Effect of Different Types of Filler Materials on Characteristics of Hot-Mix-Asphalt Concrete

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List of Definitions

AASHTO = American Association of State Highway and Transportation Officials

ASTM = American Society for Testing of Materials

AC = Asphalt Cement

CBPD = Cement bypass dust

DSR = Direct Shear Rheometer

D10 = Particle size at 10 percent passing.

D30 = Particle size at 30 percent passing.

D60 = Particle size at 60 percent passing.

$|E*|$ = Dynamic modulus of mixtures, as determined from the formula developed by asphalt institute

F/B = Fines to bitumen ratio

f = The load frequency in hertz, applied in the formula for dynamic modulus determination

HMA = Hot Mix Asphalt

JMF = Job-Mix Formula

MOTH = Ministry of transportation and housing of Oman

OBC = Optimum binder content, percent by total weight of mixture

P_a = Percent air voids in mixture %.

P_{be} = Effective asphalt content in the mixture %

P_b = Asphalt content, percent by total weight of mixture.

P_{ba} = Absorbed asphalt, percent by weight of aggregate.

P_s = Aggregate content, percent by total weight of mixture.

P_{200} = The percentage by weight of aggregate passing through a no. 200 sieve

P_{77^0F} = The penetration value of asphalt cement, in units of 0.25mm.

SHRP = Strategic Highway Research Program

T = The temperature in ^{0}F, applied in the formula for dynamic modulus determination

V_a = Volume of air voids in percent

V_b = Volume of bitumen in percent

VFA = Voids filled with asphalt %.

VMA = Voids in mineral aggregate %.

λ = The asphalt viscosity at 70^{0}f in 10^6 Poise.

ABSTRACT

Various studies have shown that the properties of mineral fillers have significant effect on the performance of asphalt concrete pavements.

This study was intended to investigate the effect of different types of mineral fillers in hot-mix-asphalt performance. The mineral fillers, with different percentages by total weight of the mixture, used in the study were crushed stone, volcanic-cinder, and limestone passing 0.075mm sieve.

Using the different types and contents of the mineral fillers, a number of trial mixes have been prepared using the Marshal Mix design procedure to arrive at asphalt concrete mixtures that fulfill the Marshal criteria. The effects of each mineral filler type on Marshal Properties of the asphalt mixtures at their respective optimum asphalt content were evaluated and possible basis for such difference in properties was discussed.

Using the different mineral fillers at their respective optimum asphalt content, specimens were prepared to investigate moisture susceptibility of asphalt mixtures. The Marshal Immersion test method was adopted to determine the moisture effect of mixtures.

The test results show that all mineral fillers do have an effect on various mixture properties. Mixtures prepared with volcanic-cinder require higher asphalt content to fulfill all the Marshal requirements. This makes these mixtures more costly from practical point of view. Higher stability values were however, obtained by mixes with volcanic-cinder as compared to limestone and crushed stone fillers. Moreover, higher retained stability values are obtained by mixes prepared with limestone and volcanic–cinder as compared to the widely used crushed stone. The dynamic moduli values, estimated using the formula developed by the Asphalt Institute, were higher for mixtures prepared with limestone fillers and crushed stone as compared to volcanic-cinder at higher filler contents starting from 5% in the mixture.

From the study, similar trend of mixture properties, particularly Marshal properties, were observed for mixes made with limestone and crushed stone fillers as compared to that of volcanic-cinder. This indicates that limestone can be used as a substitute for the widely used crushed stone where available. This, of course, requires further investigation that better simulates the field condition. On the other hand, inconsistent mixture properties were observed from mixes made with volcanic-cinder. This also entails further investigation if it is deemed to be used as filler materials in asphalt concrete.

Generally, different characteristics of bituminous mixtures were observed by varying the fillers in the mixture by type and content. This indicates that, mineral fillers are recognized as an important ingredient in the mixture property. From the test results obtained, there is a common trend in obtaining different mixture properties with varying filler content, which shows, there exists optimum filler content that best mix performance could be achieved.

The results of this research work is hoped to be used as the basis for further investigation on the effects of mineral fillers and improve asphalt concrete mixtures as well as find alternative materials.

INTRODUCTION

CHAPTER 1. INTRODUCTION

1.1 GENERAL

Hot mix asphalt (HMA) pavements are being increasingly constructed in Ethiopia, as the government is allocating huge amount of resources to upgrade the existing road network nation wide. However, it is reported that common premature distresses such as permanent deformation (rutting) and fatigue cracking are being observed within a few years after opening the roads for traffic. Subsequently, this induces large amount of maintenance and road users cost that would have negative effect on the nation's economy. In various developed countries, researches have been conducted to produce mixes with improved properties by altering the HMA constituting ingredients. Thus, in the HMA mix design process, care must be exercised while selecting the type of ingredient materials and their relative proportion in the mixture. This will enable the mix designer to get the desired mixture property.

Hot mix asphalt mix design is the process of determining appropriate proportion of the materials that would give long lasting performance paving mixture during its service life. It is a mixture of binder, aggregate, and air in different relative proportions that determine the physical properties of the mix and, ultimately, how the mix will perform as a finished pavement. Many different, and sometimes conflicting, performance demands are placed up on the asphalt mixtures and this makes it a complex material. Thus, the design of asphalt paving mixes is largely a matter of selecting and proportioning the ingredient materials to optimize all desired properties in the finished paved road. The main objective in the design of HMA mixture is to determine cost effective proportion of ingredients in the mixture having the following properties.

i. Durability: The mix should provide adequate durability as a paved road, where it must not suffer excessive aging and hardening during production and service life. The HMA durability is related to asphalt binder film thickness around aggregate particles and air voids in the mix. If the available film thickness is not adequate, the asphalt cement will be exposed to air and leads to rapid hardening or aging. It has been found that age hardening of asphalt cement in pavement results in progressively lower penetration or higher viscosity and this causes a progressive increase in the brittleness (and lack of binding characteristics) of asphalt cement which subsequently induces raveling. Besides, inadequate film thickness results with mixes more susceptible to moisture induced damages, where it is possible that the aggregate may become accessible to water through holes in the film. If the aggregate is hydrophilic, water will displace the asphalt film and asphalt-aggregate cohesion will be lost. This process subsequently results in moisture induced damage typically referred to as stripping. Thus the optimum asphalt content as determined by mix design should provide adequate film thickness around aggregate particles [17].

ii. Stability: The mix must provide sufficient stability under traffic loading through its service life. The stability of a mixture under traffic load is the amount of resistance to deformation. This is achieved by selecting quality aggregates of good surface and abrasion characteristics with proper gradation and selecting optimum asphalt content that could result adequate voids in the mix.

iii. Fatigue resistance: The mix, as a paved road, must resist cracking effects that may induced due to repeated traffic loading over time. The cracking of mixes under repeated traffic loading over time is referred to as fatigue cracking. HMA fatigue cracking is mainly related to asphalt binder stiffness, content and amount of fillers in the mixture. The optimum asphalt binder content as determined by mix design should provide sufficient flexibility to the mix so as to deform elastically rather than fracture under the repeated load. Selecting an asphalt binder with lower stiffness will also increase the mixtures fatigue life by providing greater flexibility. Excessive amount of mineral fillers will tend to increase the stiffness of the mixture, and hence, decreases the resistance to fatigue cracking. However, care should be made by considering the potential for permanent deformation (rutting).

iv. Air voids content: There must be sufficient voids in the total compacted mix to allow for a slight amount of additional compaction under traffic loading and a slight amount of asphalt expansion due to temperature increases without flushing, bleeding, and loss of stability.

v. Low temperature cracking: HMA pavements may be subjected to high cooling rates during low temperature seasons. The low temperature develops tensile stress due to shrinkage which eventually develops transverse cracking when the tensile stress exceeds the fracture strength of the mix. This property is mainly influenced by asphalt cement temperature susceptibility. Asphalt cements highly susceptible to temperature change are not desirable in the HMA mixture.

vi. Moisture damage resistance: HMA must be resistant to moisture induced damages. This property is mainly influenced by the characteristics of aggregate with asphalt binder and air voids. Some aggregates are characterized as more water loving (hydrophilic). Bituminous mixtures containing water loving aggregates if subjected to water or moisture, adhesion between the aggregate and asphalt binder may loose (or weaken) and finally may result stripping. When the air voids in the mixture is greater than 8 percent by volume (for a typical dense graded HMA), they may allow water to easily penetrate the HMA and cause moisture damage. Thus, to address this effect, HMA mix design must obtain an optimum asphalt binder content and aggregate gradation that produces design air voids of about 4 percent.

vii. Skid resistance: HMA designed for surfacing should provide sufficient resistance to skidding. This property is mainly controlled by aggregate characteristics such as texture, shape, size and resistance to polish. Excessive asphalt binder can also cause HMA bleeding which results in slippery surface.

viii. Workability: The mix must be capable to provide sufficient workability and hence permit efficient placement and compaction of the mix with reasonable effort without segregation, sacrificing stability, and performance.

By considering the above control objectives during HMA mix design process, well designed bituminous mixtures can be expected to serve successfully for many years under the variety of loading and environmental conditions. The most common methods used to go about HMA mix design are the Hveem, Marshall and Super pave methods. Using either mix design method, the final goal is to select a unique design asphalt content that could achieve a balance among the various desired objectives. This means that there is no single asphalt content that will maximize all of the above objectives; instead, asphalt content is selected on the basis of optimizing the properties necessary for the specific conditions.

The performance of bituminous surfaced roads is directly affected by the proportion and quality of ingredient materials in the mixture. The mix design has been a major concern where various studies (5-15) were conducted. These studies revealed that certain modifications in the mixture such as, changing the type, size and gradation of aggregate, varying the filler to asphalt ratio, type and amount of filler alter the physical properties of HMA concrete. Fillers, in particular, as one of the ingredients in HMA, have only been thought to fill voids in the aggregate. However, studies indicated that the role of fillers in asphalt mixture performance is more than filling voids depending on the type used.

This study was intended to evaluate the effect of different mineral fillers: crushed stone, volcanic cinder and limestone passing 0.075mm sieve at various contents. The Marshal and moisture susceptibility tests were used to investigate the mixtures in the laboratory.

Different mixtures were prepared by varying contents of respective filler type in accordance with the Marshal Mix design procedure. Using the Marshal Mix design criteria for heavy traffic, optimum asphalt content was selected. Further test specimens were prepared at their optimum asphalt content in order to investigate the moisture susceptibility for conditioned and unconditioned mixtures.

1.2 PROBLEM STATEMENT

Researches show that modification made in the ingredients of bituminous mixtures such as type of ingredient materials and relative proportion has altered and sometimes improved the properties of HMA. Among these researches, some studies [1,2,3,4,5,6,7,11,14,18,19] proved that mineral fillers have important role in the performance of HMA. Depending on the fillers characteristics, it was found that their purpose was not only to fill the voids but also modifying the mixture. This study was, therefore, made to evaluate effect of different types of mineral fillers, namely crushed stone, volcanic-cinder and limestone at various contents.

On the other hand, in the construction of highway pavements, one of the main problems is insufficiency of amount of mineral fillers from crushing of aggregates. Moreover, there is also environmental deterioration resulting from blasting of more quarry areas to produce the required amount of mineral fillers and its mode of production has made it to be expensive. Therefore, it is important to find an alternative type of mineral filler materials. Thus, this study was made with this intention.

1.3 RESEARCH OBJECTIVE

The overall objective of this study is to investigate the characteristics of HMA mix using different types of mineral fillers.

The specific objective is to investigate the effect of different mineral fillers (crushed stone, volcanic-cinder and limestone) on the Marshal properties and moisture resistance of HMA concrete and give recommendation.

1.4 SCOPE AND LIMITATION

The research reported herein was focused on asphalt concrete characteristics such as the Marshal Properties and moisture susceptibility. The materials selected for this study were collected from different sources, i.e. aggregate from Midroc Construction quarry and crusher site located at Kaliti, limestone filler from natural source of existing quarry pit located at Ambo-Senkele (about 130 Km from Addis Ababa), and volcanic-cinder filler from a natural source found at the entrance of Nazareth (about 97 Km from Addis Ababa). All these materials were tested in the laboratory and evaluated. The mineral fillers (all pass 0.075mm sieve) were separated when the aggregates are dried for the production of asphalt concrete.

The mixtures were prepared using each type of mineral fillers with different amount. The results produced in this research were based on the Marshal Mix design and Marshal Immersion procedures.

Equipment for determining the tensile and rutting potential of mixes was not functioning properly for the research. Thus, the tensile strength and creep tests were not conducted.

LITERATURE REVIEW

CHAPTER 2. LITERATURE REVIEW

2.1 INTRODUCTION

Various studies [1,2,3,4,5,6,7,11,14,18,19] have been conducted on the properties of HMA using minor changes on the ingredients of the mixture. In general the main objectives of the researches were to understand in a better way the characteristics of bituminous mixtures and evaluate the effects of constituent ingredients on the performance.

Among the various studies conducted, many were concerned on investigation of effects of aggregates on the bituminous mixture performance. This is as the aggregate make up 90 to 95 percent by total weight of the mixture, they are a prime suspects influencing the performance of the mixture.

The research herein with concentrates and builds on the Marshal Properties and moisture susceptibility of HMA mixtures prepared using different mineral fillers by type and content. This evaluation on the subject matter was conducted by comparing the traditional crushed stone mineral filler vs. limestone and volcanic cinder fillers. There are well-established literatures [2, 5, and 18] that indicate limestone filler (P-No. 200 sieve) being under practice on HMA performance, but not for the volcanic cinder as mineral filler.

In this chapter, procedure in the bituminous mix design and review of researches conducted on the effect of mineral fillers on HMA performance will be discussed.

2.2 BASIC PROCEDURE IN HMA MIX DESIGN

Hot-Mix-Asphalt mixture consists of two basic ingredients: mineral aggregate and asphalt binder. The process in HMA mix design involves determining what type of aggregate to use, what asphalt binder to use and what proportion of these two ingredients to use so as to achieve the desired bituminous mixture performance. HMA is a complex material where different, and sometimes conflicting, performance demands are placed. It must resist deformation and cracking, be durable over time, resist water damage, and yet be inexpensive, readily made and easily placed.

The most common methods used to go about this process are the Hveem, Marshall and Superpave methods. In general, all mix design methods involve manipulation of three basic variables: namely aggregate selection, asphalt binder choice and optimum asphalt binder content determination [9] where they are briefly discussed under this section.

2.2.1 Aggregate Type and Quality Selection

The properties of aggregates are very important to the performance of hot mix asphalt (HMA) pavements. Often pavement distress such as rutting, stripping, surface disintegration, and lack of adequate surface frictional resistance can be attributed directly to improper aggregate selection and use. Thus, care has to be made while selecting the mineral aggregate and all quality test assurance has to be conducted to confirm whether they satisfy a definite project specification. The study conducted by Kim et al [17], disclosed that aggregate type has a significant effect on the fatigue resistance and permanent deformation of asphalt mixtures. Aggregates are deemed to give the mixture stability after various traffic loads, resistance to wear due to abrasive action of traffic, and still resistant to frost action. Thus, to obtain a mixture having good performance, evaluation of various mineral aggregate physical properties is essential.

Aggregate Gradation and Size

An aggregate's particle size distribution, or gradation, is one of its most influential characteristics. It determines almost every HMA properties including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage [17]. This makes gradation the primary factor in the asphalt mix design.

Matthews and Monismith [14] investigated a study to evaluate aggregate gradation on the creep response of asphalt mixtures and pavement rutting estimates. They have used both methods of measuring rutting performance (stabilometer and creep tests). From their study, it was indicated that mixtures with aggregate particles size distribution around the mid band of gradation limits, termed as "medium graded", provide significantly better resistance to rutting than the mixtures with aggregate gradation below the mid band of aggregate gradation, termed as "coarse graded". However, Kim et al. [11] have showed that changing the proportions of fine and coarse aggregates with the same nominal maximum aggregate size did not affect the permanent deformation significantly. This was verified by Kandhal and Allen [8] that from their study on rutting potential of both coarse and fine graded mixtures. The statistical analysis of the test data revealed that there is no significant difference between the rutting resistance of coarse and fine graded Superpave mixtures.

A study was made by Kandhal and Cross [15] on effects of gradation on the asphalt content where both wearing and binder mixes were considered. Further, they have carried out regression analysis on test data to investigate the relationship between asphalt content and gradation. Their study shows that no correlation exists between asphalt content and the percent passing the 4.75mm (No. 4) and 2.36mm (No. 8) sieves for the wearing mix. On the other hand, for binder mixes there exists a relationship between changes in gradation and measured asphalt content that shows as the mix becomes finer for the given sieve size, the asphalt content increases.

Gradation with high amount of fines (either naturally occurring or caused by excessive abrasion) may cause distortion in mixtures as the large amount of fine particles tend to push the larger particles apart and act as lubricating ball-bearings between these larger particles, and this in turns problem in deformation resistance of mixtures under traffic loading [21].

In conjunction with this, care has to be taken while determining maximum aggregate size in a mixture. In HMA mixtures, instability may result from excessively small maximum sizes; and poor workability and/or segregation may result from excessively large maximum sizes [17]. Maximum aggregate sizes for surface mixes and binder course mixes vary from 9.5mm to 19mm and 19mm to 38mm respectively [20].

2.2.2 Asphalt Binder Selection

Asphalt binder is supplied in various forms and grades having a wide range of consistency from fluid to hard and brittle for bituminous pavement construction.

Asphalt binders are most commonly characterized by their physical properties. This is because an asphalt binder's physical properties directly describe how it will perform as a constituent in HMA pavement. Different quality tests were carried out on asphalt cement during this study to assess its physical properties through various laboratory steps.

2.2.3 Optimum asphalt binder content determination

Mix design methods are generally distinguished by the way in which they determine the optimum asphalt binder content. This process can be subdivided into:

- Make several trial mixes with different asphalt binder contents.
- Compact these trial mixes in the laboratory. This compaction is meant to be a rough simulation of actual field conditions.
- Run laboratory tests to determine key sample characteristics.
- Pick the asphalt binder content that best satisfies the mix design objectives.

The various important mixture properties which show weight-volume relationship and strength are discussed here in after.

Bulk Specific Gravity Determination

The bulk specific gravity test on the freshly compacted specimens may be performed as soon as when they have cooled to room temperature. This test is conducted according to ASTM D 2726, “Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-dry Specimens”.

In the Marshal Mix design procedure, the density varies with asphalt content in such a way that it increases with increasing asphalt content in the mixture as the hot asphalt lubricates the particles allowing the compaction effort to force them closer together. The density reaches a peak and then begins to decrease because additional asphalt cement produces thicker films around the individual aggregates, and tend to push the aggregate particles further apart subsequently resulting lower density.

The bulk density of the compacted mixture can also be altered with the proportion of mineral filler. It is expected that the bulk density increases as the amount proportion of mineral filler increases in the mixture up to some point and then decreases. This is because an increased amount of mineral fillers will increase the amount of fines in the mix and the large amount of fine particles tend to push the larger particles apart and act as lubricating ball-bearings between these larger particles which subsequently lower the bulk density.

On the other hand, using different types of mineral fillers, depending on their characteristics, may also vary the bulk density of the mixtures.

Percent Voids in the Mineral Aggregate in Compacted Bituminous Mixture

The voids in the mineral aggregate, VMA, is the total available volume of voids between the aggregate particles in the compacted paving mixture that includes the air voids and the effective asphalt content expressed as a percent of the total volume. It is calculated based on the bulk specific gravities of the combined aggregates and compacted paving mixture using the following formula.

The VMA has two components: the volume of voids that is filled with asphalt, and air volume remaining after compaction for thermal expansion of the asphalt cement during hot weather. It is significantly important for the performance characteristics of a mixture. For any given mixture, the VMA must be sufficiently high enough to ensure there is space for the required asphalt cement, for its durability purpose, and air space. If the VMA is too small, there will be no space for the asphalt cement required to coat around the aggregates and this subsequently results in durability problems. On the other hand, if VMA is too large, the mixture may suffer stability problems.

The available VMA will decrease as the amount of mineral fillers in the mixture increases. This can be due to both fillers can be used for filling voids or extend the asphalt binder.

Percent Air Voids in Compacted Mixture

The air voids, P_a, in a compacted paving mixture that consists of small air spaces between the coated aggregate particles expressed as percent of the bulk volume of the compacted paving mixture. To address this, HMA mix design seeks to adjust items such as asphalt content and aggregate gradation to produce design air voids.

Percent Voids Filled with Asphalt in Compacted Mixture

The voids filled with asphalt, VFA, is a percentage of intergranular voids space between the aggregate particles (VMA) that are filled with asphalt cement. The amount of asphalt cement that fills the voids in the mixture is termed as "effective asphalt content". It is this effective asphalt cement that provides the required asphalt film thickness around the aggregate particles, which subsequently determines the durability of the mixture.

Marshal Stability and Flow

Marshal stability values can be determined by conducting a test on a prepared bituminous specimen. It is the maximum load carried by a compacted specimen tested at 60^oC at a loading rate of 50.8mm/minute. The stability value obtained is an indication of the mass viscosity of the aggregate-asphalt cement mixture. In most cases, it is affected significantly by the angle of internal friction of the aggregate and the viscosity of the asphalt cement at 60^oC. Hence, one of the easiest ways to increase the stability of an aggregate-asphalt mixture is to use a higher viscosity grade of asphalt cement. It is also possible to increase the stability of the mix by selecting a more crushed angular aggregate than rounded shape aggregates.

The flow is measured as the vertical deformation of the specimen in hundreds of inch from start of loading up to the point where the stability begins to decrease. It is obtained at the same time as the Marshal Stability test is conducted. Generally, high flow values indicate a plastic mix that is more prone to permanent deformation problem due to traffic loads, whereas low flow values may indicate a mix with higher than normal voids and insufficient asphalt for durability and could result premature cracking due to mixture brittleness during the life of the pavement.

2.3 MOISTURE SUSCEPTIBILITY OF HOT-MIX ASPHALT

One of the desirable properties of bituminous mixtures is that the resistance to moisture induced damages. The moisture-induced damages (typically called as stripping) can be defined as the weakening or eventual loss of the adhesive bond between the aggregate surface and the asphalt binder in a HMA pavement or mixture, usually under the presence of moisture. The resistance to moisture damage under the presence of moisture in the mixture is a complex matter and the degree mainly depends on the properties of each ingredient materials in the mixture, type and use of mix, environment, traffic, construction practice, and the use of anti-strip additives. Among these factors, aggregate response to asphalt cement under water is primarily responsible for this phenomenon, although some asphalt cement are more subjected to stripping than others.

2.4 THE EFFECT OF MINERAL FILLERS ON HMA

Mineral fillers are added to asphalt paving mixtures to fill voids in the aggregate and reduce the voids in the mixture. However, addition of mineral fillers has dual purpose when added to asphalt mixtures. A portion of the mineral filler that is finer than the asphalt film thickness mixed with asphalt binder forms a mortar or mastic and contributes to improved stiffening of mix. This modification to the binder that may take place due to addition of mineral fillers could affect asphalt mixture properties such as rutting and cracking. The other portion of fillers larger than the asphalt film thickness behave as a mineral aggregate and serves to fill the voids between aggregate particles, thereby increasing the density and strength of the compacted mixture. In general, filler have various purposes among which, they fill voids and hence reduce optimum asphalt content and increase stability, meet specifications for aggregate gradation, and improve bond between asphalt cement and aggregate [17].

A research [2] was conducted on the effects of mineral fillers on rutting potential of bituminous mixtures. The mineral aggregate used in the research was crushed limestone aggregate in combination with different materials passing 0.075mm sieve, such as limestone dust, hydrated lime, and Portland cement. The research was carried out using limestone dust (control mix) and replacing by hydrated lime and Portland cement in different proportions. From various tests conducted, the authors arrive at following conclusions.

- Greater raise in softening point of asphalt mastics was achieved when replacing limestone dust with hydrated lime than Portland cement.
- Mixtures prepared by replacing limestone dust with hydrated lime at higher filler content, acquire higher optimum asphalt content, higher air voids, and lower unit weights than those containing Portland cement. This is attributed to the higher specific surface area and asphalt absorption of the hydrated lime particles than Portland cement.
- Increasing filler content in the mixture enhances the Marshal and Hveem stability, as expected. This is because increasing filler content from 3% to 5.5% fills the voids among aggregate particles thus producing dense mixes, hence increasing stability, whereas increasing filler content beyond 5.5% reduce the contact among coarse aggregate particles, hence reducing the stability.

- While replacing limestone dust by either hydrated lime or Portland cement in the mixes, there was a decrease in resilient modulus values.
- Replacing part of limestone dust by hydrated lime or Portland cement aggravates the resistance of mixes to rutting. The rut depth increases as the percentage replaced increases; where higher rut depth was observed when replacing limestone mixes with hydrated lime than Portland cement.

A study carried out by Shahrour and Saloukeh [18] evaluated the effects of different types and quantity of mineral fillers on asphalt mixtures. The authors have pointed out that, different types of mineral fillers result different stiffening effect on asphalt binder as shown in Table 2-1. At higher field temperatures, the deformation behavior of asphalt pavement becomes critical. For this reason, the highest possible viscosity for the filler-bitumen mixture is desirable because this has a favorable influence upon the deformation resistance of the pavement. Thus, at a certain temperature an increase in the viscosity can be achieved either with more filler or with the use of effective filler. In this study, the Marshal parameters were not significantly affected by changing the type of filler at specific filler contents. However, the type of filler significantly affected the filler-bitumen properties by stiffening the binder to different degrees. It was also indicated that hydrated lime filler has shown superior stiffening properties when mixed with the binder compared to all other filler types.

Table 2-1 Properties of filler-bitumen mixture, [10]

S/N	AC 60/70 + Type of filler	F/B ratio by Weight	Penetration 25⁰C	30⁰C	35⁰C	Softening Point (⁰C)	Kinematics Viscosity @135⁰C	Stiffening Ratio based on Viscosity @135⁰C
1	Lime Stone	0.5	43	72	119	56.90	883	1.90
		1.5	27	42	66	67.40	*	
2	Gibca	0.5	43	71	118	55.80	810	1.70
		1.5	26	38	56	64.10	*	
3	Manama	0.5	44	68	107	56.90	841	1.80
		1.5	23	34	51	72.90	*	
4	Kadra	0.5	46	72	113	52.40	773	1.70
		1.5	25	38	58	67.30	*	
5	Wadi Filly	0.5	42	72	123	54.30	789	1.70
		1.5	27	40	60	64.40	*	
6	Al Tawoon	0.5	42	70	117	55.40	817	1.70
		1.5	25	37	55	69.30	*	
7	Siji	0.5	45	69	109	52.20	852	1.80
		1.5	24	34	52	66.50	*	
8	KS-300	0.25	**	**	**	59.00	*	**
9	O.P. Cement	0.5	44	71	115	56.30	676	1.40
		1.5	26	40	62	66.10	*	
10	Hydrated Lime	0.5	34	52	80	60.90	2066	4.40
		0.8	23	33	46	79.40	*	

* : Can not be determined as per ASTM D2170

**: The mix was exceeding the fluid property, and therefore can not be tested as per related ASTM standards.

Berhanu [5] conducted Marshal Stability tests on bituminous mixes with 60/70 grade bitumen and mineral fillers such as stone dust, marble, and limestone. Generally, Marshal Stability values of all mixes were improved with addition of fillers. This attributes to the fact that lower air voids can be achieved as filler content in the mix increases. The conclusions made in this study include:

- The content of fillers in the mixture have greater influence on determination of optimum asphalt content and strength where, better results could be found at 5 to 7.5 percent filler content.

- Higher values of compressive strength and modulus of elasticity was achieved by mixes prepared using marble dust as compared to lime and stone dust.
- From the low temperature tensile strength test, higher values were exhibited by mixes prepared using marble dust. This shows better performance can be achieved by using marble dust in paving mixtures when compared to others.

The physical properties of mineral fillers influence the performance of asphalt mixture such as permanent deformation, fatigue cracking, and moisture susceptibility of HMA. An investigation undertaken [10] to determine which P-200 material characterization tests are most related to the performance of asphalt paving mixtures. The study conducted Superpave shear test for evaluating permanent deformation and fatigue cracking, and the Hamburg wheel tracking and AASHTO T283 tests for evaluating moisture susceptibility. A total of 12 mixtures containing different types of P-200 materials and fines/asphalt ratios were used in the study. From the statistical analysis of the test data, the authors revealed the following important characteristics of mineral fillers (P-200) most related to the performance of asphalt mixtures:

- The rutting potential of asphalt mixtures is not affected by any of P-200 characteristics at a significant level in the 0.8 filler to asphalt ratio, whereas good correlation were obtained between the rutting potential and gradation indicators (fineness modulus, D10, D30, D60, and specific surface area) in the 1.5 filler to asphalt ratio. It appears that the finer the P-200 material, the more it modifies the asphalt binder and stiffens the HMA mix. The correlations are generally better for the 1.5 filler to asphalt ratio (because higher amounts of P-200 were used) than the 0.8 filler to asphalt ratio.
- There were no significant correlations between P-200 sieve size material properties and fatigue factor in 0.8 or 1.5 filler to asphalt ratio gradations.

- The fineness of P-200 materials (especially D10) has a significant effect on the stripping characteristics of HMA mixtures. This is because of that the smaller the size of P-200 (especially the smaller D10 size), the more the binder is being stiffer and/or extended. Stiffer asphalt binder in the mix provides stiffer mixture and extended asphalt binder increases the asphalt content in the mix. This will subsequently increase the resistance to stripping.

The authors recommended the following tests on evaluating mineral fillers for hot mix asphalt mixtures, which are related to HMA performance:

- The fineness expressed by a test parameter D60 and the methylene blue of P-200 materials are related to the HMA performance in terms of permanent deformation.
- There was no characterization test of P-200 materials which relates with the fatigue cracking resistance of HMA mixtures at a significant level.
- The gradation parameter expressed by D10 and methylene blue of P-200 materials correlates well with stripping potential of mixtures.

In 1992, Anderson et al. [4] conducted a study to determine whether the addition of baghouse fines affects the failure or fracture properties of HMA mixtures. With respect to fracture properties, it was concluded that the mineral filler fraction could have a significant effect and that

- Gradation of the baghouse fines does not necessarily relate to stiffening—the finest dust acted in much the same manner as the coarser dust—and
- Fracture toughness of the mixture appeared to be sensitive to the source of the aggregate as well as to the amount of added baghouse dust. In general, the addition of the dust increased the fracture toughness of the HMA mixture.

In another study, Anderson et al. [3] stated that the importance of mineral filler fraction was often overlooked even though it is one of the most important components of HMA. Two mineral fillers, quartz and calcite, were added to four asphalt cements, and the rheological properties and failure properties of the resulting mastics were determined using the test methods developed by SHRP. DSR, flexural creep, and direct tension were found to be applicable to void less filler–asphalt cement mastics. Based on the study, it was found that:

- The addition of the mineral filler does not affect the temperature shift factors of the rheological response but does change the frequency dependency by lengthening the relaxation times, thereby stiffening the asphalt.
- The presence of the mineral filler did not significantly affect the rate or level of oxidative or physical hardening.

The authors concluded that asphalt mastics can play a major role in defining the performance of HMA. The data also led the authors to conclude that void-less mastics, similar in volume concentration to the mineral filler–asphalt fraction in typical HMA, can be characterized with the same test methods as those developed for neat asphalt cement.

In 2004, Karasahin and Terzi [12] conducted an investigation on marble waste as filler material in asphalt mixtures. Samples were prepared having marble dust and limestone dust filler. The optimum binder content was then determined by Marshal Test procedure. They have also carried out dynamic plastic deformation tests on both mixes using marble waste and limestone dust. The study indicated that both Marshal and plastic deformation test results for mixes using both limestone and marble waste are almost the same. Hence, conclusion was made that those marble wastes which are in dust form can be considered as an alternative filler material to other materials. However, some care should be taken into account for mixes with marble dust since they have higher values of plastic deformation and hence, they should be used on low volume roads.

Ramzi et al. [16] have evaluated the use of cement bypass dust (CBPD) as filler in asphalt mixtures. They have both investigated the effect of adding either lime or CBPD in different proportion on binder and Marshal Properties. From their test data, they have made the following conclusions:

- For any filler type (lime or CBPD), penetration and ductility of the filler-binder mortar generally decreased as filler content was increased. However, such decrease was steeper and more pronounced when lime rather than CBPD was used as filler. On the other hand, softening point increased with the filler content where more significant increment was observed when lime rather than CBPD.
- When considering the Marshal properties, the substitution of 5% CBPD for lime as a filler would be the optimum value used in asphalt concrete mixtures. Any percentages higher than 5% CBPD would require more asphalt binder and thus produce an uneconomical mix.

From many studies conducted to investigate the effects of mineral fillers on HMA performance revealed that, mineral fillers have different effects on characterization of HMA. However, the effect of mineral fillers, passing 0.075mm sieve, on the fundamental mechanical properties of hot-mixed asphalt is not well understood [4].

2.5 SUMMERY OF LITERATURE REVIEW

The importance of mineral fillers in the bituminous mixtures have been over looked where their effect was considered to be only filling the voids in the mixture and fulfilling the gradation criteria. However, recent researches demonstrate that they are more than just filling the voids in the aggregate particles.

In this literature review, it is exhibited that different mineral fillers and quantity influence the performance of HMA mixtures.

Some filler have a considerable effect on the properties of asphalt cement mortar as compared to the neat asphalt cement and some filler types are also found to make HMA mixtures more susceptible to moisture-induced damages.

While considering the effect of filler types in the bituminous mixtures, various desirable characteristics such as: increased stability, resistant to moisture effect and rutting were obtained by many researchers.

RESEARCH METHODOLOGY

CHAPTER 3. RESEARCH METHODOLOGY

3.1. INTRODUCTION

This study involved investigating the Marshal properties and moisture susceptibility of bituminous mixtures prepared in the laboratory using different types of mineral fillers (all P-200 sieves) namely crushed stone, limestone, and volcanic Cinder.

This study involves collecting of materials for the preparation of bituminous mixtures. The materials used in the mixture includes: coarse and fine aggregates, different types of mineral fillers, and asphalt binder.

The crushed stone coarse and fine aggregates are purchased from MIDROC construction quarry and crusher site located at Kaliti area. The Volcanic cinder and limestone were collected from natural source at the entrance to Nazareth city from Addis Ababa and Ambo-Senkelle respectively to be used as filler materials. The asphalt cement of 80/100 penetration grade was obtained on purchasing.

These ingredient materials were subjected to various laboratory tests in order to determine their physical properties whether they can meet common specification limits. These quality assurance tests conducted on the aggregates include: gradation, Los Angeles abrasion, soundness, flakiness, aggregate crushing value, asphalt affinity, specific gravity and water absorption tests. The tests carried out on the asphalt cement sample include: penetration, flash point, ductility, durability, purity and specific gravity. The results obtained are indicated in Table-3.1, 3.2 and 3.3 in comparison with the common specifications.

Test specimens were then prepared using each type of the mineral fillers with different proportion by weight in the mix. In accordance with the Marshal Mix design procedure and criteria different mixture properties were obtained and the optimum asphalt binder content was determined.

Finally, mixtures were prepared using different types of mineral fillers at their respective optimum asphalt cement content to investigate the mixture resistance to moisture damages using the Marshal immersion test method.

3.2. Characteristics of Materials

3.2.1 Mineral Aggregate

The mineral aggregates used in the research were subjected to various tests in order to assess their physical characteristics and suitability in the road construction. The aggregates were obtained from Midroc Construction quarry and crusher site located at Kaliti, volcanic-cinder filler from an existing pit at the entrance to Nazareth (97 Km from Addis Ababa) and limestone filler from natural source located at Ambo-Senkelle (130 Km from Addis Ababa).

The coarse and fine aggregate particles were separated into different sieve size and proportioned to obtain the desired gradation for bituminous mixtures of ASTM 3515 for 19mm nominal maximum aggregate size. Incorporating different amount of mineral fillers, the Job-Mix-Formula (JMF) for the aggregate particle size distribution that would be used for the preparation of mixtures is shown in Table 3-1 where keeping the coarse aggregate size distribution unchanged and varying distribution in the fines. The specified grading limits and that of obtained for this study are as shown in Table 3-1.

Table 3-1 ASTM D-3515 Aggregate gradation Requirement

Sieve Size	JMF for Different Filler Content						Specification
	2 (%)	4 (%)	5 (%)	6 (%)	7 (%)	8 (%)	
1” (25.0mm)	100	100	100	100	100	100	100
¾” (19mm)	100	100	100	100	100	100	90-100
½” (12.5 mm)	81.5	81.5	81.5	81.5	81.5	81.5	-
3/8” (9.5mm)	69	69.0	69.0	69.0	69.0	69.0	56-80
No. 4 (4.75mm)	45.6	45.6	45.6	45.6	45.6	45.6	35-65
No. 8 (2.36mm)	34.1	34.1	34.1	34.1	34.1	34.1	23-49
No. 16 (1.18mm)	25.4	25.4	25.4	25.4	25.4	25.4	-
No. 30 (0.60mm)	17	17.0	17.0	17.0	17.0	17.0	-
No. 50 (0.30mm)	10.1	10.1	10.1	11.1	12.1	13.1	5-19
No. 100 (0.15mm)	5.3	5.3	6.3	6.3	7.3	8.3	-
No. 200 (0.075mm)	2.0	4.0	5.0	6.0	7.0	8.0	2-8

To investigate the physical properties of the aggregates and their suitability in road construction, various tests were conducted and the results are indicated in Table 3-2. The specific surface area was determined, for each of the aggregate size distribution, by multiplying surface area factors by the percentage passing the various sieve sizes and adding together [17]. As can be seen from the results, as the filler content increases in the aggregate proportion, the specific surface area will also increase.

Table 3-2 Aggregate physical properties

S/N	Test description	Test Method	Result	Specification Requirements (ERA, Pavement Design Manual, 2002)
1	Cleanliness and Deleterious materials,%	AASHTO T176	51	> 40
2	Los Angeles Abrasion, %	AASHTO T96	16	< 30
3	Durability and soundness, %	AASHTO T104	4.7	< 12
4	Specific Gravity (Bulk) i. Coarse Aggregate ii. Fine Aggregate	AASHTO T85 AASHTO T84	2.59 2.77	-
5	Particle shape, Flakiness, %	BS 812, Part 105	27	< 45
6	Aggregate Crushing Value, ACV, %	BS 812, Part 110	17	< 25
7	Water absorption, %	ASTM C 127	1.2	< 2
8	Affinity for Asphalt (Coating and Stripping), %	AASHTO T-182	99	> 95
9	Specific Surface Area (m^2/Kg) • Using 2% Filler • Using 4% Filler • Using 5% Filler • Using 6% Filler • Using 7% Filler • Using 8% Filler		3.7 4.4 4.8 5.2 5.7 6.2	- - - - - -

3.2.2 Asphalt Binder

An asphalt binder of grade 85/100 penetration was used in the preparation of mixtures since it is widely used and acceptable for temperature condition like Ethiopia. It was then subjected to various tests in the laboratory to determine its physical properties, where the summery of test results obtained are as shown in Table 3-3.

Table 3-3 Asphalt Binder Physical Properties

S/N	Test description	Test Method	Recommended	Result
1	Penetration	AASHTO T49	85 – 100	95
2	Flash Point, ^{o}c	AASHTO T48	232	293
3	Ductility, cm	AASHTO T51	min. 100	100
4	Durability, %	AASHTO T179	1 (max)	0.02
5	Purity, %	AASHTO T44	99	99.61
6	Specific Gravity	AASHTO T228	-	1.01

3.2.3 Mineral Fillers

The mineral fillers, used the current study namely crushed stone, volcanic cinder, and lime stone, are all materials passing No. 200 sieve. Their physical properties, which are believed to be major suspects of affecting the bituminous mixture property [10], such as gradation parameters and plasticity index were determined as shown in Table 3-4.

To distinguish the particle size distribution of each type of mineral fillers, hydrometer analyses were conducted in the laboratory and results are as shown in Figure 3-1. From the hydrometer analysis, other gradation parameters such as fineness modulus, D10, D30, and D60 were determined.

The most common method used for estimating aggregate surface area is to make calculations using specific surface area factors and the aggregate gradation [17]. A simple method developed by Chapuis and Legare [6] to determine surface area of fine aggregates and fillers, was used. This method is developed based on simple geometric considerations. If d is the diameter of a sphere or the edge length of a cube, the surface area of a collection of such spheres or cubes is:

$$S = \frac{6}{\rho} \sum \frac{P_{No\ D} - P_{No\ d}}{d_i}$$

where S is total specific surface area in m^2/Kg, ρ is the density (Kg/m^3) of spheres or cubes, $(P_{No\ D} - P_{No\ d})$ is the percentage by weight smaller than size D and larger than next size d.

Table 3-4 characteristics of Mineral Filler Used

Test	Filler type		
	Crushed Stone	Volcanic Cinder	Lime Stone
Specific Gravity	2.877	2.339	2.801
Fineness Modulus	2.79	2.85	2.87
D10 (micron)	2.3	3.4	3.0
D30 (micron)	4.4	4.9	4.6
D60 (micron)	18	17	18
Specific Surface Area, (m^2/Kg)	465.75	461.85	418.40
Plasticity Index	NP	NP	NP

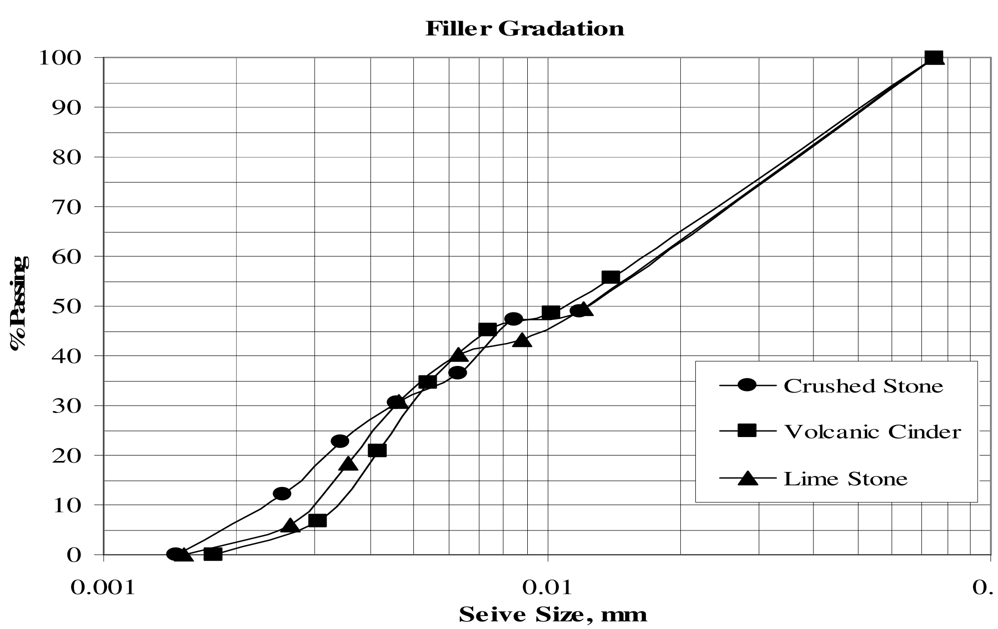

Figure 3-1. Gradations for Each Mineral Fillers

From the test results, it is clear that limestone filler has lower specific surface area which indicates that it is coarser than crushed stone and volcanic cinder fillers. Crushed stone filler has higher specific surface area, lower fineness modulus value, and higher specific gravity than other types of fillers which indicates as it is finer than others.

3.3. Tests carried out

3.3.1.Marshal Tests

Marshal Mix Design method was used to determine the optimum asphalt content and evaluate the stability of the mixtures in the laboratory. Before the preparation of test specimens, mixing and compaction temperatures were determined. This was established by testing the asphalt cement viscosity at different temperatures and plotting the viscosity versus temperature relationship. The temperature that produce viscosities of 170 ± 20 centistokes kinematics and 280 ± 30 centistokes kinematics were established as the mixing and compaction temperatures respectively [20]. The plotting as shown in Figure 3.2 indicates that the mixing and compaction temperatures are 135^0C and 125^0C respectively.

An aggregate weighing about 1200gm and the 85/100 grade asphalt were heated to a temperature of 175^oC and 130^oC, respectively. Then, these ingredients were mixed at a temperature of 135^0C, as previously determined. The percent by weight of asphalt content for all mixes was taken with respect to the total weight of the mixture. The mixture was then placed in the preheated mold and compacted using a 75 blows on either sides of the specimen. After compaction, the specimen were allowed to cool and removed from the mold by means of an extrusion jack. In accordance with the Marshal procedure, each compacted test specimens were subjected to determination of unit weight, void analysis, stability and flow tests. Then, plots were made to determine values of each respective specimen prepared using different types of mineral fillers as indicated in Appendix A.

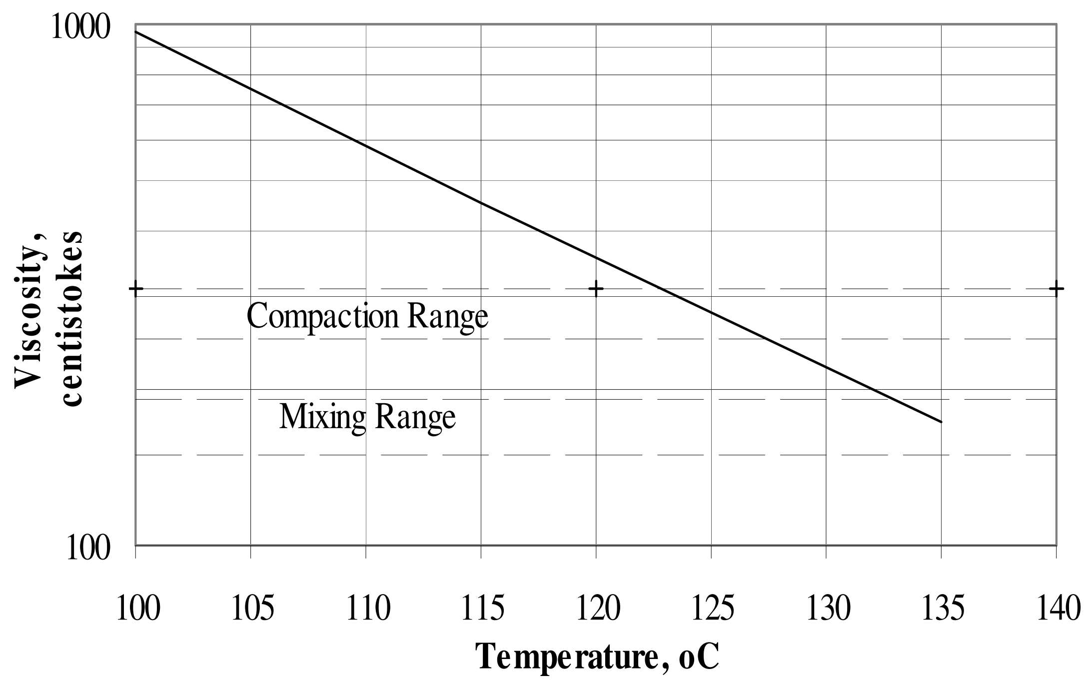

Figure 3.2 Determination of Mixing and Compaction Temperatures

The procedure for determining for optimum asphalt content for a particular mixture under evaluation was adopted from the publication by the Asphalt Institute [20], where both the American Society for Testing and Materials given by ASTM D1559 and American Association of State Highway and Transportation Officials given by AASHTO R-12 standardized it. Accordingly, as a starting point, the manual recommends choosing the asphalt content at the median of the percent air voids limit, which is four percent. Thus, all the calculated and measured mix properties for asphalt content at four percent air voids were determined and then evaluated by comparing them to the Marshal Mix design criteria shown in Table 3-5. Then after, an asphalt content that optimizes all the Marshal criteria for heavy traffic was selected as optimum asphalt content for respective mixes. The Marshal properties at each asphalt content are indicated in graphs and in Table-1A as given in Appendix-A. The Marshal properties of individual mixes, prepared using each type and amount of filler, obtained at their optimum binder content was evaluated and will be discussed in chapter 4.

Table 3-5 Suggested Marshal Criteria for Asphalt Concrete Mix Design [20]

Marshal Method Mix Criteria	Light Traffic Surface - Base		Medium Traffic Surface - Base		Heavy Traffic Surface - Base	
	Min	Max	Min	Max	Min	Max
Compaction, number of blows each end of specimen	35		50		75	
Stability, N	3336	-	5338	-	8006	-
Flow, 0.25 mm (0.01 in)	8	18	8	16	8	14
Percent Air Voids	3	5	3	5	3	5
Percent Voids Filled With asphalt (VFA)	70	80	65	78	65	75
Percent VMA (for 4% Air voids and Nom. Max. Particle size of 19mm)	13	-	13	-	13	-

The effective asphalt binder content was also determined which is important to predict the durability of mixtures.

The effective asphalt content, P_{be}, of a paving mixture is the total asphalt content minus the quantity of asphalt lost by absorption into the aggregate particles. The formula used to obtain is given as:

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

where, P_{be} = effective asphalt content,

P_b = asphalt content, percent by total weight of mixture,

P_{ba} = absorbed asphalt, percent by weight of aggregate,

P_s = aggregate content, percent by total weight of mixture.

3.3.2.Moisture Susceptibility of Mixtures

The performance of hot-mix asphalt in the presence of water is a complex issue where it depends on various variables as reviewed in section 2.3. Many test methods have been developed and used, where they can be divided into two main categories, namely qualitative and quantitative tests. The qualitative tests provide a subjective evaluation of the stripping potential of mixes and the quantitative tests provide value for a specific parameter such as strength before and after conditioning.

Among the various types of quantitative tests, the Marshal Immersion test, which it's conditioning process is similar to that of the Immersion compression test standardized in ASTM D1075 and AASHTO T165-55, is used for evaluating all the Marshal specimens prepared using different fillers by type and amount. The Marshal Immersion test uses the Marshal Stability test as a strength parameter rather than the compressive strength as that for the immersion compression test [13].

Two groups of compacted specimens are used in this test method. One group is submerged in a 49° C water bath for 4 days for conditioning, and the other group is maintained dry. An alternative approach to conditioning is to immerse the test specimens in water for 24 h at 60°C where this is adopted in this study. The stability testing was done at 60°C using a deformation rate of 50.8mm per minute for both the dry and wet sets. The retained stability expressed as a percentage of the ration of conditioned stability to controlled stability.

3.3.3.Dynamic Complex Modulus of HMA

The dynamic complex modulus is one of the various types of tests used to predict the stress-strain properties of bituminous mixtures. It is used to represent the elastic stiffness of HMA. The test is determined by applying a sinusoidal vertical load that simulates the traffic loading at different specified temperature to cylindrical test specimens while recording the deformation. The absolute value of the complex modulus is commonly referred to as the dynamic modulus.

The determination of the dynamic modulus of bituminous mixtures by laboratory tests is difficult for two reasons, i.e. for its time taking test and requires highly complicated and expensive testing equipment. For this reason, different methods are developed to determine the dynamic modulus of bituminous mixtures with out actually conducting the tests in the laboratory. Nomographs or formulas are commonly used for determining the dynamic modulus of mixtures. They are developed based on the properties of the asphalt and the volume concentration of the aggregate in the mix [22]. The Asphalt Institute has developed a formula that can be used to obtain the dynamic modulus without performing the modulus tests. This formula is used in this study to determine the dynamic modulus of different mixtures.

The formula developed by the Asphalt Institute is given below as:

$$|E^*| = 100{,}000 \times 10^{\beta_1}$$

$$\beta_1 = \beta_3 + 0.000005\ \beta_2 - 0.00189\ \beta_2 f^{-1.1}$$

$$\beta_2 = \beta_4^{0.5}\ T^{\beta_5}$$

$$\beta_3 = 0.553833 + 0.028829\ (P_{200}{}^{f\ -\ 0.1703}) - 0.03476V_a + 0.070377\lambda + 0.931757f - \ 0.02774$$

$$\beta_4 = 0.483V_b$$

$$\beta_5 = 1.3 + 0.49825 \log f$$

where β_1 to β_5 are temporary constants, f is the load frequency in Hertz, T is the temperature in ^{0}F, P_{200} is the percentage by weight of aggregate passing through a No. 200 sieve, V_a is the volume of air voids in %, λ is the asphalt viscosity at 70^{0}F in 10^6 poise, and V_b is the volume of bitumen in %. If the asphalt viscosity is not given, λ can be determined using the following formula.

$$\lambda = 29{,}508.2\ (P_{77^0 F})^{-2.1939}$$

where P77^{0}F is the penetration at 77^{0}F (25^{0}C).

For this study, the temperature and loading frequency is taken as 25^{0}C and 0.1 respectively, where the test method ASTM D3497-79 usually adopts. The value of 0.1Hertz for frequency was used to simulate the most likely estimated number of design traffic loading at peak hour for trunk road in Ethiopia. The penetration at 25^{0}C is taken from the asphalt cement penetration test result as 95.

3.4. Analysis of Data

The results obtained from investigations conducted on all bituminous mixtures prepared using different mineral fillers by type and content as described on preceding sections were evaluated. The evaluation of the results was made in a way that could direct to interpret and give conclusive statements on the objective of the study. The test results are tabulated and plotted for mixtures prepared using respective filler types and content. Relationships between various bituminous mixture properties and the filler type were examined graphically. Moreover, a statistical analysis was carried out to show the correlation between the mineral filler characteristics and different mixture properties. The mixture properties assessed include Marshal Properties, moisture susceptibility and dynamic modulus.

TEST RESULT EVALUATION

CHAPTER 4. ANALYSIS and EVALUATION of TEST RESULTS

4.1. General

In this study, eighteen sets of bituminous mixtures using different types and amount of mineral fillers were evaluated using the Marshal Mix design method. These mixtures were prepared using crushed stone, volcanic cinder, and limestone fillers with varying the content by the total mixture and their effects on Marshal Properties were assessed. Moisture susceptibility test was then carried out for mixtures prepared at their optimum asphalt content. To evaluate the stiffness of mixtures, dynamic modulus of mixes for various specimens was calculated using the formulas developed by Asphalt Institute.

Different researches made on the effect of fillers on bituminous mixtures, as reviewed in Chapter 2, revealed that type and amount of fillers affect the performance of HMA mixes. The test results obtained in this thesis research are discussed under subsequent sections.

4.2. Effect of fillers on Marshal Properties of bituminous mixtures

The results of Marshal Tests on bituminous mixes prepared at various filler contents by total mix of the three types of fillers are given in Table 1-A of Appendix A. From the test results, optimum asphalt content was selected for all respective mixtures using different types and amount of mineral fillers. Table 4-1 indicates the properties of mixtures at their optimum asphalt content for mixes with each filler type and content. The effect of mineral fillers on various properties of the asphalt mixtures will be discussed under subsequent sections.

Table 4-1 MARSHAL PROPERTIES OF BITUMINOUS MIXES AT OBC

Marshal Property	Filler Type	Filler Content (%)					
		2	4	5	6	7	8
Optimum asphalt Content, %	Crushed Stone	6.71	6.02	5.57	5.35	5.40	5.60
	Volcanic Cinder	6.52	6.24	6.18	5.77	5.79	6.13
	Lime stone	6.53	6.65	5.59	5.35	5.40	5.41
Air Voids, %	Crushed Stone	4.00	4.00	4.00	4.00	4.00	4.00
	Volcanic Cinder	4.00	4.00	4.00	4.00	4.00	4.00
	Lime stone	4.00	4.00	4.00	4.00	4.00	4.00
Marshal Stability, (KN)	Crushed Stone	9.91	8.84	9.61	9.84	10.89	7.94
	Volcanic Cinder	11.51	10.18	10.12	10.77	10.83	11.17
	Lime stone	9.45	8.23	9.31	10.52	10.51	9.89
Flow, (mm)	Crushed Stone	2.93	3.09	2.36	2.60	2.69	2.63
	Volcanic Cinder	2.18	2.57	2.55	2.87	2.85	2.77
	Lime stone	2.04	2.79	2.66	2.56	3.04	2.69
Bulk Density, (Kg/m^3)	Crushed Stone	2376.82	2392.20	2416.54	2407.01	2413.90	2406.26
	Volcanic Cinder	2379.63	2409.35	2392.39	2414.88	2409.94	2401.10
	Lime stone	2376.44	2365.89	2392.42	2404.19	2405.64	2420.86
VFA, (%)	Crushed Stone	76.33	76.41	73.62	73.35	73.10	73.72
	Volcanic Cinder	76.09	73.06	74.06	70.82	71.86	72.24
	Lime stone	76.27	73.01	74.24	73.13	73.33	71.93
VMA, (%)	Crushed Stone	17.44	15.93	14.72	14.91	14.66	15.28
	Volcanic Cinder	16.72	14.84	15.23	13.93	14.01	14.50
	Lime stone	16.95	17.34	15.56	14.91	14.93	14.44

Effect on Optimum Asphalt Content

As indicated in Figure 4-1 below, the optimum bitumen content (OBC) of mixtures, prepared with different mineral fillers by type and amount, vary over a wide range. The OBC obtained using varying amount of all types of mineral fillers exhibit similar trend that is as filler content in the mixture increases, the OBC decreases up to a minimum and then increases. This is due to the fact that, an increased amount of filler content in the mixture fills the voids in the aggregate. This, subsequently, decreases the voids in the mineral aggregate (See Figure 4), as a result, lower space is available for asphalt. However, at higher (7% and 8%) filler content, the over all surface area of aggregate is increased and requires higher asphalt content to fulfill the Marshal requirements.

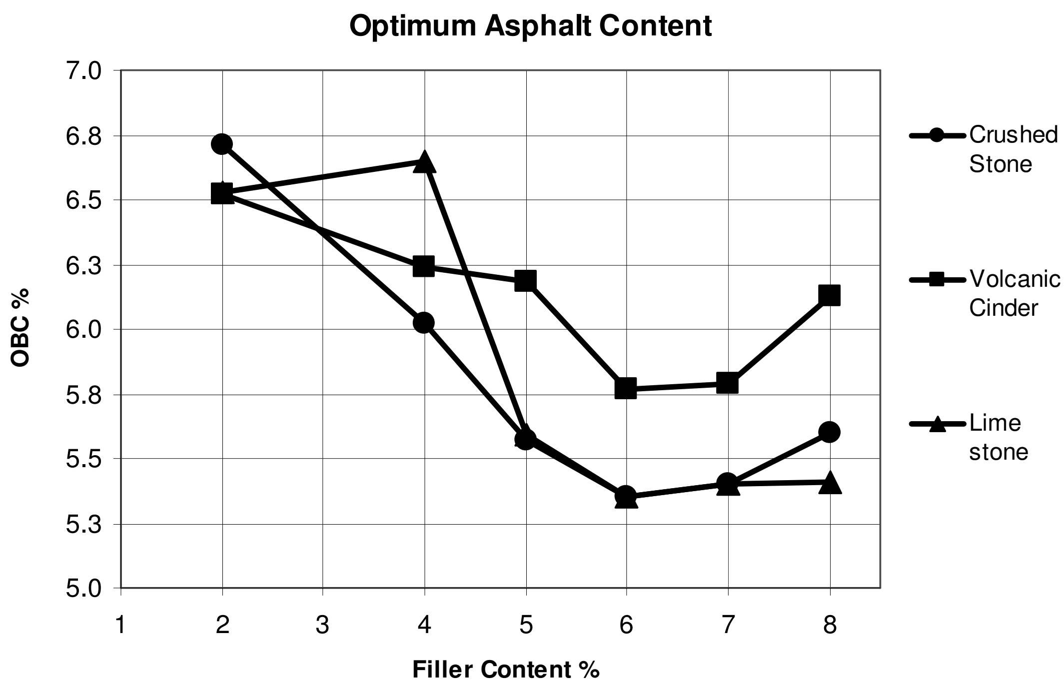

Figure 4-1- Effect of filler type and content on optimum asphalt content

When we see the individual effect of different types of mineral fillers in the optimum binder content, mixtures using volcanic cinder possess higher asphalt content than the mixes using crushed stone or limestone fillers. This attributes to mixes using volcanic-cinder have higher asphalt cement absorption than other filler types. This is evidenced by the calculation made to obtain effective asphalt content, as shown in Figure 4-7, where almost in all cases lower effective asphalt content was obtained. This may be due to lower specific gravity of volcanic-cinder than other types of mineral fillers.

Lower specific gravity of aggregates indicates that there is relatively higher volume of aggregates at similar weight as compared to aggregates of higher specific gravity. Thus, higher volume aggregates needs higher volume asphalt to coat all the aggregates particles.

Mixes made with crushed stone and lime stone filler exhibit nearly similar optimum binder content except for 4% filler content. The optimum bitumen content for mixes using 4% limestone filler is 6.65%, while it is 6.02% for mixes using crushed stone fillers. The highest value of optimum asphalt content (6.71%) was obtained with 2% crushed stone, while the lowest value (5.35%) was obtained with 6.0% crushed stone. The increase was about 23%. This is attributed to the effect of fillers on the voids in mineral aggregates.

Effect on Unit Weight

The effect of both filler type and their content on the unit weight of compacted mixes is shown in Figure 4-2. Mixes made with limestone filler showed a trend of increase in unit weight as filler content increases, while for mixes made with crushed stone and volcanic cinder increases up to maximum and then decreases as the filler content increases. It is shown that at 4% filler content, mixes made with limestone possessed lower unit weight (2365.89 Kg/m^3) and highest unit weight value for mixes made with volcanic cinder (2409.35 Kg/m^3). The opposite trend at 8% filler content was observed, that is, the lowest unit weight value of 2401.10 Kg/m^3 for mixes made with volcanic cinder and highest value of 2420.86 Kg/m^3 for mixes made with limestone fillers. For mixes made with 2% filler content, regardless of the filler type, the unit weight obtained is relatively the same. This may be due to that effect of filler type at lower content is insignificant. The results obtained show a wide variability in unit weight for respective filler type and content, and hence it would be difficult to give an explanation on filler type effects.

In fact, the effect of filler content on unit weight, for mixes made by crushed stone and volcanic-cinder fillers, is that the values increase up to maximum point then decreases. This is because while filler content increases in the mix, it fills the voids hence increase unit weight. However, at higher content the mix becomes stiffer that needs greater compaction effort then consequently lower dense mixtures obtained. This phenomenon did not work for the mixtures prepared using limestone fillers. The unit weight of these mixes simply increases as the filler content in the mix increases. It is difficult to explain why this is happening, but it may be due to that the voids in the mineral aggregate decreases as the filler content increases (see Figure 4-4) that is it does not reach its minimum value, hence increased unit weight.

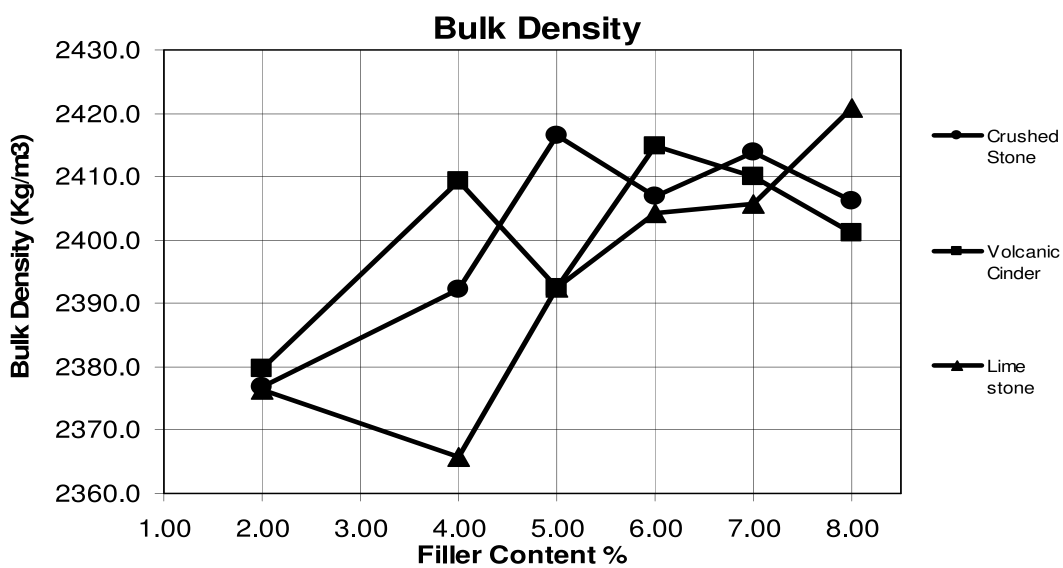

Figure 4-2- Effect of filler type and content on unit weight at OBC

Effect on Marshal Stability

Figure 4-3 demonstrates the effect of filler type and their contents on Marshal Stability. All fillers have similar trend on their effect on Marshal stability by content, i.e., as filler content in the mixes increase, Marshal Stability also increases up to maximum then decreases except for mixtures with volcanic-cinder. This is due to the fact that voids at lower filler content is too high and the aggregate tend to be finer as filler content increases, hence both effect tend to reduce the stability values. Moreover, anything that increases the viscosity of the asphalt cement increases the Marshal stability. Thus, a small addition of fine material (filler) in the mixture may have the effect of making the asphalt cement/dust mixture act as a more viscous binder thus increasing the Marshal stability. However, if the dust is extremely fine, it may extend the asphalt cement, making act like higher asphalt content, and lower the stability, depending on the shape of the Marshal stability versus asphalt content curve [17].

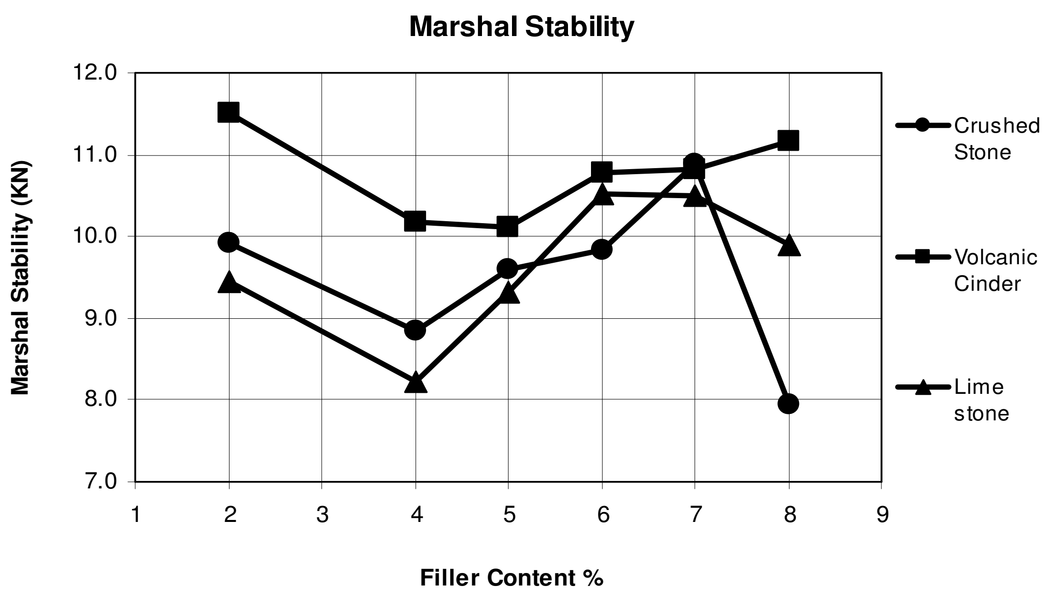

Figure 4-3- Effect of filler type and content on Marshal Stability at OBC

The test results obtained for individual filler type revealed that crushed stone filler is finer than other types of fillers. Thus the finer the material the more it modifies the asphalt mixtures by extending the asphalt binder, hence would rather give lower stability values. On the other hand, the stability values obtained by mixes made with volcanic cinder are relatively higher than all mixes made with either crushed stone or limestone fillers. This can be related with the effective asphalt cement content and voids in mineral aggregate in the mixture. The mixtures prepared with volcanic-cinder have relatively lower effective asphalt cement content and voids in mineral aggregate than the mixtures prepared either with limestone or crushed stone fillers. The effective asphalt cement content and voids in mineral aggregate have an important role in the stiffness of mixture, that is lower values of both factors may increase the stiffness of the mixture and increases the stability.

The figure can illustrate the above theory, where addition of fines could increases the stability of the mixture, whereas if very fine filler is added in the mix, it could reduce the stability by acting like an asphalt extender. This is why mixtures prepared using filler content of 4% and 5%, higher stability values were gained using crushed stone where as lower values using limestone and still highest values using volcanic cinder at all contents. This is due to the fact that volcanic cinder has intermediate size between crushed stone and lime stone fillers. This shows that there exists an optimum filler size that gives better stability.

Effect on Voids in Mineral Aggregate (VMA)

The effect of different fillers on voids in mineral aggregate was also evaluated and the results are shown in Figure 4-4. It is a common trend that, as filler content in the mixes increase, the voids in mineral aggregate decrease up to minimum value then increases at higher content. As can be seen from Figure 4-4, mixtures using both volcanic cinder and crushed stone filler types exhibit same manner, but mixtures made using limestone filler, the voids in mineral aggregate keeps decreasing as the filler content in the mix increases.

Higher voids in mineral aggregate were obtained from mixes prepared by limestone except for 2%, and 8% filler content. This attributes to the fact that limestone is coarser than crushed stone and volcanic cinder filler types. Lowest voids in mineral aggregate were achieved on mixes prepared using 6% and 7% volcanic cinder, where these mixtures possess higher optimum binder content relative to mixes prepared by crushed stone and limestone fillers at respective content, which results more voids in the mixes. Moreover, effect of filler content is found to be more considerable than that of effect of filler type. When we see the trend of effect of filler content on VMA values, it seems that there would be an optimal filler content that would better improve the bituminous mixture performance.

Minimum VMA is necessary in mixtures to accommodate enough asphalt content, so that aggregate particles can be coated with adequate asphalt film thickness. This consequently results in a durable asphalt paving mixtures. It can be seen from the figure that lower VMA are available in mixtures containing volcanic-cinder and hence, results lower effective asphalt content (see figure 4.7). These mixes could be less durable than that of containing limestone and crushed stone fillers.

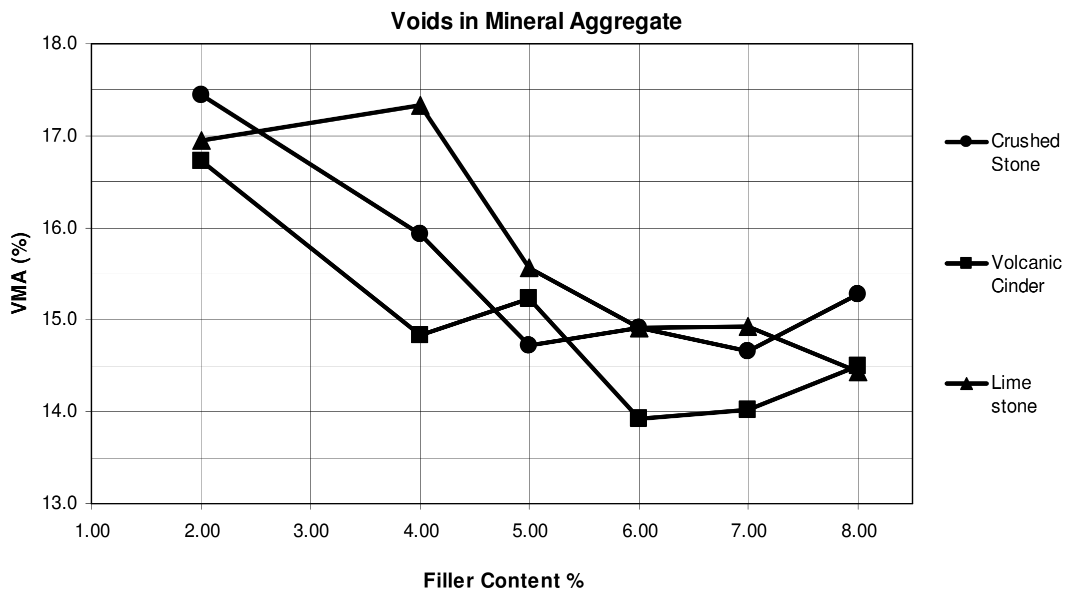

Figure 4-4 Effect of filler type and content on VMA at OBC

Effect on Voids Filled with Asphalt (VFA)

Effect of filler types on the voids filled with asphalt property of the mixture is indicated on Figure 4-5. Voids filled with asphalt values are greater than 70% for all types of fillers and contents, where the Marshal Criteria for VFA is 65% - 75%. This criterion is important for the durability of mixes and is related to the effective asphalt content in the mix. If the percentage of voids filled with asphalt is lower than the limit indicated, there will be less asphalt film around the aggregate particles. Lower asphalt films are more subjected to moisture and weather effects where they can be detached from the aggregate particles and subsequently lower performance. On the other hand, if the limit is exceeded, more voids are filled with asphalt than required for durability. This can be explained as the asphalt film around aggregate particles is thicker and lower voids than required are left. This increased amount of effective asphalt results bleeding and lower stiffness of the mix.

For mixtures prepared by 2% filler content of all types and 4% crushed stone filler type, the voids filled with asphalt is greater than the maximum limit set by Marshal Criteria, and the trend is same as that of VMA and effective asphalt content as filler content increases in the mixes.

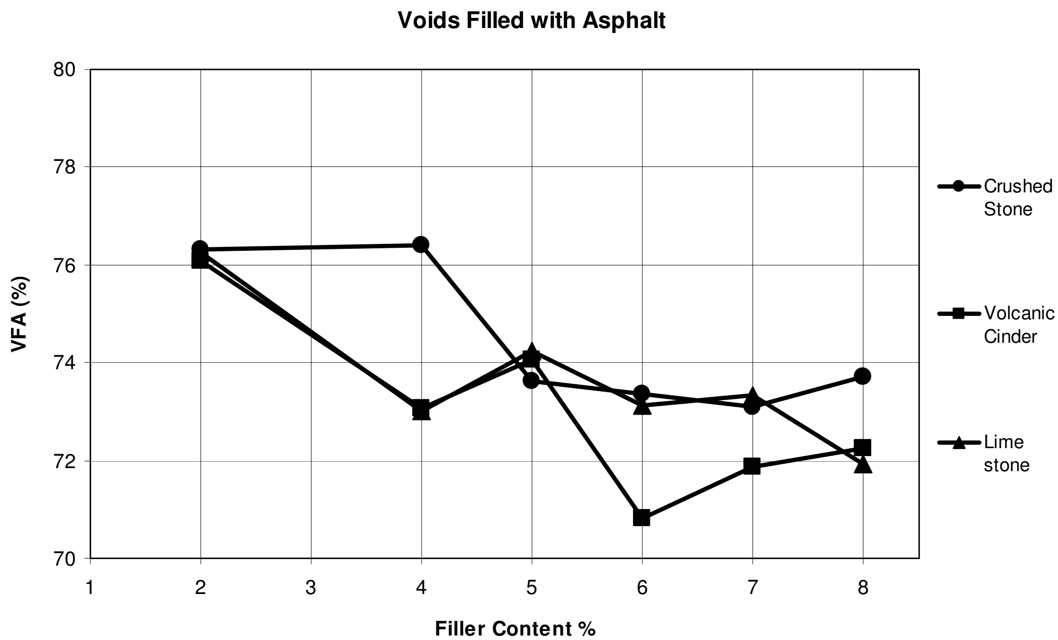

Figure 4-5 Effect of filler type and content on VFA at OBC

Effect on Marshal Flow

As it is clearly shown in Figure 4-6 below, the Marshal Flow values obtained from the laboratory prepared mixes using all filler types, meet the Marshal criteria (2.0mm – 3.5mm). For mixes prepared using 5%, 6%, 7%, and 8% volcanic cinder and crushed stone fillers, the flow values obtained are relatively the same. Higher values of flow were also obtained for mixtures prepared using 2% and 4% crushed stone and 7% limestone fillers. At higher filler content using crushed stone, lower flow values were obtained, attributes to crushed stone filler are finer and stiffens the mixture more than other types of fillers.

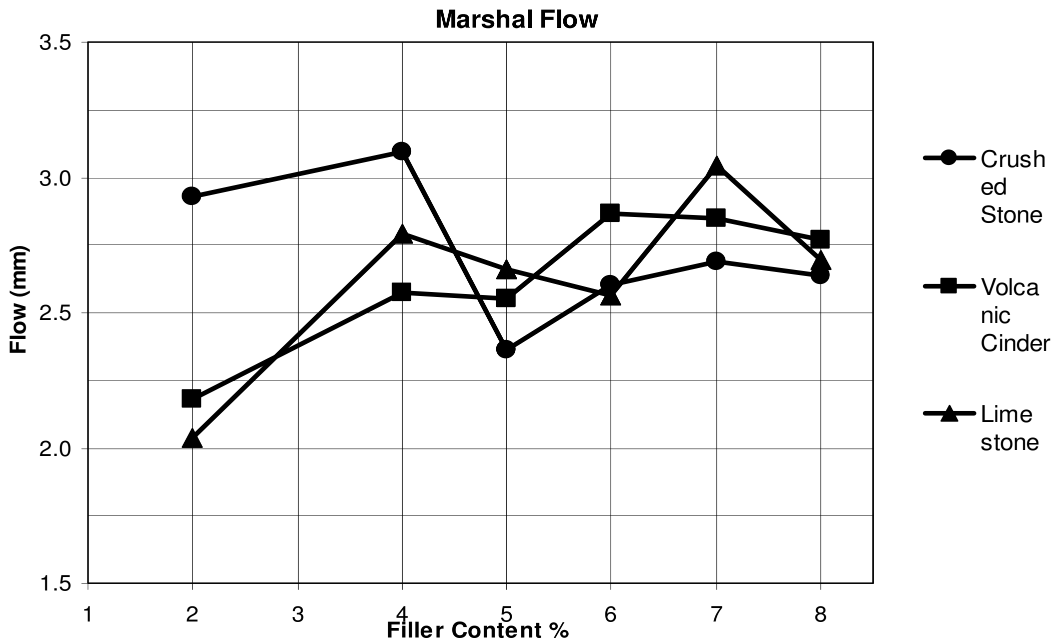

Figure 4-6 Effect of filler type and content on Flow Values at OBC

Effect of Mineral Fillers on Effective Asphalt Content

It is considered that the effective asphalt content in the mixture determines the performance of mixtures. This can be explained as that it is the effective asphalt binder content that makes the asphalt film around the aggregate particles. If the asphalt film thickness around the aggregate particles is thick enough, various desirable characteristics such as better durability, more fatigue resistance, and higher resistance to moisture induced damage can be achieved from bituminous mixtures. But, there should be a maximum limit where up on an increase in temperature and loading, the asphalt content in the mix gets increased and results bleeding on the surface of paved road.

Figure 4-7 is plotted for the effective asphalt content that is present in mixes for respective filler type and content. The figure shows that there exists a common trend among the filler types with respect to their content in the mixture. That is, the effective asphalt content decreases as the filler content in the mix increases except for mixes prepared using 5% volcanic-cinder. This is probably because more voids will be filled with mineral filler as the filler content in the mix increases, which results lower total asphalt content, and hence lower effective asphalt. Besides, as the filler content in the mix increases, more asphalt will be absorbed by fine aggregates due to higher proportion of fines in the mix.

From Figure 4-7, it can be seen that mixes with volcanic-cinder have lower effective binder content than the other filler types. This is due to the fact that volcanic-cinder in the mixes absorbs more binder content. It is the effective asphalt content that determines the available asphalt film thickness around aggregate particles, i.e. thick film thickness is obtained with higher effective asphalt content in the mixture. Thick asphalt films do not age or harden as rapidly as thin ones do and consequently, retain its original characteristics longer. This makes mixtures having thick film of asphalt around aggregates more durable over time. Thus, mixtures containing volcanic-cinder are probably less durable than the others do. On the other hand, excessive film thickness in mixtures may suffer stability problems. This is attributed by the stability values obtained for mixtures using limestone and crushed stone fillers.

The effective asphalt content that is present in mixes with limestone is relatively higher except at 8% filler content. This can be explained as the limestone filler is coarser than volcanic-cinder and crushed stone and hence believed to be less asphalt absorbent.

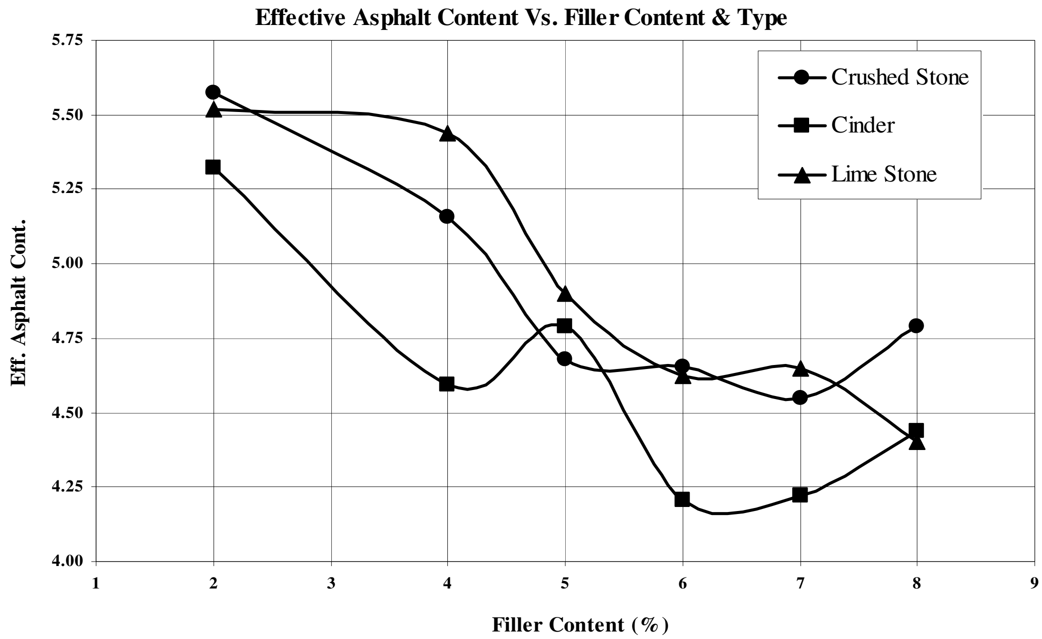

Figure 4-7 Effect of Fillers on Effective Asphalt Content

4.3. Effect of Fillers on Moisture Susceptibility of HMA

From the marshal immersion test conducted for mixtures prepared at their optimum asphalt content, the retained stability values are obtained as a ratio of conditioned stability to controlled stability. Mixtures prepared at 4%, 6%, and 8% were evaluated to indicate the effect of mineral filler types used in the mixes.

The test results are tabulated and plotted as shown in Table 4-2 and Figure 4-8 respectively. The figure is provided here for comparison between values obtained using different mineral fillers in the mix. The trend with respect to filler content in the mix is not included here as the mixture evaluation is made for three different contents in the mix only.

The figure indicates that mixes prepared using 4% and 6% limestone filler provide highest retained stability as compared to mixes prepared with crushed stone or volcanic-cinder fillers. This indicates that mixes prepared using limestone fillers provide better resistance to moisture effects for the sample test. On the other hand, mixes with 8% filler content, highest retained stability values were obtained from mixes with volcanic-cinder, followed by mixes with limestone and the lowest using crushed stone filler.

Table 4-2 Retained Stability Results from Marshal Immersion Test

Filler Type	Filler Content, %	OBC, %	Stability (KN)		Retained Stability, %
			Control	Conditioned	
Crushed Stone	4	6.02	8.8	6.3	71.1
	6	5.35	8.3	6.0	72.2
	8	5.6	7.4	5.1	68.8
Volcanic Cinder	4	6.24	10.0	9.0	90.7
	6	5.77	10.2	9.3	90.9
	8	6.13	10.7	9.7	91.3
Limestone	4	6.65	8.1	7.9	97.1
	6	5.35	9.5	9.0	95.1
	8	5.41	9.3	7.6	82.5

For all the tests carried out to determine the moisture susceptibility showed that mixes using volcanic-cinder and limestone fillers provide better resistance to moisture effect than mixtures using crushed stone filler.

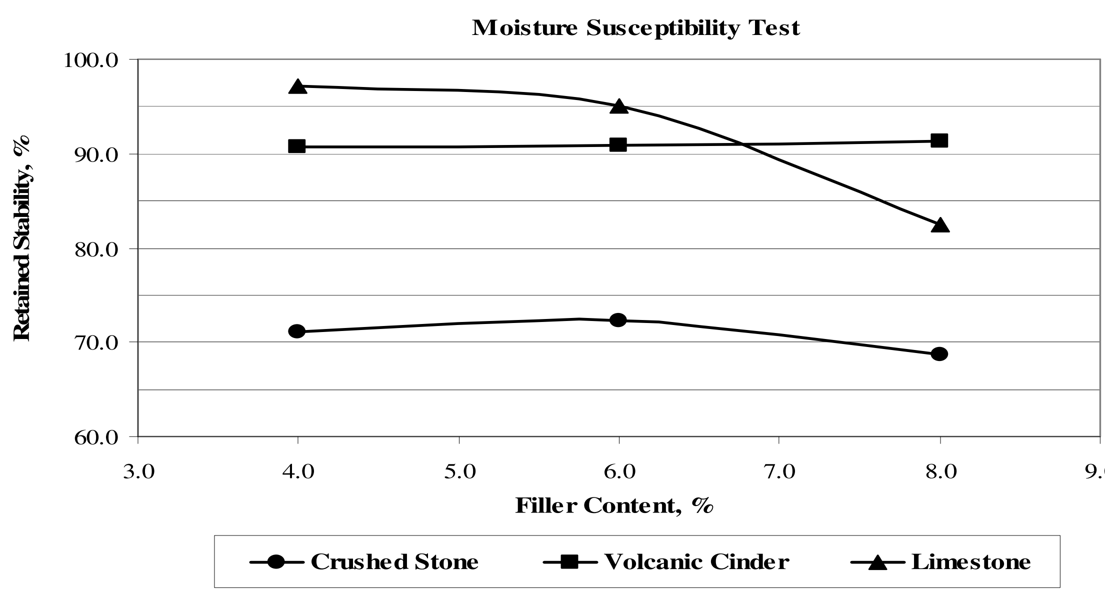

Figure 4-8 Effect of Filler Type and Content on Moisture Susceptibility at OBC

4.4. Effect of Fillers on Dynamic Modulus of HMA

The dynamic modulus values obtained are used to determine the stiffness of mixtures, where higher values show the mix is stiffer and lower values indicate the mix is flexible (less stiff). Stiffer mixes are considered to be more resistant to permanent deformation and lower resistant to fatigue cracking. The dynamic moduli of all mixtures were evaluated at their optimum asphalt content and the results are plotted as shown in Figure 4-9. The figure indicating the dynamic modulus for all filler types for the asphalt content used in the mixture are presented in Appendix B.

As indicated in the figure, the dynamic modulus values will increase with the mineral filler content in the mix irrespective to their type. This is true if mineral fillers are considered to be mainly of filling voids and densify the mix.

While considering the effect of each type of mineral filler, higher and relatively similar dynamic modulus values were obtained from mixtures with limestone and crushed stone fillers using 5%, 6% and 7% filler content. Whereas, mixtures with volcanic-cinder have relatively similar dynamic modulus values at 4%, 6%, 7% and 8% filler content with that of crushed stone.

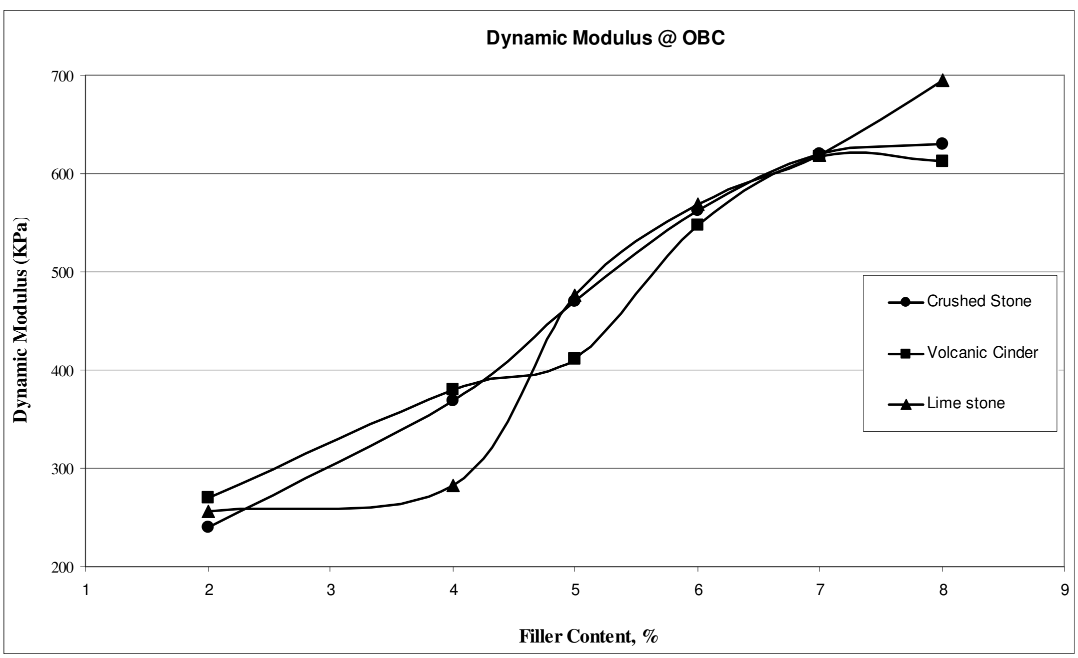

Figure 4-9 Effects of Fillers on Dynamic Modulus of HMA at OBC

Mixtures using 8% filler content, higher dynamic modulus values were obtained from limestone followed by crushed stone and volcanic-cinder.

The stiffness of mixtures is considered as a function of the effective asphalt content that exists around the aggregate particles, where higher effective asphalt content in the mix results thicker film thickness and more flexible mixes can be obtained. The lower effective asphalt content obtained (see Figure 4-7) from mixtures using volcanic-cinder were lower than other mixtures and should have higher dynamic modulus values. But, it is surprising to get lower stiffness values from mixtures containing volcanic-cinder starting from 5% filler content.

In most cases, mixtures with higher dynamic modulus are believed to provide better resistance to rutting effects. However, if the mixtures are excessively stiff, their resistance to fatigue cracking will be low.

4.5. Data Analysis

A correlation matrix was used to determine the mixture test results with the filler characteristics using the MINITAB program. The mixture property were evaluated at similar filler content and the results are as shown in Tables 4-3, 4-4 and 4-5 for 4%, 6% and 8% filler content respectively. This filler content was selected so as to study their values for comparison of the filler characteristics determined for this study with that of the mixture properties obtained using respective filler type.

In this study, the tests conducted for the mineral fillers include: specific gravity, fineness modulus, D10, D30, D60, and specific surface area parameters. Thus, the correlation was made between these filler properties and the mixture test results determined only.

It appears from table 4-3 that the fineness of mineral Fillers expressed by the test parameters fineness modulus and specific surface area has better relationship with the optimum asphalt content. At 6% filler contents (see Table 4-4), the D60, D30, D10 and specific gravity test parameters has highest correlation with the optimum asphalt content. From Table 4-5, this is also true for mixtures at 8% filler content except for D10. Generally, at higher filler content, the correlation factor indicates that as the filler material size at 60% passing increases, that is the coarser it gets, the OBC obtained will be decreased and as the specific gravity of the mineral fillers decreases, the OBC gets increased.

For mixtures containing lower filler content, the filler property determined by specific surface area and D60 correlates better (although at lower significance level) with the bulk density of the mixtures. Table 4-3 shows, as the materials specific surface area increases, become finer, the OBC also increases. From Table 4-4, the D60 and specific gravity correlates well with the bulk density in such a way that as their values increases, the bulk density will decrease.

Better relationship was obtained between the stability of mixtures and D60 and specific gravity at 4% fillers content (see Table 4-3). From the table it can be explained that as the specific gravity and D60 values increases, lower stability values can be obtained.

From Table 4-4, relatively higher relationship exists between the stability and fineness indicators of fillers expressed by fineness modulus, D10 and D30.

Table 4-3 Between P-200 Aggregate Properties and HMA Properties, for Mixtures Using 4% Filler Content

Filler Properties	Optimum Asphalt Content	Bulk Density	Marshal Stability	Flow	VMA	VFA	Effective Asphalt Content	Retained Stability from Moisture Susceptibility Test
Specific Gravity	0.041* 0.974*	-0.714 0.494	-0.904 0.281	0.886 0.306	0.746 0.464	0.599 0.592	0.896 0.293	-0.404 0.735
Fineness Modulus	0.899 0.289	-0.356 0.768	-0.03 0.981	-0.779 0.431	0.311 0.799	-0.974 0.146	0.048 0.969	1 0.003
D10	0.486 0.677	0.244 0.843	0.548 0.631	-0.998 0.043	-0.289 0.813	-0.929 0.242	-0.533 0.642	0.822 0.386
D30	0.234 0.85	0.495 0.671	0.752 0.458	-0.979 0.13	-0.535 0.64	-0.795 0.415	-0.74 0.47	0.639 0.558
D60	0.172 0.89	-0.799 0.41	-0.952 0.198	0.818 0.39	0.827 0.38	0.489 0.675	0.946 0.21	-0.281 0.818
Specific Surface Area	-0.962 0.176	0.888 0.304	0.689 0.516	0.162 0.896	-0.866 0.334	0.573 0.611	-0.702 0.504	-0.742 0.468

* Top values are correlation coefficients R and bottom values are significance levels P in each cell.

For mixtures validation test using the 8% filler content, there exists significant relationship (less than 0.05 level of significance) between the D10 parameter and the stability values, as shown in Table 4-5. Thus, both Table 4-4 and 4-5 reveal that as the size at 10% passing increases, the stability of the mixture increases. The D30 value has also better relationship with the stability values, even if it is less significant. So at higher filler content, the test parameter determined by D10 is considered to have more influence than other filler characteristics.

D10 and D30 have high relationship with the flow values at 4% and 8% filler content respectively. From Table 4-3, it can be seen that as the material D10 value increases, which means coarser, lower flow values can be attained. But, the effect of D10 on flow values is the reverse for mixtures containing 8% filler content. Besides, as shown in Table 4-4 and 4-5, D60 has also a relationship with the flow values at higher filler content.

Table 4-4 Between P-200 Aggregate Properties and HMA Properties, for Mixtures Using 6% Filler Content

Filler Properties	Bptimum Asphalt Contnet	Bulk Density	Marshal Stability	Flow	VMA	VFA	Effective Asphalt Content	Retaimed Stability from Moisture Susceptibility Test
Specific Gravity	-0.991 *	-0.926	-0.794	-0.969	0.991	0.999	0.997	-0.463
	0.083*	0.247	0.416	0.159	0.083	0.033	0.045	0.694
Fineness Modulus	0.277	0.024	0.875	0.161	-0.277	-0.352	-0.334	0.998
	0.821	0.985	0.322	0.897	0.821	0.771	0.783	0.044
D10	0.778	0.592	0.995	0.698	-0.778	-0.825	-0.814	0.857
	0.433	0.597	0.067	0.508	0.433	0.383	0.395	0.344
D30	0.918	0.786	0.930	0.864	-0.918	-0.946	-0.940	0.688
	0.260	0.424	0.239	0.336	0.260	0.210	0.222	0.517
D60	-1.00	-0.967	-0.708	-0.993	1.00	0.997	0.998	-0.343
	*	0.164	0.499-	0.076	*	0.050	0.038	0.777
Specific Surface Area	0.434	0.649	0.329	0.538	-0.434	-0.362	-0.380	-0.697
	0.714	0.550	0.787	0.638	0.714	0.764	0.752	0.509

* Top values are correlation coefficients R and bottom values are significance levels P in each cell.

As shown in Table 4-4 and 4-5, the VMA results have better relationship with D30, D60 and specific gravity at 6% and at 8% filler content, the fineness modulus and D10 have better correlation.

Table 4-3 shows that the fineness modulus and D10 have better relationship with the VFA values, even though the relationship is at lower significance level. The D60 test parameter is the most influencing characteristics of mineral fillers on the VFA values (see Table 4-4).

Table 4-5 Between P-200 Aggregate Properties and HMA Properties, for Mixtures Using 8% Filler Content

Filler Properties	Bptimum Asphalt Contnet	Bulk Density	Marshal Stability	Flow	VMA	VFA	Effective Asphalt Content	Retaimed Stability from Moisture Susceptibility Test
Specific Gravity	-0.926 *	0.603	-0.872	-0.952	0.557	0.472	0.532	-0.868
	0.247*	0.588	0.326	0.198	0.624	0.687	0.643	0.330
Fineness Modulus	0.024	0.490	0.798	0.661	-0.984	-0.997	-0.989	0.801
	0.985	0.674	0.412	0.540	0.114	0.051	0.095	0.408
D10	0.592	-0.098	0.999	0.972	-0.908	-0.863	-0.896	1.000
	0.597	0.937	0.024	0.152	0.275	0.338	0.293	0.020
D30	0.786	-0.361	0.973	0.999	-0.763	-0.696	-0.744	0.971
	0.424	0.765	0.149	0.021	0.447	0.510	0.466	0.153
D60	-0.967	0.702	-0.800	-0.904	0.444	0.353	0.417	-0.797
	0.164	0.505	0.409	0.281	0.707	0.770	0.726	0.413
Specific Surface Area	0.649	-0.946	-0.192	0.008	0.615	0.689	0.637	-0.198
	0.550	0.209	0.877	0.995	0.579	0.516	0.560	0.873

* Top values are correlation coefficients R and bottom values are significance levels P in each cell.

As shown in Tables 4-3 and 4-4, the filler characteristics that indicate higher relationship with the effective asphalt content in the mixture are the D60 and specific gravity values for 4% filler content and 6% filler contents respectively. D30 has also a negative relationship with the effective asphalt content at 6% filler content although it is less significant. Thus, from both tables it is clear that, as the material size at 60% passing increases, and the fines become coarser, the effective asphalt content in the mix increases. However, as the material size at 30% passing becomes smaller, the effective asphalt content increases. This may be due to the presence of excessively fine materials in the mix which may extend the asphalt cement and subsequently higher asphalt content. Regarding the specific gravity, higher values may result with higher effective asphalt content in the mix. This is due to the fact that light weight aggregates tend to absorb higher asphalt content and results lower effective asphalt content. the effective asphalt content obtained (see Figure 4-7) from mixes containing volcanic-cinder have lower effective asphalt content, as their specific gravity values are lower than other types fillers.

From Table 4-3 and Table 4-4, the D10 and fineness modulus have high correlation with retained stability values. The effect of D10 on the moisture susceptibility test shows that as the material size at 10% passing increases, resistance to moisture damage increases. The test result for the moisture susceptibility has indicated that higher resistance for moisture damage was obtained from mixtures containing limestone and volcanic-cinder fillers. At 8% filler content, the retained stability significantly related with D10 and D30. In general, the fineness indicators of mineral fillers have better relationship with retained stability.

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The effect of mineral fillers in the properties of asphalt concrete was investigated from which different results are obtained. From the research conducted and review of literatures made on the effects of fillers on bituminous mixtures, the following conclusions are drawn.

- For mixtures prepared with volcanic-cinder at higher filler contents (5% - 8%), higher optimum asphalt content values were required to fulfill the Marshal requirements. This is probably due to the fact that there is higher asphalt cement absorption when mixes prepared with volcanic-cinder. In practice, one of the main objectives in bituminous mix design is to obtain a mixture that satisfies all the criteria provided that it is economical and practical. However, in this study, mixes with volcanic-cinder filler requires higher asphalt content that makes them to be costly from practical point of view. Whereas, mixtures prepared with limestone or crushed stone filler, optimum asphalt content are relatively the same. For 2% filler content in the mixture, the effect due to filler type is less.
- The bulk density increases up to some point and then decreases with increasing filler content in the mixture using crushed stone and volcanic-cinder. While for mixtures with limestone filler, the bulk density keeps increasing with the filler content.
- Stability values of mixes prepared with crushed stone and limestone were found to be increasing up to maximum and then decreasing with the increase in the amount of filler content starting from 4%. Whereas, the stability values of mixes containing volcanic-cinder keeps increasing with the filler content.
- Higher stability values were obtained from mixtures containing volcanic-cinder for all filler contents. Mixes prepared with crushed stone provide higher stability values than the mixes containing limestone for all fillers content except 6% and 8%.

- The voids in mineral aggregate values obtained indicate relatively similar decreasing trend despite of the filler type used.
- Voids filled with asphalt (VFA) values of mixtures using 2% of all types of mineral fillers and 4% of crushed stone were found to be higher than the maximum value of Marshal criteria.
- The effective asphalt content in the mix provides the required film thickness around the aggregate particles. It is the available film thickness that determines flexibility and durability of mixtures. Mixes made with volcanic-cinder have lower effective asphalt content as compared to mixes containing limestone and crushed stone fillers. Thus, mixtures containing volcanic-cinder have lower film thickness around aggregate particles than mixes containing either limestone or crushed stone fillers and may be less durable.
- The dynamic modulus values increases with the fillers content for all mixtures.
- Higher retained stability values were obtained from mixtures prepared with limestone and volcanic-cinder as compared to crushed stone.
- From this study, the test results obtained from mixes with limestone have relatively similar trend with that of using crushed stone fillers as compared to mixes with volcanic-cinder. Besides, better performance was obtained from mixes using limestone when compared to crushed stone fillers. As a result, this shows us that limestone fillers can be used as alternative filler type in bituminous mixtures to the widely used crushed stone. However, this study is limited when considering the tests conducted and even not verified in the filed. Therefore, further investigation is important in the subject matter so as to characterize limestone filler in relation with mixture properties not only in the laboratory but also in the field.
- The statistical data analysis indicated that there exists relationship between the filler properties and mixture test results. In most cases, the gradation parameters such as D10, D30 and D60 have more correlation with the properties of asphalt concrete. D10 and fineness modulus have high correlation with the moisture susceptibility values.

D60 and fineness modulus have better relationship with the effective asphalt content results.

5.2. Recommendations

The test results obtained during this study revealed that the Marshal properties, moisture susceptibility and stiffness of mixes vary considerably due to variation of filler type and content in the mixes. The mixes for this study were made using different types and amount of mineral fillers only.

Mixtures prepared with limestone fillers show relatively similar trend as crushed stone when compared to the volcanic-cinder. Whereas, inconsistent mixture properties were observed for mixes made with volcanic-cinder. Nowadays, it is becoming common to use limestone material as fillers in asphalt mixtures and researches show that it can be used in asphalt paving mixtures as an alternate to the widely used crushed stone. However, this study indicates that further investigation on the characterization tests for limestone filler in relation with the performance of asphalt concrete that would better simulate the actual field condition is important. The investigation should also seek for its suitability in the asphalt mixtures as alternative mineral filler to the crushed stone.

From the test results obtained, there exists a range of filler content that would result better mixture properties using limestone and crushed stone fillers, where better results were found at 5 to 7 percent filler content.

It is indicated in this study and supported by literature that mineral fillers have an important role in the performance of asphalt concrete. The properties of asphalt mixtures were found to be different depending on the filler type and amount in the mix. Thus, it is important to conduct further investigation on the effect of different types of mineral fillers on the performance of asphalt mixtures.

REFFERENCES

1. Roberts F.L., P.S. Kandhal, E.R. Brown, D. Lee, and T. W. Kennedy, *Hot Mix Asphal Materials, Mixture Design, and Construction.* Second Edition, National Asphalt Pavement Association, Lanham, MD., 1996.
2. The Asphalt Institute, *Mix Design Methods for Asphalt Concrete and other Hot Mix Types*, MS-2, Sixth Edition, 1993.
3. Atkins Harold N., Highway Materials, Soils, and Concretes. Third Edition, 1997.
4. The Asphalt Institute, The asphalt Handbook, MS-4, 1989 Edition
5. Berhanu A. Feyissa, Strength Characteristics of Bituminous Concrete With Different Types of Fillers, 2001.
6. Al-Suhaibani, A., Al-Mudaiheem, J., and Al-Fozan, F., "Effect of Filler Type and Content on Properties of Asphalt Concrete Mixes," Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia, 1992.
7. Anderson, D. A., Bahia, H. U., and Dongre, Raj, "Rheological Properties of Mineral Filler-Asphalt Mastics and Their Relationship to Pavement Performance," Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia, 1992.
8. Anderson, D. A., Dongre, R., Christensen, D. W. III, and Dukatz, E. L. "Effects of Minus No. 200-sized Aggregate on Fracture Behavior of Dense Graded Hot-Mix Asphalt," Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia, 1992.
9. Chapuis, R.P. and Legare, P. –P., "A Simple Method for Determining the Surface Area of Fine Aggregates and Fillers in Bituminous Mixtures," Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia, 1992.

10. Sharrour, A. M., and Saloukeh, G.B., "Effect of Quality and Quantity of Locally Produced Filler (Passing Sieve No. 200) on Asphaltic Mixtures in Dubai", Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia, 1992.
11. Fwa, T. F. and Tan, S. A., "Laboratory Evaluation of Rutting Potential of asphalt Mixtures," Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia, 1992.
12. Shuler, T. S., and Huber, G. A., "Effect of Aggregate Size and Other Factors on Refusal Density of asphalt Concrete by Vibratory Compaction", Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia, 1992.
13. Abdulshafi, O., "Effect of Aggregate on asphalt Mixture Cracking Using Time-Dependent Fracture Mechanics Approach", Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia, 1992.
14. Kim, Y. R., Kim, N., and Khosla, N. P., "Effects of Aggregate Type and Gradation on Fatigue and Permanent Deformation of Asphalt Concrete," Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia, 1992.
15. Matthews, J. M. and Monismith, C. L., "The Effect of Aggregate Gradation on the Creep response of Asphalt Mixtures and Pavement Rutting Estimates," Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia, 1992.
16. Perdomo, D., Button, J. W., and Lytton, R. L., "A New Approach for Prediction of Permanent Deformation," Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C.

Meininger, Ed., American Society for Testing and Material, Philadelphia, 1992.

17. Bouchard, G. P., “Effects of Aggregate Absorption and Crush Percentage on Bituminous Concrete”, Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia, 1992.
18. Cross, S. A. and Brown, E. R., “Selection of Aggregate Properties to Minimize Rutting of Heavy Duty Pavements,” Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia, 1992.
19. Parker, F. and Brown, E. R., “Effects of Aggregate Properties on Flexible Pavements Rutting in Alabama,” Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia, 1992.
20. Kandhal, P.S., C.Y. Lynn, and F. Parker, Jr., Characterization Tests for Mineral Fillers Related to Performance of Asphalt Paving Mixtures. NCAT Report No.98-2. Auburn University, AL., January 1998.
21. Ramzi Taha, A. M. ASCE, Amer Al-Rawas, and Ali Al-Harthy; and Ahmed Qatan, Use of Cement Bypass Dust as Filler in asphalt Concrete Mixtires, Journal of Matrials in Civil Engineering / July/August, 2002.
22. M. Karasahin, S. Terzi, Use of Marble Waste Dust in the Mixture of Asphaltic Concrete as Mineral Filler, Euro Bitume, Viyana, 2004.
23. John, P. Zaniewski and Carlos H. Reues, Evaluation of the Effect of Fines on asphalt Concrete, Asphalt Technology Propgram, Department of Civil Engineering Morgantown, West Verginia, June 2003.
24. Christensen D. W., and Bonaquist R. F. Evaluation of Indirect Tensile Test (IDT) Procedures for Low-Temoerature Performance of Hot Mix Asphalt, National Cooperative Highway Research Program, NCHRP Report 530, 2004.
25. Washington Asphalt Pavement Association, Inc. 2002, (http://www.asphaltwa. com/wapa-web)

26. The Asphalt Institute, Construction of Hot Mix asphalt Pavements, MS-22, Sixth Edition, 1993.
27. Jingna Zhang, L. Allen Cooley, Jr., and Kandhal, Prithvi S., Comparison of Fundamental and Simulative Test Methods for Evaluating Permanent Deformation of Hot Mix Asphalt, National Cooperative Highway Research Program, NCHRP Report 02-07, 2002.
28. Prithvi S. Kandhal, Frazier Parker, Jr., and Rajib B. Mallick, Aggregate Tests for Hot Mix Asphalt: State of the Practice, November 1997.
29. Prithvi S. Kandhal and Stephen A. Cross, Effect of Aggregate Gradation on Measured Asphalt Content, NCAT Report No. 93-1, April 1993.
30. Brian D. Prowell, Jingna Zhang and E. Ray Brown, Aggregate Properties and the Performance of Superpave-Designed Hot Mix Asphalt, NCHRP Report 539, Washington, D.C. 2005.
31. Yiping Wu, Frazier Parker, and Ken Kandhal, Aggregate Toughness/ Abrasion Resistance And Durability/Soundness Tests Related To Asphalt Concrete Performance In Pavements, March 1998.
32. Brian D. prowell, B.D., Zhang, J., and Brown, E. R., “Aggregate Properties and the Performance of Superpave- Designed Hot Mix Asphalt” NHCRP Report 539, WASHINGTON, D.C. 2005.

Appendix A

Test Results from Marshal Mix Design

Appendix B

Calculated Dynamic Modulus for All Mixtures