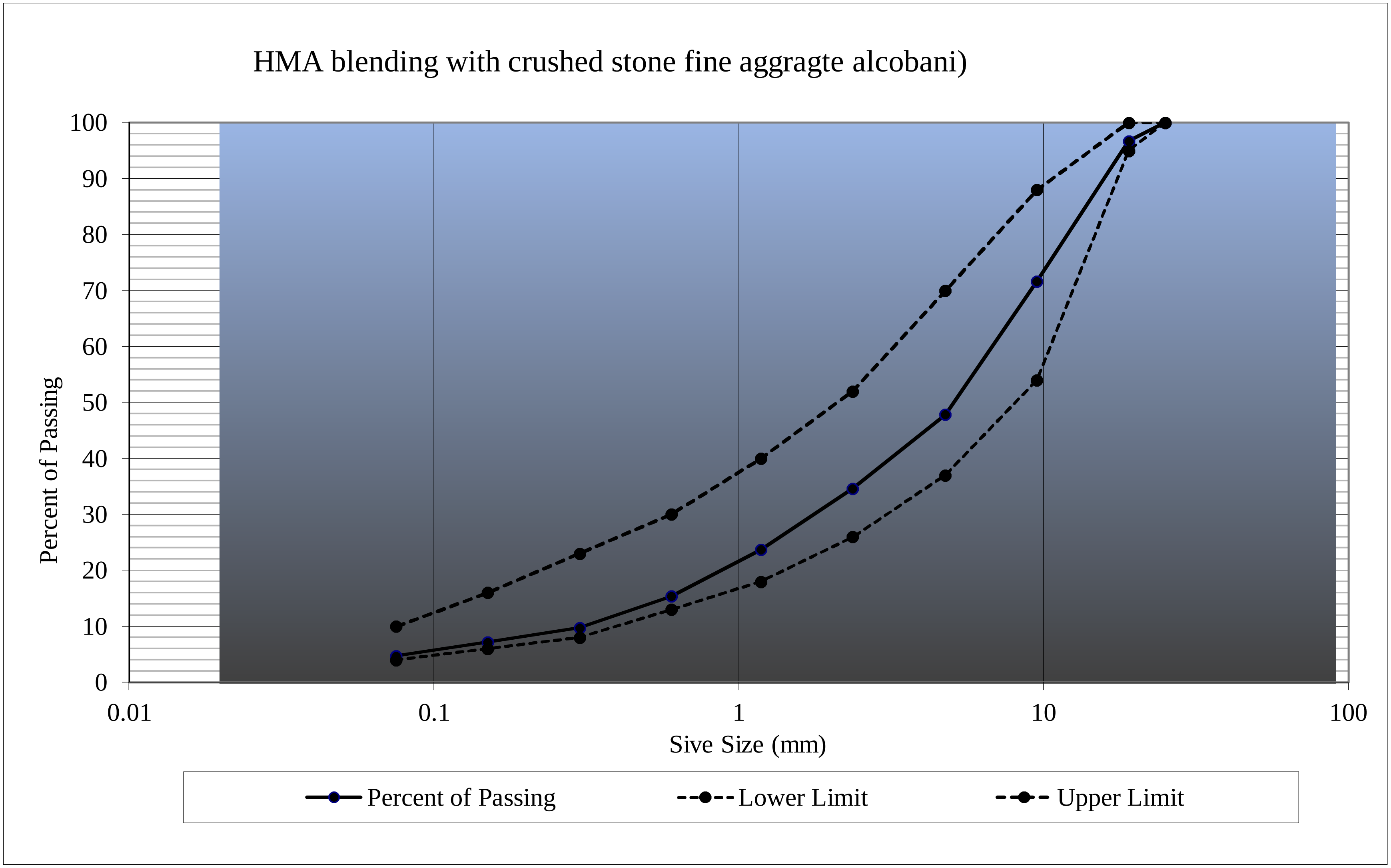


Figure (A-1)HMA blending with crushed stone fine aggregate (Petrodalta)



1. ***Figure (A-2) HMA blending with crushed stone fine aggregate alcobani)***

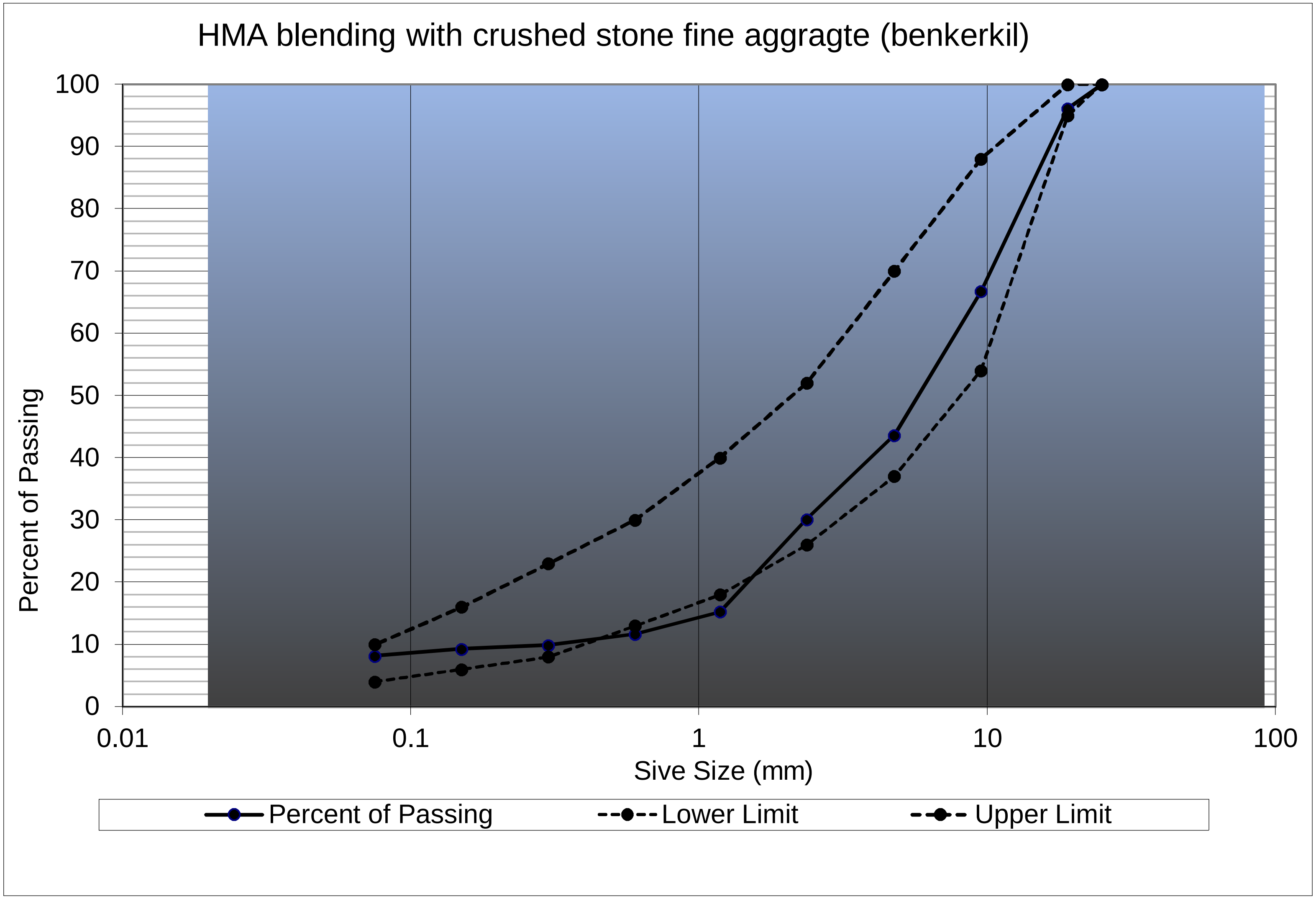


Figure (A-3) HMA blending with crushed stone fine aggregate (benkerkil)

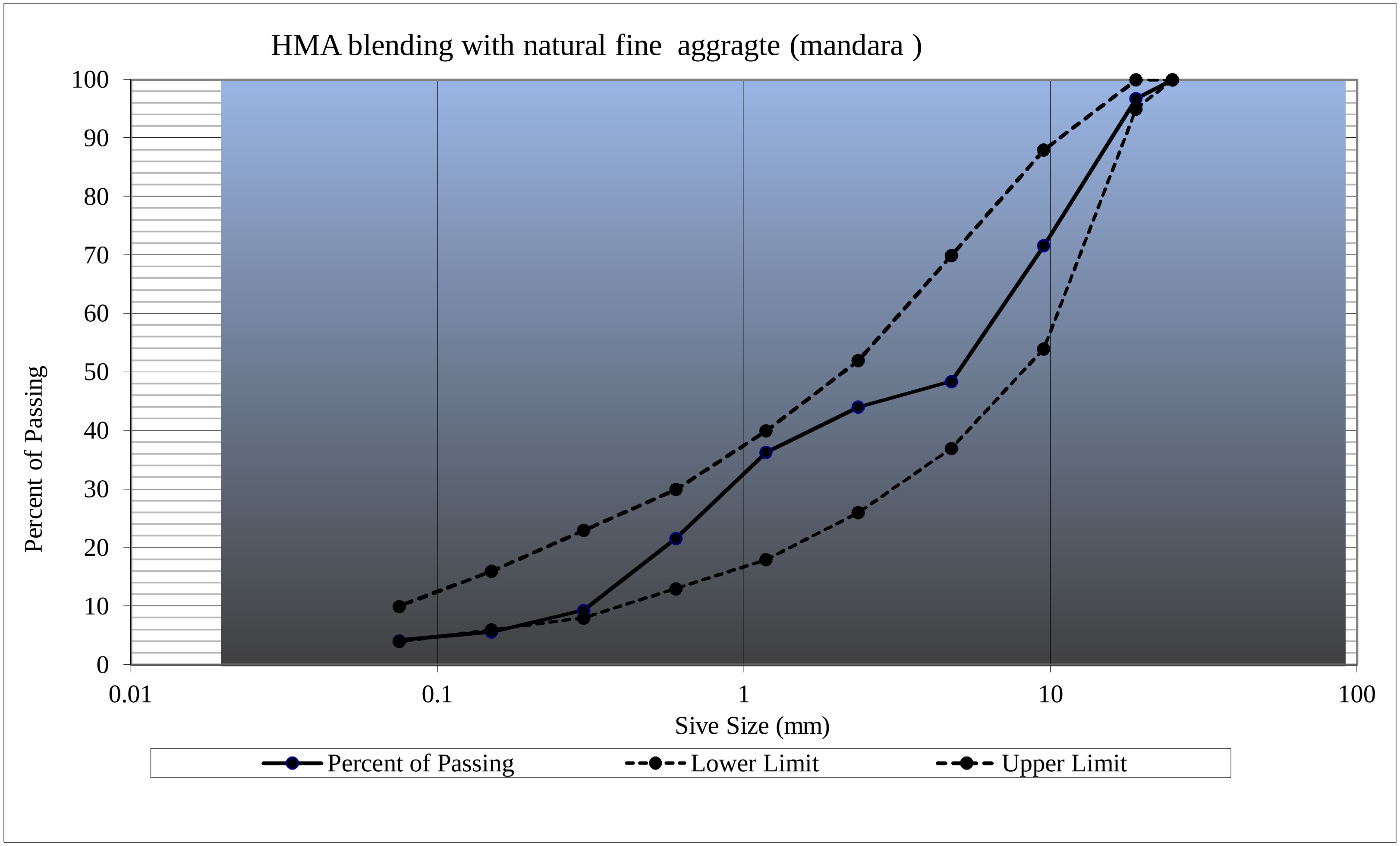


Figure (A-4) HMA blending with natural fine aggregate (mandara)

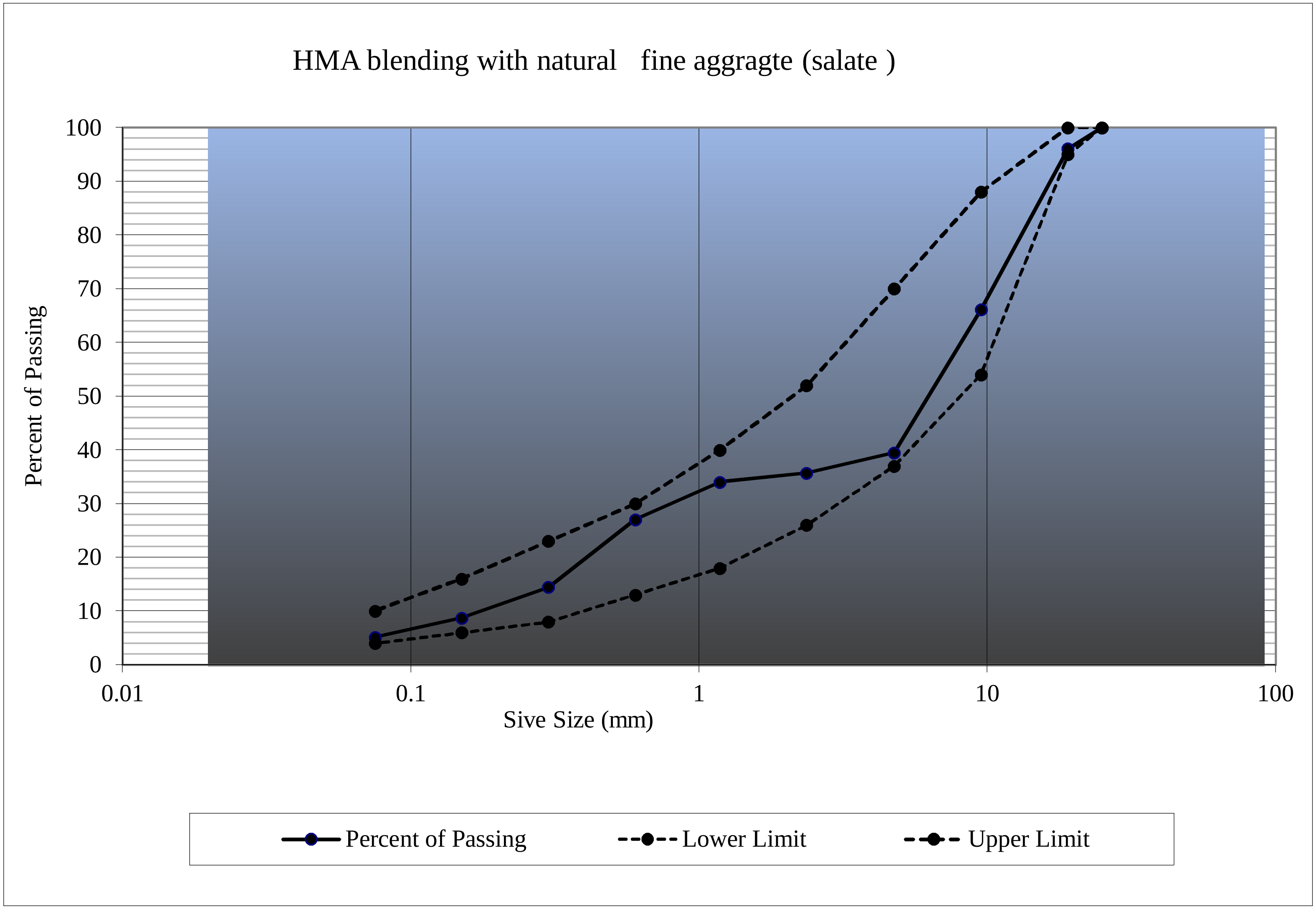


Figure (A-5)HMA blending with natural fine aggregate (salate)

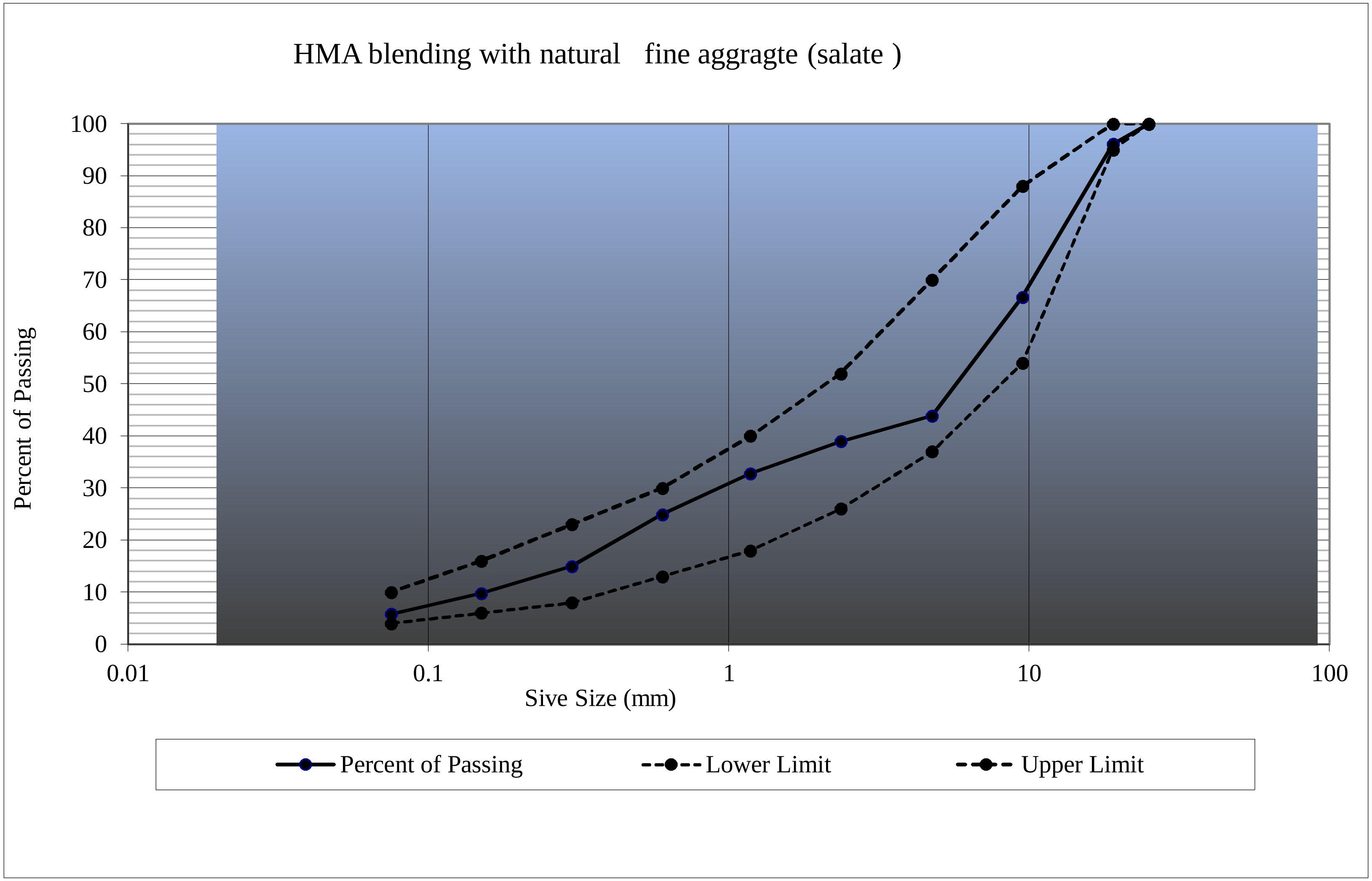


Figure (A-6) HMA blending with natural fine aggregate (salate)

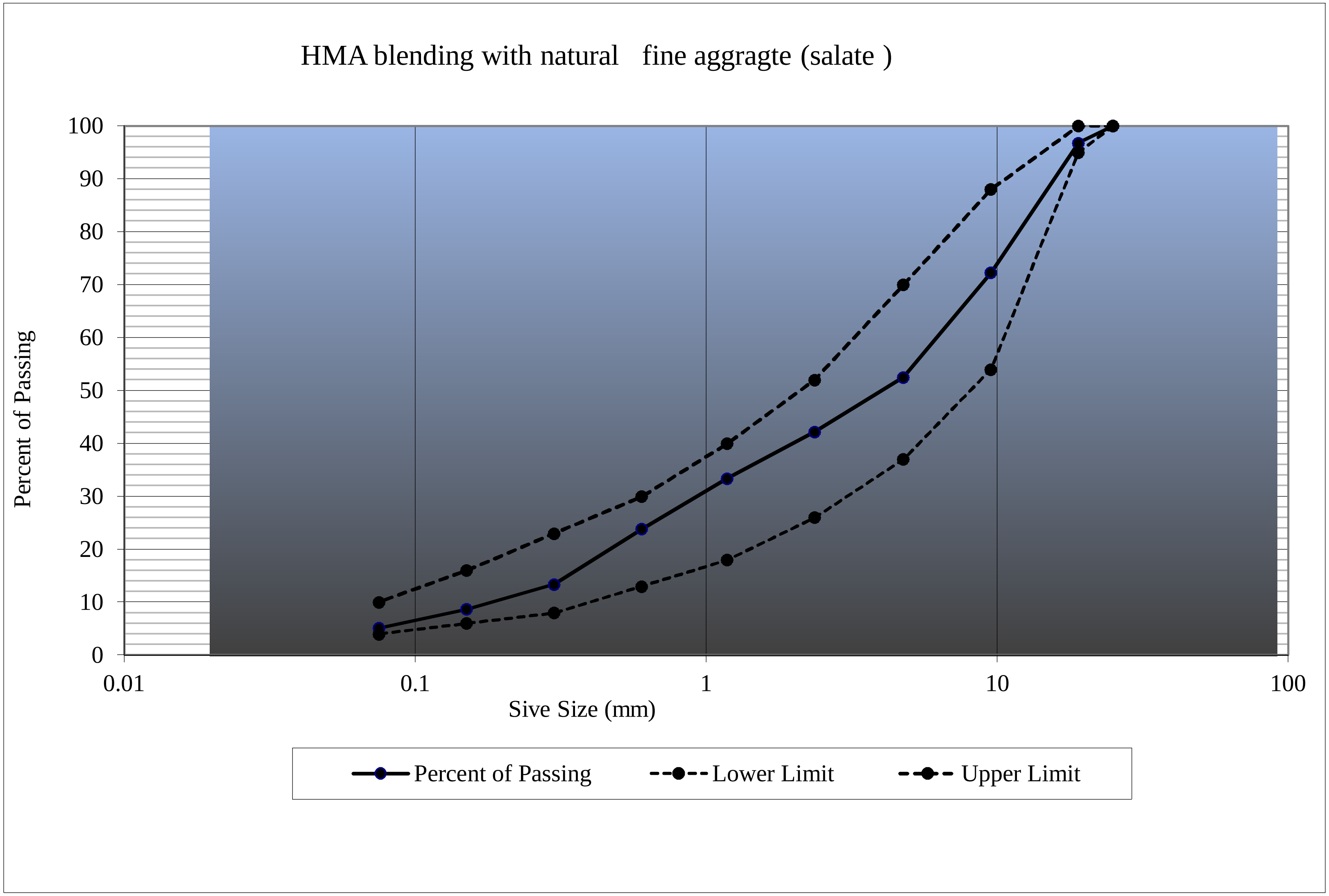


Figure (A-7)HMA blending with natural fine aggregate (salate)