Effect of Fillers on Hot-Mix Asphalt Concrete

By

K.M. Faruk Hossain

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering in the Department of Civil Engineering

Khulna University of Engineering & Technology
Khulna-9203, Bangladesh

July 2018

Declaration

This is to certify that the thesis work entitled "*Effect of Fillers on Hot-Mix Asphalt Concrete*" has been carried out by *K. M. Faruk Hossain* in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

Signature of Supervisor

Signature of Candidate

Approval

This is to certify that the thesis work submitted by *K. M. Faruk Hossain* entitled "*Effects of Fillers on Hot-Mix Asphalt Concrete*" has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of *Master of Science in Civil Engineering* in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh in July 2018.

BOARD OF EXAMINERS

1.	________________ Dr. Quazi Sazzad Hossain Professor Department of Civil Engineering Khulna University of Engineering & Technology	Chairman (Supervisor)
2.	________________ Dr. Md. Shahjahan Ali Professor & Head Department of Civil Engineering Khulna University of Engineering & Technology	Member
3.	________________ 19.7.18 Dr. Quazi Hamidul Bari Professor Department of Civil Engineering Khulna University of Engineering & Technology	Member
4.	________________ Dr. H. M. Iqbal Mahmud Associate Professor Department of Civil Engineering Khulna University of Engineering &Technology	Member
5.	________________ Mohd. Abdus Sobhan Professor Department of Civil Engineering Rajshahi University of Engineering & Technology	Member (External)

Acknowledgments

I would like to express my sincere appreciation and gratitude to Dr. Quazi Sazzad Hossain Professor of the Department of Civil Engineering, Khulna University of Engineering &Technology (KUET) under whose supervision this work was done. His invaluable guidance, suggestions, words of encouragement and keen interest in my endeavor are greatly acknowledged.

I am greatly indebted to all of the faculty members of the Department of Civil Engineering, KUET for their kind co-operation during the period of study.

Finally, I express my gratitude to Mr. Md. Shahidul Islam, Laboratory Attendant, Department of Civil Engineering, KUET who give me all facilities to conduct all tests at laboratory.

Author

Contents

LIST OF FIGURES

LIST OF ILLUSTRATIONS

LIST OF TABLES

Nomenclature

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.
F/B	Fines to bitumen ratio determination.
G	Specific gravity.
Ga	Specific gravity of compacted mineral
Gt	Theoretical Specific gravity of mixture
Gta	Theoretical maximum Specific gravity of mineral aggregate
HMA	Hot Mix Asphalt
JMF	Job-Mix Formula
MOT	Ministry of transportation
OBC	Optimum binder content, percent by total weight of mixture
P200	The percentage by weight of aggregate passing through a no. 200 sieve
Va	Volume of air voids in percent
Vb	Volume of bitumen in percent
VFA	Voids filled with asphalt %.
VMA	Voids in mineral aggregate %
Wa	Adjusted Wight in air (gm)
Ww	Adjusted Wight in water (gm)

Abstract

Different studies have shown that the properties of fillers have significant effect on the performance of HMA concrete pavements.

This study was intended to investigate the effect of different types of fillers on Hot-Mix-Asphalt performance. The fillers, with different percentages (4% to 8%) by total weight of the mixture, used in the study where crushed stone dust, brick dust and fly ash passing 0.075mm sieve.

Using the different types and quantity of the fillers, a number of trial mixes have been prepared using the Marshall mix design procedure to arrive at asphalt concrete mixture that fulfilled the Marshall criteria. The effects of each filler type on Marshall properties of the HMA mixtures at their individual optimum asphalt content were calculated and possible basis for difference in properties was discussed.

Using the different fillers at their optimum asphalt content, sample were prepared to observe Marshall properties and moisture susceptibility of asphalt mixtures. The Marshall Immersion test method was adopted to determine the moisture effect of mixtures in the laboratory.

The test results show that all types of fillers have an effect on various mixture properties. Mixtures prepared with brick dust require higher bitumen content to fulfill all the Marshall requirements. This makes these mixtures more costly practically. Higher stability values obtained by mixes with stone dust as compared to brick dust and fly ash. Higher retained stability was obtained by mixes prepared with brick dust and fly ash as compared to the widely used stone dust. From the study, similar trend of mixture properties, particularly Marshall properties were observed for mixes made with brick dust and stone dust as compared to that of fly ash. This indicates that brick dust can be used as an alternative for the widely used stone dust.

Different characteristics of HMA mixtures were observed by varying the fillers in the mixture by type and quantity. This indicates that, Fillers are indicates as an important

ingredient in the HMA mixture properties. From the results obtained, there is a common trend in obtaining different mixture properties with different filler content, which shows, there exists optimum filler content that based performance will be achieved.

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

CHAPTER I

Introduction

1.1 General

As the traffic demand is growing at a rapid rate along with the increase in the axle loads, it is necessary to improve the highway paving materials. Hot-mix asphalt (HMA) concrete mixture is formed from aggregates and asphalt and is widely used in the surface layer of flexible-pavement road. The aggregates are expected to provide a skeleton to resist the repeated traffic load applications and the asphalt provides adhesive action among aggregate particles and contributes viscous-elastic properties to the mixture (Read and Whiteoak 2003). Generally, aggregates that are larger than 4.75 mm are categorized as coarse, whereas those smaller than 4.75 mm and larger than 0.075mm are fine aggregates. Filler refers to mineral particles that are finer than 75 µm in size. Hot mix asphalt (HMA) pavements are being increasingly constructed in Bangladesh, as the government is allocating large amount of resources to improve the existing road network all over the country. However, it is stated 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. Consequently, this induces large amount of maintenance and road users cost that would have negative effect on the nation’s economy. In various developed and developing countries, researches have been conducted to produce mixes with improved properties by modifying the HMA constituting ingredients. Thus, in the HMA mix design process, it is important to select 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 (HMA) 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 (bitumen), aggregate, filler and air in different relative proportions that determine the physical properties of the mixture. 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 which is sufficiently durable, strong, resistive to fatigue and permanent deformation, economical and environment friendly.

The performance of asphalt surfaced roads is directly affected by the proportion and quality of ingredients in the mixture. The mix design has been a major concern where various studies (Roberts et al, 1996; Tayebali et al, 1998; Sharma et al., 2010) were conducted. The pavement performance is improved by ensuring that sufficient behavior of the bituminous mixtures is achieved, which essentially depends on their composition. Therefore, selecting the proper type of filler would upgrade the HMA properties and thus enhance the mixture's performance (Kandhal, 1981).

The mix design has been a major concern where various studies (Fwa and Tan, 1992; Shuler and Huber, 1992; Kim et al., 1993) 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.

As the filler particles are small in size, it is well documented that filler plays a significant effect on the characteristics and performance of asphalt-concrete mixture. Good packing of the coarse aggregate, fine aggregate and filler provides a strong strength for the mixture (Vavrik et al. 2002; Qui 2006). The presence of filler is associated with reduced optimum asphalt content (Brwon et al. 1989; Kandhal et al., 1998; Tayebali et al. 1998). However, an excessive amount of filler may weaken the mixture by increasing the amount of asphalt needed to coat the aggregates (Elliot et al. 1992; Kandhal et al. 1998) and affects the workability of asphalt mixture. Moreover, the fillers also affect the workability, moisture sensitivity, stiffness and ageing characteristics of HMA (Mogawer and Stuart, 1996). The influence of different types of fillers on the properties of HMA mixture varies with the particle size, shape, surface area, surface texture and other physio-chemical properties (Bahia et al., 2011). It also contributes to change the visco-elastic properties of the asphalt mastic, which influence the overall performance of the mixture (Taylor, 2007).

This study was intended to evaluate the effect of different fillers: crushed stone dust, brick dust and fly-ash passing 0.075mm sieve at various contents. The Marshall test and moisture susceptibility test were followed to investigate the bituminous mixes in the laboratory. Different mixtures were prepared by varying contents of respective filler type in accordance with the Marshall Mix design procedure. The performance characteristics of the asphalt concrete mixture containing different types and fractions of filler evaluated by various laboratory tests. Using the Marshall 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 mixtures.

1.2 Problem Statement

Researches show that the modification made in the constituents of bituminous mixtures such as type of ingredient materials sometimes improved the properties of HMA. Among these researches, some studies (Roberts et al. 1996; Atkins, 1993; The Asphalt Institute, 1993; Anderson et al., 1992; Fwa and Tan, 1992; Kim et al., 1992; Zulkati et al., 2012, Rahman et al., 2012; Bhat and Mittal, 2016) proved that 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 the effect of different types of fillers, name crushed stone dust, brick dust and fly ash at various contents (percentage).

In the construction of highway pavements, one of the main problems is insufficiency of amount of mineral fillers from crushing of aggregates. Therefore, it is important to come across an alternative type of filler materials. In Bangladesh, conventionally cement and stone dust are used as fillers. Moreover, the performance characteristics of the mixture containing different types of filler were evaluated by examining fundamental material properties and by performing various laboratory tests. The potential use of non-conventional filler i.e. brick dust and fly ash were also investigated in order to find out alternative type of filler materials.

1.3 Objectives

The overall objective of this study is to investigate the characteristics of HMA mix using different types of fillers. The specific objective is to investigate the effect of different fillers (crushed stone dust, brick dust and fly-ash) on the Marshall Properties and moisture resistance of HMA concrete.

1.4 Scope and Limitations

The research reported herein was focused on hot-mix asphalt (HMA) concrete characteristics such as the Marshall Properties and moisture susceptibility. The materials selected for this study were collected from different sources. The mixtures were prepared using each type of fillers with different amount. The results produced in this research were based on the Marshall Mix design.

1.5 Thesis Outline

Chapter I covers a brief introduction of the different types of fillers in flexible pavements. Additionally, the chapter summarized the objectives and problem statement of this thesis. Chapter II presents the relevant literature review. Chapter III presents the research methodology of the experimental program. Chapter IV presents a comprehensive experimental results and discussions of each mixture. Chapter V presents conclusions and future scope of the research.

CHAPTER II

Literature Review

2.1 General

Various studies (Neubauer and Partl, 2004; Kim et al. 2003; Taha et al. 2002; Kandhal and Parker, 1998; Harris and Stuart, 1998; Ali et al. 1996; Ishai et al. 1980) have been conducted on the properties of HMA using insignificant changes on the ingredients of the mixture. In general the main objectives of the researches were to realize the characteristics of bituminous mixtures and evaluate the effects of constituent ingredients on the performance HMA concrete. Among the various studies conducted, most of them were concerned on investigation of effects of aggregates on the bituminous mixture performance and the aggregates are the main influencing factor of the performance of the HMA concrete mixture.

In this research Marshall Properties and moisture susceptibility of HMA mixtures prepared using different fillers were concentrated. This evaluation was conducted using the crushed stone dust, local brick dust and fly ash as filler. Bituminous mix design and review of different researches conducted to know the effect of filler on HMA concrete will be discussed.

2.2 Procedure in HMA Mix Design

Mineral aggregates and asphalt binder (Bitumen) are the two basic ingredients of Hot-Mix-Asphalt mixture. The aggregate composition typically varies in size from coarse to fine particles. Many different compositions are specified throughout the world. The mixes designated in any given locality generally are those that have proven adequate through long-term use. The process in HMA mix design involves determining the type of aggregate to use, asphalt binder to use and proportion of these two ingredients to use in order to get the desired bituminous mixture performance. HMA is a complex material where different type and quantity of aggregate, filler and asphalt binder are used. It must resist deformation and cracking, be durable over time, resist water damage, and yet be not expensive, 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 three basic variables: namely aggregate selection, asphalt binder choice and optimum asphalt binder content determination.

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 disclosed that aggregate type has a significant effect on the fatigue resistance and permanent deformation of asphalt mixtures. Aggregates that are well-graded from coarse to fine are generally sought in high-type bituminous paving mixtures. Well-graded materials tend to produce the densest mixtures and therefore the most durable, requiring minimum bitumen content for satisfactory results. The concept simply is that in a well-graded aggregate each smaller sizes or fraction of aggregate serves to fill the voids in the next larger one. 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.

2.2.2 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. Matthews and Monismith (1992) investigated a study to evaluate aggregate gradation on the creep response of asphalt mixtures and pavement rutting estimates. 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. (1992) 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 (1998) 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 Super pave mixtures.

A study was made by Kandhal and Cross (1996) on effects of gradation on the asphalt content. Further, regression analysis was carried out 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. Gradation with high amount of fines 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 causes problem in deformation resistance of mixtures under traffic loading.

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. Maximum aggregate sizes for surface mixes and binder course mixes vary from 9.5mm to 19mm and 19mm to 38mm, respectively

2.2.3 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.

2.2.4 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. Each trial mixture is prepared in a manner that is intended to secure a very density. Densities generally represent the ultimate densities that are practically attainable either in the laboratory or in the field. The various important mixture properties which show weight-volume relationship and strength are discussed here in after.

2.2.5 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 Marshall 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 filler. It is expected that the bulk density increases as the amount proportion of filler increases in the mixture up to some point and then decreases. This is because an increased amount of 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.

2.2.6 Percent Voids in the Mineral Aggregate (VMA) in Compacted Bituminous Mixture

The voids in the mineral aggregate, VMA, is the volume of intergranular void space between the aggregate particles of a compacted paving mixture that includes the voids and the effective asphalt content expressed as a percent of the total volume of the sample. It is calculated based on the bulk specific gravities of the combined aggregates and compacted paving mixture. The VMA is based on the bulk specific gravity of the aggregate and is expressed as a percentage of the bulk volume of the compacted paving mixture. Therefore, it can be calculated by subtracting the volume of the aggregate determined by its bulk specific gravity from the bulk volume of the compacted paving mixture.

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 very 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 fillers in the mixture increases. This can be due to both fillers can be used for filling voids or extend the asphalt binder.

2.2.7 Percent Air Voids in Compacted Mixture

The air voids in a compacted paving mixture consist of the small air spaces between the coated aggregate particles. In order to produce design air voids, HMA mix design adjust asphalt content and aggregate gradation.

2.2.8 Percent Voids Filled with Asphalt in Compacted Mixture (VFA)

The voids in the mix are often expressed in terms of the percentage of the total voids in the mineral aggregate that are filled with asphalt, VFA. 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.

2.2.9 Marshall Stability and Flow

Marshall Test is a simple and low cost standard laboratory test adopted all over the world for design and evaluation of bituminous mixtures. Marshall 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 60^0C at a loading rate of 50.8mm/minute. In most of the cases, the stability value is affected significantly by the angle of internal friction of the aggregate and the viscosity of the asphalt cement at 60^0C. Consequently, one of the easiest ways to increase the stability of an aggregate-asphalt mixture is to use a higher viscosity grade of asphalt cement or the stability can be increased by improving the aggregate quality.

The flow is measured as the total deformation of the specimen in hundreds of inch occurring in the specimen between no load and maximum load during the stability test. In general, high flow values indicate a plastic mixture which is responsible for permanent deformation problem due to traffic loads, whereas low flow values may indicate a mixture with higher than normal voids and insufficient asphalt for durability and could result premature cracking due to mixture brittleness.

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 can be defined as the weakening or ultimate loss of the adhesive bond between the aggregate surface and the asphalt binder in a HMA 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 Effect of Fillers on HMA

Filler material is produced at the production stage by crushing and screening of the material passing the number 200 sieve. Mineral filler that is finer than the thickness of asphalt film will make the asphalt binder more mastic. Harrigan (2011) defines mineral filler as that certain mineral particle which were suspended in bitumen. In general, fillers reduce the voids and increase the density, stability and toughness of the asphalt mixes. As filler content increases, the brittleness and tendency to crack in service also increase. 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 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 .

Sharma et al. (2010) have shown that presence of high calcium oxide in fly ash is an important parameter governing the strength characteristics of bituminous mixes and fly ash up to 7 percent can be used as filler. Karasahin and Terzi (2007) used marble dust as filler material in asphalt concrete mixes. The Marshall and plastic deformation tests showed that limestone dust and marble dust gave almost the same results. Marble dust had higher values of plastic deformation and hence suggested for low traffic volume roads.

Sadoon (2010) studied the effect of different filler types on the performance properties of asphalt paving. Six different types of filler were used to evaluate the resistance to plastic flow using Marshall stiffness test and low temperature cracking and temperature susceptibility using indirect tensile strength test in addition to study retained strength test and resistance to permanent deformation by using indirect tensile creep test. The results indicated that filler type had a great effect on the cohesion of the mix where such types show high indirect tensile strength values with respect to other types of filler at different test temperature.

Karasahin and Terzi (2004) 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 Marshall Test procedure. In this test, dynamic plastic deformation tests on both mixes using marble waste and limestone dust were carried out. The study indicated that both Marshall 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.

Kim et al. (2003) tested sand particles mixed with plain asphalt binders and asphalt mastics. It was concluded that the filler type affected the fatigue behavior of asphalt binders and mastics. Fillers also stiffened the binders and the hydrated lime was more effective in stiffening binders than limestone dust (LSD) fillers.

Ramzi Taha et al. (2002) investigated the use of cement bypass (CBPD) as filler in asphalt concrete mixtures. Results indicated that the substitution of 5% CBPD for lime would essentially produce the same optimum asphalt binder content as the control mixture without any negative effect on the asphalt’s concrete properties. However, the use of 13% CBPD for lime and fine aggregate will require higher optimum asphalt content and will produce an uneconomical mix.

Berhanu (2001) conducted Marshall Stability tests on bituminous mixes with 60/70 grade bitumen fillers suchas stone dust, marble and limestone. Generally, Marshall 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 content of fillers in the mixture has greater influence on determination of optimum asphalt content and strength. The physical properties of mineral fillers influence the performance of asphalt mixture such as permanent deformation, fatigue cracking, and moisture susceptibility of HMA.

Kandhal and Parker (1998) stated that influence that mineral filler can have on the performance of HMA mixtures depended on the particle size. An over-rich HMA mix can lead to flushing and rutting. In many cases the amount of asphalt cement used must be reduced to prevent a loss of stability or pavement bleeding.

Tayebali et al. (1998) investigated the possibility of increasing the amount of fines in asphalt mixtures based on a washed sieve analysis, from a maximum of about 8% as currently specified, without adversely affecting the performance of the mixture. At the same time, it was also desirable to investigate the influence of the mineral filler type on asphalt mix design and on the shear permanent deformation performance. It was found that by increasing the amount of mineral filler the Marshall stability and unit weight increased. This procedure led to a higher shear resilient modulus due to increased unit weight without adversely affecting its rutting during the repeated shear testing.

In another study, Anderson et al. (1992) 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.

Ali et al. (1996) investigated the effects of fly ash on the material and mechanical properties of asphalt mixtures; results from this study indicated that fly ash can be used as a mineral filler to improve resilient modulus characteristics and stripping resistance. Ishai et al. (1980) proposed that different fillers have different effects on the same bitumen and these are attributable to the surface activity of the fillers. The study was limited in regard to the range of fillers studied, but found that hydrated lime had both the highest geometrical irregularity and surface activity. These observations were based on hygroscopic measurements.

Fwa and Aziz (1995) performed a series of tests to arrive at an acceptable mix using incinerator residue as a partial replacement for the aggregate in Singapore. Mix design analysis and stability, durability and resistance to moisture susceptibility tests were performed on mixes. Mixes containing incinerator residue showed higher values of stability and better resistance to moisture susceptibility.

Harris and Stuart (1995) concluded that fillers play a dual role in asphalt mixtures, first, they act as a part of the mineral aggregate by filling the voids between the coarser particles in the mixtures and thereby strengthen the asphalt mixture, second, when mixed with asphalt, fillers form mastic; a high consistency binder or matrix that cements larger binder particles together; most likely a major portion of the filler remains suspended in the binder while a smaller portion becomes part of the load bearing framework.

A study carried out by Shahrour and Saloukeh (1992) evaluated the effects of different types and quantity of mineral fillers on asphalt mixtures. At higher field temperature, the deformation behavior of asphalt pavement becomes critical. Thus, at a certain temperature an increase in the viscosity can be achieved either with more filler or with the use of effective filler. It was also seen that the Marshall parameters were not significantly affected by changing the type of filler at specified filler contents. It was also indicated that hydrated lime filler has shown better stiffening properties when mixed with the binder compared to all other filler types.

Al-Sayed (1988) carried out extensive research work on filler used in asphalt mixes. It was suggested that substitution fines passing by stronger and cleaner filler would improve the properties of asphalt mixes and consequently reduce rutting, swelling, and cracking of pavement surface.

Sofia (1986) found that the use of collected dust fines to substitute ordinary fillers gave quite satisfactory results in terms of stability values and other Marshall properties. Filler has a great influence on the adhesion i.e the asphalt-filler mastic is considered as asphalt which has a viscosity higher than the asphalt alone, which improves the mechanical properties of asphalt mix.

Chari and Jacob (1984) studies the influence of lime and stone dust fillers on fatigue performance of bituminous concrete mixes. Between the two fillers, lime was found to have substantial influence on the fatigue properties, although static strength remained more or less same for both the fillers. Suhaibani et al. (1992) investigated the effect of filler type and content on rutting potential of bituminous concrete.

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 (Asphalt Institute Method, 1984)

Craus et al. (1981) investigated the role of fillers in long term durability of bituminous concrete mixes. Durability tests were conducted on mixes consisting of one type of aggregate, one gradation and six types of filler. The results indicated that the properties of filler have a pronounced effect on the durability potential of the mixture.

Kallas and Puzinauskas (1967) believed that filler performed a dual role in asphalt-aggregate mixtures. A portion of the filler with particles larger than the asphalt film will contribute in producing the contact points between aggregate particles, while the remaining filler is in colloidal suspension in the asphalt binder, resulting in a binder with a stiffer consistency. It was also found that the stabilities of asphalt mixtures increased up to a certain filler concentration, then decrease with additional filler.

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 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. Conventionally stone dust, cement and lime are used as fillers. An attempt has been made in this investigation to assess the influence on non-conventional and cheap fillers such as brick dust and fly ash in HMA mixtures. The fillers used in this investigation are likely to partly solve the solid waste disposal of the environment.

CHAPTER III

Methodology

3.1. Introduction

In this study, Marshall Properties and moisture susceptibility of HMA mixtures using different types of fillers (crushed stone dust, brick dust and fly ash) were investigated. This study also involves collecting the materials for the preparation of HMA mixtures. The materials used in the mixtures are coarse and fine aggregates, different types of fillers and asphalt binder.

The crushed stone coarse and fine aggregates are purchased from local business source and crusher site located at Khulna City Corporation area. The brick dust collected from local brick crusher source and fly ash collected from cement factory. The asphalt cement of 80/100 penetration grade was purchased from market.

Various laboratory tests were conducted of the ingredient materials to determine their physical properties. These tests conducted on the aggregates include: gradation, Los Angeles abrasion, soundness, flakiness, aggregate crushing value, specific gravity and water absorption. The tests carried out on the asphalt cement sample include: penetration, flash and fire point, ductility, durability, solubility and specific gravity. The results obtained are indicated in comparison with the common specifications. Then test specimens were prepared using each type of the mineral fillers with different proportion by weight in the mix.

In accordance with the Marshall Mix design procedure and criteria, different mixture properties were obtained and the optimum asphalt binder content was determined. HMA mixtures were prepared using different types of fillers as per the optimum asphalt content to investigate the resistance to moisture damage using Marshall Immersion test.

3.2. Characteristics of Materials

3.2.1 Aggregate

The aggregates used in this study were subjected to various tests in order to assess their physical characteristics and suitability in the road construction.

3.2.1.1 Coarse Aggregate

The coarse aggregate should have good abrasion value, impact value and also crushing strength. The function of coarse aggregates is to bear the stresses due to wheels. Function of coarse aggregates is also resisting wear due to abrasion. That portion of the mixture which is retained on 4.75 mm sieve is termed as coarse aggregates.

Figure 3.1Stone Chips (retained on 4.75 mm sieve)

3.2.1.2 Fine Aggregate

Voids which remain in the coarse aggregates are filled by the fine aggregates. So the function of fine aggregates in to fill the voids of coarse aggregates. Fine aggregates consist of crushed stone or natural sand. Aggregates that passed through 4.75 mm sieve and retained on 0.075mm sieve were selected as fine aggregates.

Figure 3.2 Sylhet Sand (4.75 mm to 2.36 mm)

The coarse and fine aggregates were separated into various sizes. The combined gradations of aggregates were chosen to approximately meet the job mix formula (JMF) of the gradation which specified for dense graded HMA mixtures of wearing course for 19mm nominal maximum aggregate size. The coarse and fine aggregates were sieved and recombined in laboratory in order to produce identical controlled gradation and to meet the selected gradation which is shown in Table 3.1 AASHTO Aggregate Gradation Requirement, Table 3.2a Gradation of Selected Aggregates (Filler 4%, Coarse Aggregate 54.26%, Fine Aggregate 41.74%), Table 3.2b Gradation of Selected Aggregates (Filler 5%, Coarse Aggregate 54.00%, Fine Aggregate 41.00%), Table 3.2c Gradation of Selected Aggregates (Filler 6% Course Aggregate53.33 Fine Aggregate 40.67), Table 3.2d Gradation of Selected Aggregate (Filler 7%, Coarse Aggregate 52.67%, Fine Aggregate 40.33%), Table 3.2e Gradation of Selected Aggregate (Filler 8%, Coarse Aggregate 52.00%, Fine Aggregate 40.00%)

Table 3.1 AASHTO Aggregate Gradation Requirement (ASTM,D3515)

Sieve Size	Job Mix Formula for different filler content					Specification Retained
	4 (%)	5 (%)	6 (%)	7 (%)	8 (%)	
1” (25.0mm)	0	100	100	100	100	0
¾” (19mm)	100	100	100	100	100	0
½” (12.5 mm)	5	5	5	5	5	0-6
3/8” (9.5mm)	32	32	32	32	32	9-40
No. 4 (4.75mm)	37	37	37	37	37	9-45
No. 10 (2.00mm)	26	26	26	26	26	8-27
Total Coarse aggregate						50-65
No. 40 (0.425mm)	32	32	32	32	32	6-22
No. 80 (0.177mm)	44	44	44	44	44	8-27
No. 200 (0.075mm)	24	24	24	24	24	5-17
Filler	4	5	6	7	8	4-8
Total Fine Aggregate and Filler						35-50

Table 3.2a Gradation of Selected Aggregates

(Filler 4%, Coarse Aggregate 54.26%, Fine Aggregate 41.74%) Mass (gm)

Sieve Size	JMF for Different Asphalt Content					
		4.5 (%)	5 (%)	5.5 (%)	6 (%)	6.5 (%)
-	Asphalt Content	58.50	65.00	71.50	78.00	84.50
-	Coarse Aggregate	673.64	670.11	666.58	663.06	659.53
½” (12.5 mm)	5	33.68	33.51	33.33	33.15	32.98
3/8” (9.5mm)	32	215.56	214.44	213.31	212.18	211.05
No. 4 (4.75mm)	37	249.25	247.94	246.64	245.33	244.03
No. 10	26	175.15	174.23	173.31	172.39	171.48
	Fine Aggregate	518.20	515.49	512.90	510.06	507.35
No. 40	32	165.82	164.96	164.13	163.22	162.35
No. 80	44	228.00	226.82	225.67	224.43	223.23
No. 200 (0.075mm)	24	124.37	123.72	123.09	122.41	121.76
Filler	4	49.66	49.40	49.14	48.88	48.62

Table 3.2b Gradation of Selected Aggregates

(Filler 5%, Coarse Aggregate 54.00%, Fine Aggregate 41.00%) Mass (gm)

Sieve Size	JMF for Different Asphalt Content					
		4.5 (%)	5 (%)	5.5 (%)	6 (%)	6.5 (%)
-	Asphalt Content	58.50	65.00	71.50	78.00	84.50
-	Coarse Aggregate	670.41	666.90	663.39	659.88	656.37
½" (12.5 mm)	5	33.52	33.35	33.17	32.99	32.82
3/8" (9.5mm)	32	214.53	213.41	212.28	211.16	210.04
No. 4 (4.75mm)	37	248.05	246.75	245.45	244.15	242.86
No. 10	26	174.31	173.39	172.48	171.57	170.66
	Fine Aggregate	509.02	506.35	503.68	501.02	498.35
No. 40	32	162.89	162.03	161.18	160.33	159.47
No. 80	44	223.97	222.79	221.62	220.45	219.28
No. 200 (0.075mm)	24	122.16	121.52	120.88	120.24	119.61
Filler	5	62.07	61.75	61.42	61.10	60.77

Table 3.2c Gradation of Selected Aggregates

(Filler 6%, Coarse Aggregate 53.33% Fine Aggregate 40.67%) Mass (gm)

Sieve Size	JMF for Different Asphalt Content					
		4.5 (%)	5 (%)	5.5 (%)	6 (%)	6.5 (%)
-	Asphalt Content	58.50	65.00	71.50	78.00	84.50
-	Coarse Aggregate	662.10	658.63	655.16	651.69	648.23
½" (12.5 mm)	5	33.10	32.93	32.76	32.58	32.41
3/8" (9.5mm)	32	211.87	210.76	209.65	208.54	207.43
No. 4 (4.75mm)	37	244.97	243.69	242.41	241.12	239.84
No. 10	26	172.14	171.24	170.34	169.44	168.54
	Fine Aggregate	504.88	502.24	499.59	496.95	494.31
No. 40	32	161.56	160.72	159.87	159.02	158.18
No. 80	44	222.15	220.99	219.82	218.66	217.50
No. 200 0.075mm)	24	121.17	120.54	119.90	119.27	118.63
Filler	6	74.49	74.10	73.71	73.32	72.93

Table 3.2d Gradation of Selected Aggregate

(Filler 7%, Coarse Aggregate 52.67%, Fine Aggregate 40.33%) Mass (gm)

Sieve Size	JMF for Different Asphalt Content					
		4.5 (%)	5 (%)	5.5 (%)	6 (%)	6.5 (%)
-	Asphalt Content	58.50	65.00	71.50	78.00	84.50
-	Coarse Aggregate	653.86	650.44	647.01	643.59	640.17
½” (12.5 mm)	5	32.69	32.52	32.35	32.18	32.00
3/8” (9.5mm)	32	209.23	208.14	207.04	205.95	204.85
No. 4 (4.75mm)	37	241.93	240.66	239.39	238.13	236.86
No. 10	26	170.00	169.11	168.22	167.33	166.44
	Fine Aggregate	500.69	498.08	495.45	492.83	490.21
No. 40	32	160.22	159.38	158.54	157.71	156.87
No. 80	44	220.30	219.15	217.99	216.84	215.69
No. 200 (0.075mm)	24	120.16	119.54	118.91	118.28	117.65
Filler	7	86.91	86.45	85.99	85.54	85.08

Table 3.2e Gradation of Selected Aggregate

(Filler 8%, Coarse Aggregate 52.00%, Fine Aggregate 40.00%) Mass (gm)

Sieve Size	JMF for Different Asphalt Content					
		4.5 (%)	5 (%)	5.5 (%)	6 (%)	6.5 (%)
-	Asphalt Content	58.50	65.00	71.50	78.00	84.50
-	Coarse Aggregate	645.58	642.20	638.82	635.44	632.06
½” (12.5 mm)	5	32.28	32.11	31.94	31.77	31.60
3/8” (9.5mm)	32	206.58	205.50	204.42	203.34	202.25
No. 4 (4.75mm)	37	238.86	237.61	236.36	235.11	233.86
No. 10	26	167.85	166.97	166.09	165.21	164.33
	Fine Aggregate	496.60	494.00	491.40	488.80	486.20
No. 40	32	158.91	158.08	157.25	156.42	155.58
No. 80	44	218.51	217.36	216.22	215.07	213.93
No. 200 (0.075mm)	24	119.18	118.56	117.94	117.31	116.69
Filler	8	99.32	98.80	98.28	97.76	97.24

Different tests were conducted to investigate the physical properties of the aggregates (Coarse and fine) and their suitability in road construction is shown in Table 3.3.

Table 3.3 Physical Properties of Coarse Aggregate

Sl No.	Test description	Test Method	Result	Specification Requirements (RHD Pavement Design Manual)
1	Los Angeles Abrasion, %	AASHTO T96	17	Max 30%
2	Durability, i. Soundness, %	AASHTO T104	4.7	-
3	Specific Gravity (Bulk) i. Coarse Aggregate ii. Fine Aggregate	AASHTO T85 AASHTO T84	1.57 2.55	-
4	Particle shape i. Flakiness, % ii. Elongation, %	BS 812-105 BS 812-106	18.4 32	Max 25% Max 25%
5	Aggregate Crushing Value, ACV, %	BS 812-110	15.3	Less than 28
6	Water absorption, i. Coarse Aggregate ii. Fine Aggregate	ASTM C127 ASTM C	1.92 3.15	Max 2%
7	Unit Weight i. Coarse Aggregate, kg/m^3 ii. Fine Aggregate, kg/m^3	ASTMC29	1566 1620	1600kg/m3
8	Moisture Content, % i. Coarse Aggregate ii. Fine Aggregate	ASTMC70	2.60 1.90	-

3.2.2 Asphalt Binder

In flexible pavement, asphalt plays the important role of binding the aggregate together by coating over the aggregate and hence it is preferred to be of good quality. The binder material of 80/100 penetration grade asphalt which commonly used in the Bangladesh was selected for this study. Same bitumen was used for all the mixes so the type and grade of binder was kept constant. The asphalt properties were evaluated by various laboratory tests, which are demonstrated in Table 3.4.

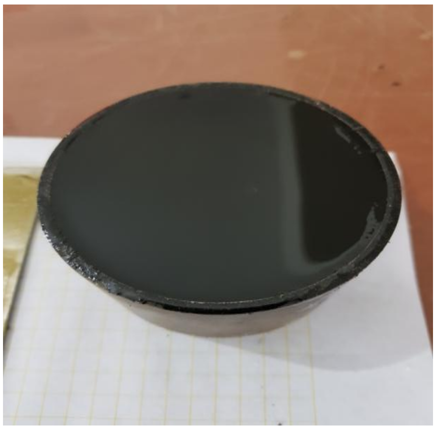

Figure 3.3 Asphalt Cement (80/100 penetration grade)

Table 3.4 Physical Properties of Asphalt Binder

Sl No.	Test Description	Test Method	Result	Specification Requirements (RHD Pavement Design Manual)
1	Penetration	AASHTO T49	86	80-100
2	Flash Point, ^{0}C	AASHTO T48	320	Min 250
3	Fire Point, ^{0}C	AASHTO T48	340	>320
4	Ductility, cm	AASHTO T51	110	Minimum 100
6	Solubility, %	AASHTO T44	98.3	Minimum 99.0
7	Specific Gravity	AASHTO T228	1.00	0.99-1.04
8	Loss on Heating, %	AASHTO T47	0.10	Max 0.5
9	Softening Point, ^{0}C	AASHTO T53	46.0	45-52

3.2.3 Fillers

As the name indicates function of filler is to fill up the voids. The fillers, used the current study namely crushed stone dust, Brick dust and Fly ash are all materials passing No. 200 sieve. Their physical properties of fillers which are affecting the HMA mixture property were determined (D_{10}, D_{30} and D_{60}). To distinguish the particle size of each type of fillers, hydrometer analysis was conducted in the laboratory and results are as shown in Table 3.5

Figure 3.4 Stone Dust

Figure 3.5 Brick Dust

Figure 3.6 Fly Ash

Table 3.5 Physical Properties of Filler

Sl No.	Test description	Test Method	Filler Type		
			Stone Dust	Brick Dust	Fly Ash
1	Specific Gravity	ASTMC128	2.71	2.68	2.69
2	D_{10} (micron)	ASTMD2487	0.9	1.2	0.7
3	D_{30} (micron)	ASTMD2487	2.5	2.5	2.5
4	D_{60} (micron)	ASTMD2487	4.5	5.2	4.5
5	Plasticity Index	ASTMD2487	Non-Plastic	Non-Plastic	Non-Plastic

3.3. Preparation and Testing of Marshall Specimens

3.3.1. Preparation of Test Specimens

The design of asphalt paving mix was largely a matter of selecting and proportioning constituent materials to obtain the desired properties in the finished pavement structure. In

Marshall Method, the resistance to plastic deformation of compacted cylindrical specimen of asphalts mixture is measured when the specimen is loaded diametrically at a deformation rate of 50 mm per minute.

Figure 3.7 Asphalt mix specimen

The Marshall stability of the mixture is defined as the maximum load carried by the specimen at a standard test temperature of 60^0C. The flow value was the deformation that the test specimen undergoes during loading up to the flow was measured in 0.25mm units with rate of loading 0.05 in.min, in this test an attempt was made to obtain optimum asphalt content for the type of aggregates mix used and the expected traffic intensity. In the Marshall Test method of mix design three compacted specimens were prepared according to the specification for each asphalt contents. At least five asphalt contents were to be tested to get the optimum asphalt content. All the compacted specimens were subjected to the bulk specific gravity determination, stability and flow tests.

The temperature that produce viscosities of 170 ± 20 centistokes kinematics and 280 ± 30 centistokes kinematics were established as the mixing and compaction temperatures respectively. The required quantity of the mix was taken so as to produce compacted asphalt mix specimens of 63.5mm thickness. The aggregates were heated to a temperature of 175^0C to 190^0C, the compaction cylindrical mould assembly (10 cm diameter and 7.5cm height consisting of a base plate and collar extension) and rammer were cleaned and kept pre-heated to a temperature of 100^0C to 145^0C. The asphalt was heated to a temperature of 121^0C to 138^0C and the required amount of first trial of asphalt (4.5% by weight of total Mix) was added to the heated aggregates and thoroughly mixed. The mix was placed in a mould and compacted with 75 blows on both ends. The specimen was taken out of the mould after few minutes using specimen extractor. In accordance with the Marshall 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. The compaction hammer is shown in Figure 3.1.

3.3.2 Testing Procedure

The specimen was measured in a bath of water at a temperature of $60^0 \pm 1^0$C for a period of 30 minutes. It was then placed in the Marshall Stability testing machine and loaded at a constant rate of deformation of 5mm per minute until failure. The total maximum load that caused failure of the specimen in KN was taken as Marshall stability. The stability value so obtained was corrected for volume. The total amount of deformation was units of 0.25mm that occurred at maximum load was recorded as Flow value. The total time between removing the specimen from the bath and completion of the test should not exceed 30 seconds. The stability correlation ratios are shown in Table 3.6.

Figure:3.8 Marshall Test Setup

Table 3.6 Stability Correlation Ratio (ASTM,D1559)

Volume of specimen cm^3	Approximate thickness of specimen		Correlation ratio
	mm	in.	
200 to 213	25.4	1	5.56
214 to 225	27.0	1 1/16	5.00
226 to 237	28.6	1 1/8	4.55
238 to 250	30.2	1 3/16	4.17
251 to 264	31.8	1 ¼	3.85
365 to 276	33.3	1 5/16	3.57
277 to 289	34.9	1 3/8	3.33
290 to 301	36.5	1 7/16	3.03
302 to 316	38.1	1 ½	2.78
317 to 328	39.7	1 9/16	2.50
329 to 340	41.3	1 5/8	2.27
341 to 353	42.9	1 11/16	2.08
354 to 367	44.4	1 ¾	1.92
368 to 379	46.0	1 13/16	1.79
380 to 392	47.6	1 7/8	1.67
393 to 405	49.2	1 15/16	1.56
406 to 420	50.8	2	1.47
421 to 431	52.4	2 1/16	1.39
432 to 443	54.0	2 1/8	1.32
444 to 456	55.6	2 3/16	1.25
457 to 470	572	2 ¼	1.19
471 to 482	58.7	2 5/16	1.14
483 to 495	60.3	2 3/8	1.09
496 to 508	61.9	2 7/16	1.04
509 to 522	63.5	2 ½	1.00
523 to 535	64.0	2 9/16	0.96
536 to 546	65.1	2 5/8	0.93
547 to 559	66.7	2 11/16	0.89
560 to 573	68.3	2 ¾	0.86

574 to 585	71.4	2 13/16	0.83
586 to 598	73.0	2 7/8	0.81
599 to 610	74.6	2 15/16	0.78
611 to 625	76.2	3	0.76

3.3.3 Density Void analysis of Bituminous Paving Mixture

3.3.3.1 Theoretical specific gravity of the mix

Theoretical specific gravity Gt is the specific gravity without considering air voids, and is given by:

$$G_t = \frac{W_1 + W_2 + W_3 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_b}{G_b}}$$

Where, W_1 is the weight of coarse aggregate in the total mix, W_2 is the weight of fine aggregate in the total mix, W_3 is the weight of filler in the total mix, W_b is the weight of bitumen in the total mix, G_1 is the apparent specific gravity of coarse aggregate, G_2 is the apparent specific gravity of filler and G_b is the apparent specific gravity of bitumen.

3.3.3.2 Bulk specific gravity of the compacted specimen

The bulk specific gravity or the actual specific gravity of the compacted specimen G_m is the specific gravity considering air voids and is found out by:

$$G_m = \frac{W_m}{W_m - W_w}$$

Where, W_m is the weight of specimen in air, W_w is the weight of specimen in water, Sometimes to get accurate bulk specific gravity; the specimen is coated with thin film of paraffin wax, when weight is taken in the water. This however requires considering the weight and volume of wax in the calculations.

3.3.3.3 Air voids percent

Air voids V_v is the percent of air voids by volume in the specimen and is given by:

$$V_v = \frac{(G_t - G_m) \times 100}{G_t}$$

Where, G_t is the theoretical specific gravity of the mix and G_m is the bulk specific gravity of the mix.

3.3.3.4 Percent volume of bitumen

The volume of bitumen V_b is the percent volume of bitumen to the total volume and given by:

$$V_b = \frac{\frac{W_b}{G_b}}{\frac{W_1 + W_2 + W_3 + W_b}{G_m}}$$

Where, W_1 is the weight of coarse aggregate in the total mix, W_2 is the weight of fine aggregate in the total mix, W_3 is the weight of filler in the total mix, W_b is the weight of bitumen in the total mix, G_b is the apparent specific gravity of bitumen, and G_m is the bulk specific gravity of mix.

3.3.3.5 Voids in Mineral Aggregate (VMA)

Voids in mineral aggregate is the volume of voids in the aggregates and is the sum of air voids and volume of bitumen, and is calculated from

$$VMA = V_v + V_b$$

Where, V_v is the percent air voids in the mix and V_b is percent bitumen content in the mix.

3.3.3.6 Voids filled with bitumen

Voids filled with bitumen (VFA) are the voids in the mineral aggregate frame work filled with the bitumen, and are calculated as:

$$VFA = \frac{V_b \times 100}{VMA}$$

Where, V_b is the percent bitumen content in the mix and VMA is the percent voids in the mineral aggregate.

Figure 3.9 Compaction Hammer.

The procedure for determining for optimum asphalt content for a particular mixture under evaluation was adopted both the American Society for Testing and Materials given by ASTM D1559 and American Association of State Highway and Transportation Officials given by AASHTO T-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 Marshall Mix design criteria. Then after, and asphalt content that optimize all the Marshall criteria for heavy traffic was selected as optimum asphalt content for respective mixes. The Marshall properties at each asphalt contents are indicated in graphs. The Marshall properties of individual mixes, prepared using each type and amount of filler, obtained at their optimum binder content was evaluated.

Table 3.7 Suggested Marshall Criteria for Asphalt Concrete Mix Design (ASTM,D1559)

Marshall Method of Mix Design	Light Traffic		Medium Traffic		Heavy Traffic	
	Surface-Base		Surface-Base		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, 0.25mm	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	-

3.4 Moisture Susceptibility of Mixtures

Water is the worst enemy of the bituminous concrete mixtures. The premature failure of a flexible pavement may be caused by the presence of water. To determine the moisture susceptibility of the mixtures, retained stability (RS) test was performed. RS is expressed as the ratio of the average Marshall stability of the particular specimen which is conditioned by immersing in water at 60^0C for 24 hours. Then transfer them to the second water bath maintained at 25^{0}C for 2 hours to the average Marshall stability of the respective unconditioned specimen. The ratio gives an indication of resistance to moisture induced damage to the bituminous mixture.

Among the various types of quantitative tests, the Marshall Immersion test, which it's conditioning process is similar to that of the Immersion compression test standardized in ASTM D1074 and AASHTO T165-55, is used for evaluating all the Marshall specimens prepared using different fillers by type and amount. The Marshall Immersion test uses the Marshall Stability test as a strength parameter rather than the compressive strength as that for the immersion compression test.

3.5. 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 filler characteristics and different mixture properties. The mixture properties assessed include Marshall Properties and moisture susceptibility.

Determination of optimum asphalt content

Calculation of optimum asphalt content selected as average binder content for maximum density, maximum stability and specified percent air voids in the total mix. Thus

$$B_0 = \frac{B_1+B_2+B_3}{3}$$

Where,

B_0=optimum asphalt content

B_1=% asphalt content at maximum unit weight

B_2=% asphalt content at maximum stability

B_3=% asphalt content at specific percent air voids in the total mixture.

CHAPTER IV

Results and Discussion

4.1. General

In this study, Eighty-Four sets (3Nos Sample/set) of bituminous mixtures using different types and amount of mineral fillers were evaluated using the Marshall Mix design method. These mixtures were prepared using crushed Stone dust, Brick dust and Fly ash fillers with varying the content by the total mixture and their effects on Marshall Properties were evaluated. Moisture susceptibility test was then carried out for mixtures prepared at their optimum asphalt content. The test results obtained in this study are discussed under following sections.

4.2. Effect of fillers on Marshall Properties of bituminous mixtures

Table 4.1 indicates the properties of mixtures at their optimum asphalt content. The effect of fillers on various properties of the asphalt mixtures will be discussed under subsequent sections.

4.2.1 Marshall Unit Weigh Curves (kg/m^3)

Fig. 4.1(a), 4.2(a) up to 4.15(a) shows the graphical representation of unit weights for variation in % of bitumen content for Marshall Specimens having Brick dust, Stone dust and Fly ash as fillers. It can be seen that with increases in percentage of bitumen, unit weight almost increases. In these figures Brick dust, Stone dust and Fly ash specimens are found to display almost same nature unit weight curve. Maximum unit weight value of 2332 kg/m^3 is observed at 5.5% bitumen content in case of 5% Brick dust as a filler, a maximum unit weight value of 2354 kg/m^3 is obtained at 5.5% bitumen content in case of

8% Stone dust as a filler and a maximum Unit weight value of 2277 kg/m^3 is obtained at 5.5% bitumen content in case of 5% Fly ash as a filler.

4.2.2 Marshall Stability Curves

Fig. 4.1(b), 4.2(b) up to 4.15(b) shows the variation of Marshall Stability with bitumen content where it is seen that stability value increases almost with bitumen content increases. Maximum stability value of 16.60 KN is observed at 5.5% bitumen content in case of 7% Brick dust as a filler, a maximum stability value of 19.25 KN is obtained at 5.5% bitumen content in case of 7% Stone dust as a filler and a maximum stability value of 15.25 KN is obtained at 5.5% bitumen content in case of 6% Fly ash as a filler. Stone dust has a higher value of stability comparative to the Brick dust and Fly ash.

4.2.3 Marshall Air Void Curves

Fig. 4.1(c), 4.2(c) up to 4.15(c) shows the variation of Marshall Air void decreases with increase in bitumen content. Minimum air void of 2.74% is observed at 6.50% bitumen content at 5% filler in case of Brick dust, in case of stone dust a minimum 1.17% air void of 6.50% bitumen content at 4% filler and in case of fly ash a minimum 3.86% air void of 6.50% bitumen content at 5% filler.

4.2.4 Marshall VMA

Fig. 4.1(d), 4.2(d) up to 4.15(d) shows the variation of Marshall VMA with bitumen content where it is seen that as usual the VMA decreases with bitumen content increases and after certain limit it will be again increases. Minimum VMA of 16.73% is observed at 5.50% bitumen content in case of 8% filler of Brick dust, in case of Stone dust a minimum VMA of 10.90% is observed at 5% bitumen content in case of 4% filler and in case of fly ash a minimum VMA of 18.45% is observed at 5% bitumen content in case of 5% filler.

4.2.5 Marshall Flow Value Curves

Fig. 4.1(e), 4.2(e) up to 4.15(e) shows the variation of Marshall Flow value with bitumen content where it is seen that as usual the flow value increases with bitumen content increases. Maximum flow value of 10.87(1/100in) is observed at 6.5% bitumen content in case of 8% filler of Brick dust, in case of stone dust a maximum flow value of

10.63(1/100in) is obtained at 6.5% bitumen content in case of 4% filler and in case of fly ash a maximum flow value of 11.22(1/100in) is obtained at 6.5% bitumen content in case of 5% filler.

4.2.6 Comparison for optimum binder content

A Comparison of Results against Various Parameters for Optimum Bitumen Content is tabulated in Table no 4.01

Table No. 4.01 Comparison of Results against Various Parameters for Optimum Bitumen Content

Filler Type	Maximum Unit Weight	Maximum Stability Value	Minimum Air Void	Minimum VMA	Maximum Flow Value
Brick Dust	5.50% (Filler 5%)	5.50% (Filler 7%)	6.50% (Filler 5%)	5.50% (Filler 8%)	6.50% (Filler 8%)
Stone Dust	5.50% (Filler 8%)	5.50% (Filler 7%)	6.50% (Filler 4%)	5.00% (Filler 4%)	6.50% (Filler 4%)
Fly Dust	5.50% (Filler 5%)	5.50% (Filler 6%)	6.50% (Filler 5%)	5.00% (Filler 5%)	6.50% (Filler 5%)

Table 4.1 Marshall Properties of HMA using Brick Dust (4%)

BRICK DUST

Filler (%)	AC (%)	Sample ht (in)	Mass (gm.)		Bulk volume (cc.)	Wa (gm.)	Ww (gm.)	Sp. Gr. (G)	Gt	Air Void (%)	Ga	Gta	VMA (%)	VFA (%)	Unit Weight (kg/m3)	Stability (KN)		Deformation (mm)	Flow value, (1/100) in
			In Air	In water												Measured	Corrected		
4%	4.50	2.89	1284.10	715.90	36.32	1110.81	619.29	2.26	2.46	8.11	2.16	2.63	18.19	55.43	2259.94	10.57	8.56	2.45	9.65
	5.00	2.91	1287.40	722.43	36.57	1106.01	620.64	2.28	2.44	6.68	2.16	2.63	17.64	62.11	2278.71	14.76	11.96	2.49	9.80
	5.50	2.90	1281.97	724.53	36.44	1105.15	624.59	2.30	2.42	5.15	2.17	2.63	17.43	70.44	2299.75	16.86	13.66	2.54	10.00
	6.00	2.87	1280.30	723.67	36.07	1115.24	630.37	2.30	2.41	4.47	2.16	2.63	17.74	74.80	2300.09	16.23	13.15	2.59	10.18
	6.50	2.89	1282.73	722.10	36.32	1109.63	624.65	2.29	2.39	4.31	2.14	2.63	18.41	76.61	2288.02	14.23	11.53	2.65	10.43

Wa = Adjusted weight in air (gm), Ww = Adjusted weight in water (gm).

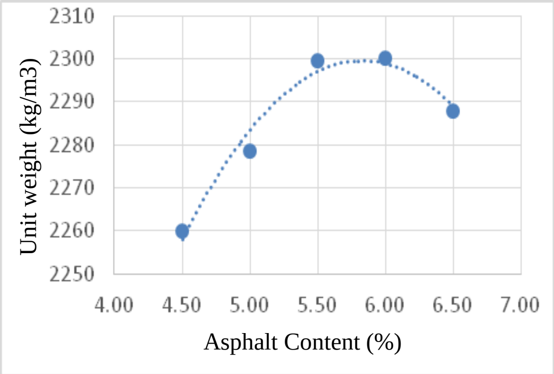

Fig. 4.1(a) Variation of Unit Weight With % of Bitumen

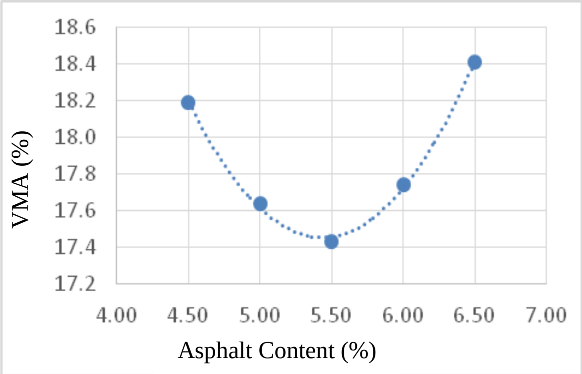

Fig. 4.1(d) Variation of VMA With % of Bitumen

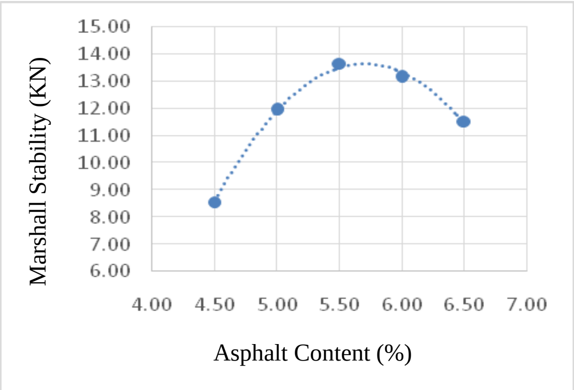

Fig. 4.1(b) Variation of Stability With % of Bitumen

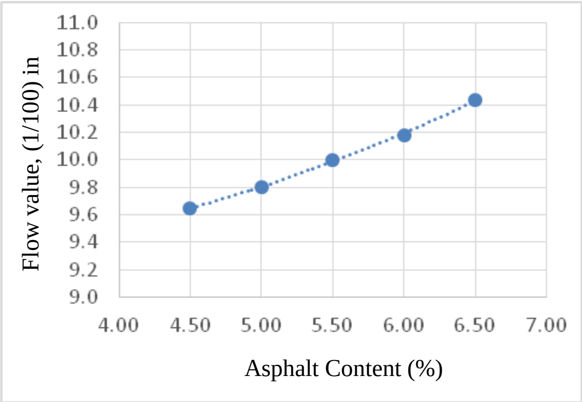

Fig. 4.1(e) Variation of Flow Value With % of Bitumen

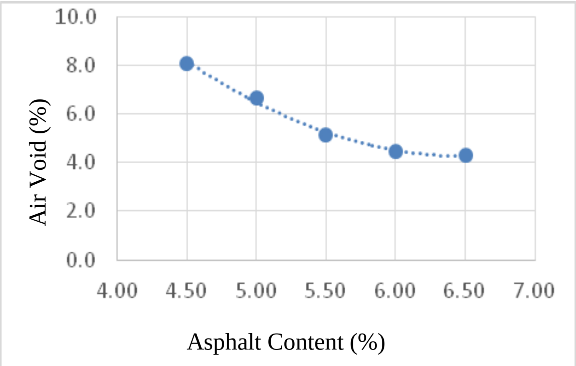

Fig. 4.1(c) Variation of Air Void With % of Bitumen

Table 4.2 Marshall Properties of HMA using Brick Dust (5%)

<u>BRICK DUST</u>

Filler (%)	AC (%)	Sample ht (in)	Mass (gm.)		Bulk volume (cc.)	Wa (gm.)	Ww (gm.)	Sp. Gr. (G)	Gt	Air Void (%)	Ga	Gta	VMA (%)	VFA (%)	Unit Weight (kg/m3)	Stability (KN)		Deformation (mm)	Flow value, (1/100) in
			In Air	In water												Measured	Corrected		
5%	4.50	2.87	1277.60	707.70	36.07	1112.89	616.46	2.24	2.46	8.89	2.14	2.63	17.63	49.59	2241.80	11.36	9.20	2.30	9.06
	5.00	2.89	1272.83	725.80	36.32	1101.06	627.85	2.31	2.44	5.95	2.21	2.63	17.25	65.51	2310.00	15.93	12.90	2.37	9.32
	5.50	2.73	1268.80	720.77	34.31	1161.90	660.05	2.33	2.43	4.66	2.19	2.63	17.32	73.09	2332.00	17.53	14.20	2.42	9.54
	6.00	2.73	1279.40	717.97	34.31	1171.61	657.48	2.33	2.41	3.82	2.14	2.63	17.75	78.48	2330.00	16.98	13.75	2.54	10.00
	6.50	2.71	1277.80	728.87	34.05	1178.78	672.39	2.29	2.39	2.74	2.18	2.63	18.42	85.12	2285.00	15.19	12.30	2.63	10.35

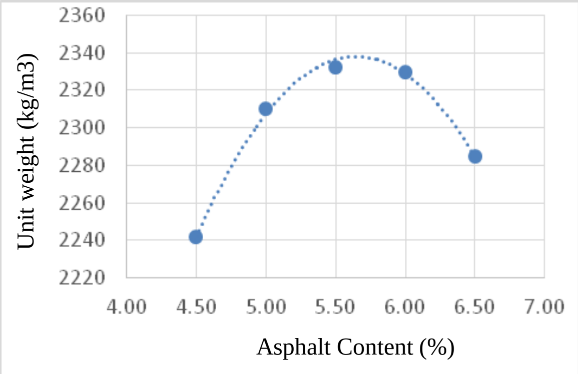

Fig. 4.2(a) Variation of Unit Weight With % of Bitumen

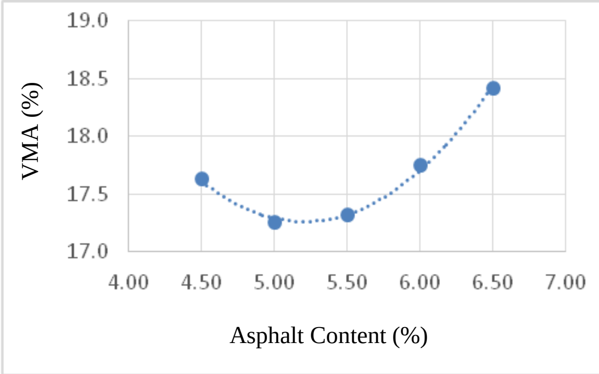

Fig. 4.2(d) Variation of VMA With % of Bitumen

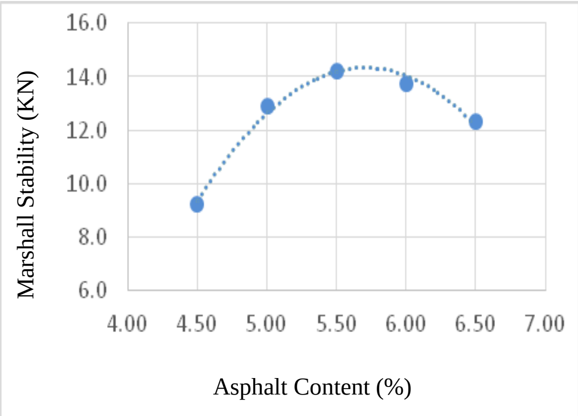

Fig. 4.2(b) Variation of Stability With % of Bitumen

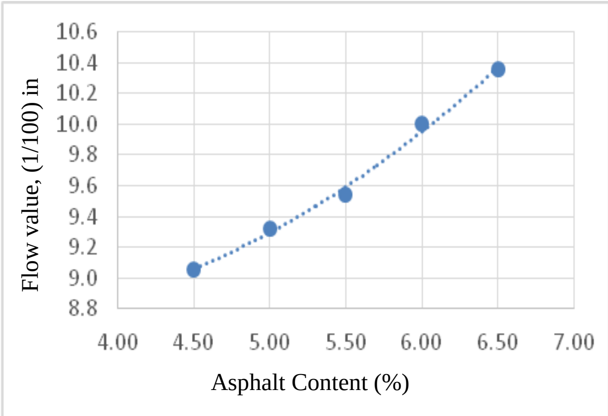

Fig. 4.2(e) Variation of Flow Value With % of Bitumen

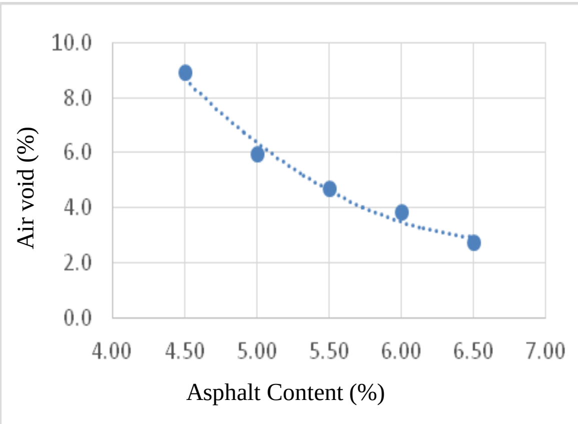

Fig. 4.2(c) Variation of Air Void With % of Bitumen

Table 4.3 Marshall Properties of HMA using Brick Dust (6%)

BRICK DUST

Filler (%)	AC (%)	Sample ht (in)	Mass (gm.)		Bulk volume (cc.)	Wa (gm.)	Ww (gm.)	Sp. Gr. (G)	Gt	Air Void (%)	Ga	Gta	VMA (%)	VFA (%)	Unit Weight (kg/m3)	Stability (KN)		Defor mation (mm)	Flow value, (1/100) in
			In Air	In water												Meas ured	Corrected		
6%	4.50	2.87	1284.70	714.63	36.07	1119.08	622.50	2.25	2.46	8.46	2.15	2.63	17.30	51.08	2253.58	7.90	6.40	2.40	9.45
	5.00	2.96	1289.30	727.63	37.20	1088.94	614.55	2.29	2.44	6.09	2.18	2.63	17.18	64.53	2285.00	12.15	9.84	2.43	9.57
	5.50	2.76	1279.53	724.23	34.68	1158.99	656.01	2.30	2.43	5.07	2.18	2.63	17.25	70.63	2304.21	14.38	11.65	2.50	9.84
	6.00	2.73	1251.97	714.43	34.31	1146.49	654.24	2.31	2.41	3.37	2.19	2.63	17.50	80.77	2310.00	13.42	10.87	2.59	10.20
	6.50	2.83	1284.87	732.27	35.56	1135.04	646.88	2.29	2.39	2.85	2.17	2.63	17.85	84.02	2290.00	11.91	9.65	2.70	10.63

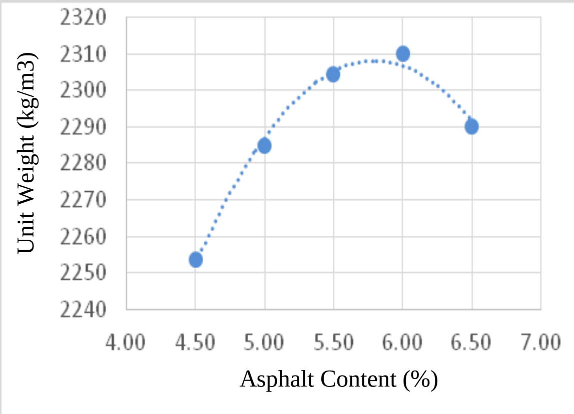

Fig. 4.3(a) Variation of Unit Weight With % of Bitumen

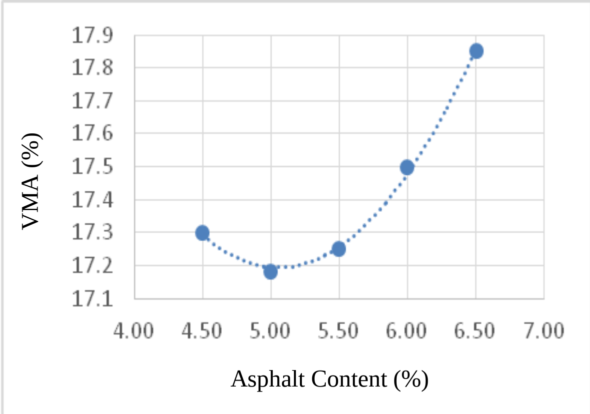

Fig. 4.3(d) Variation of VMA With % of Bitumen

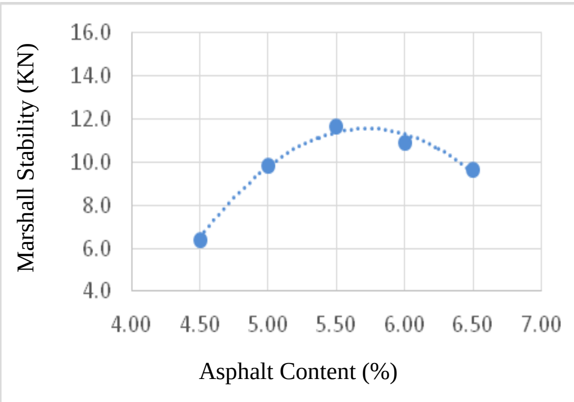

Fig. 4.3(b) Variation of Stability With % of Bitumen

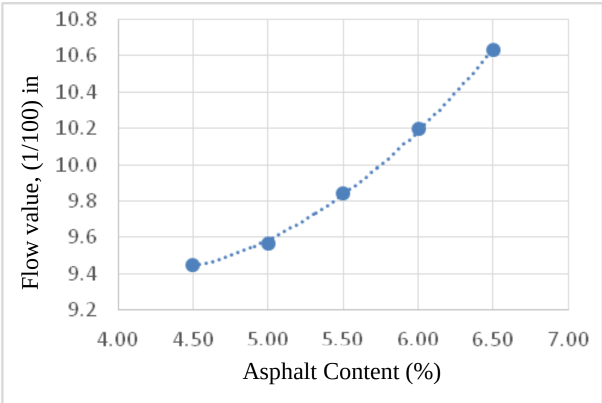

Fig. 4.3(e) Variation of Flow Value With % of Bitumen

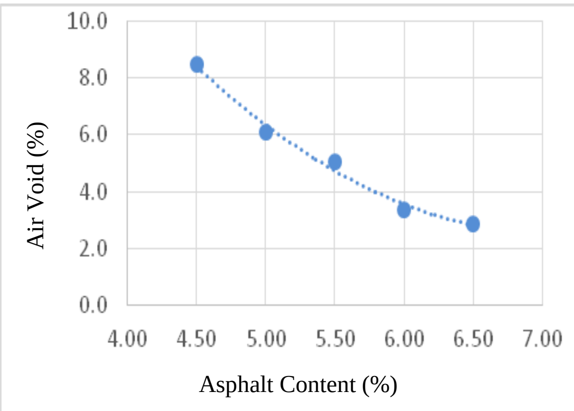

Fig. 4.3(c) Variation of Air Void With % of Bitumen

Table 4.4 Marshall Properties of HMA using Brick Dust (7%)

BRICK DUST

Filler (%)	AC (%)	Sample ht (in)	Mass (gm.)		Bulk volume (cc.)	Wa (gm.)	Ww (gm.)	Sp. Gr. (G)	Gt	Air Void (%)	Ga	Gta	VMA (%)	VFA (%)	Unit Weight (kg/m3)	Stability (KN)		Deformation (mm)	Flow value, (1/100) in
			In Air	In water												Measured	Corrected		
7%	4.50	2.89	1270.70	698.37	36.32	1099.22	604.13	2.23	2.46	9.87	2.12	2.63	19.48	49.32	2230.00	8.83	7.15	2.45	9.63
	5.00	2.94	1287.90	708.67	36.95	1095.15	602.61	2.26	2.45	7.95	2.11	2.63	18.47	56.96	2260.00	16.54	13.40	2.48	9.75
	5.50	2.78	1285.27	723.43	34.93	1155.82	650.57	2.29	2.43	5.81	2.16	2.63	18.03	67.79	2287.61	20.49	16.60	2.55	10.03
	6.00	2.70	1270.27	723.03	33.93	1176.18	669.47	2.29	2.41	4.95	2.18	2.63	18.62	73.42	2292.00	19.75	16.00	2.65	10.43
	6.50	2.80	1245.03	690.77	35.19	1111.63	616.76	2.28	2.39	4.97	2.10	2.63	20.24	75.45	2275.00	16.37	13.26	2.73	10.75

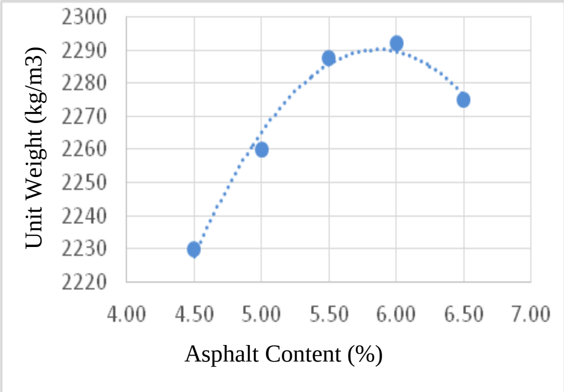

Fig. 4.4(a) Variation of Unit Weight With % of Bitumen

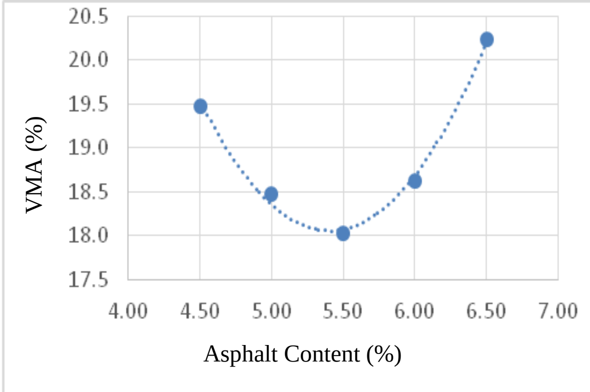

Fig. 4.4(d) Variation of VMA With % of Bitumen

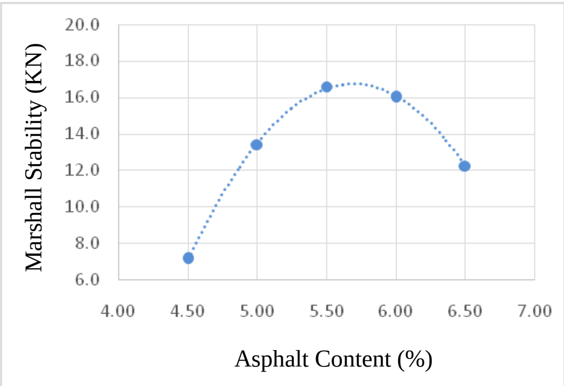

Fig. 4.4(b) Variation of Stability With % of Bitumen

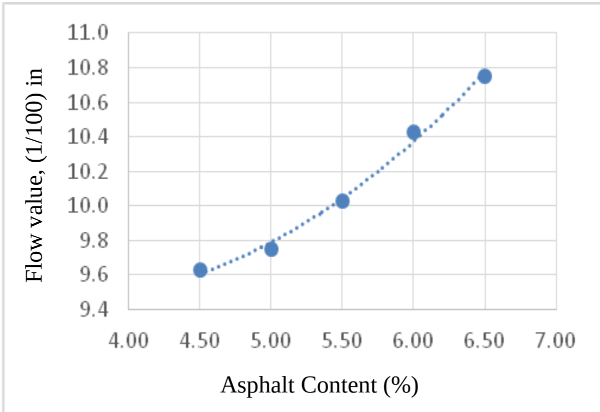

Fig. 4.4(e) Variation of Flow Value With % of Bitumen

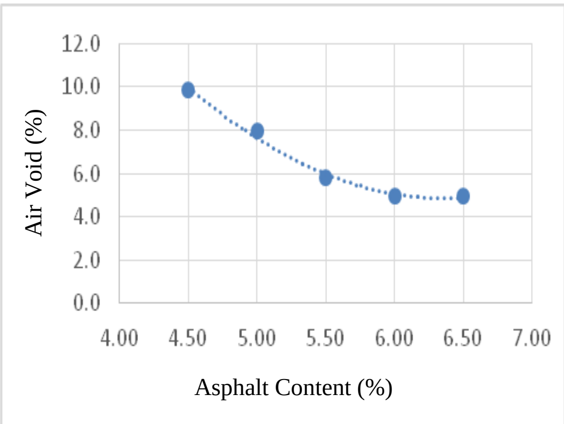

Fig. 4.4(c) Variation of Air Void With % of Bitumen

Table 4.5 Marshall Properties of HMA using Brick Dust (8%)

BRICK DUST

Filler (%)	AC (%)	Sample ht (in)	Mass (gm.)		Bulk volume (cc.)	Wa (gm.)	Ww (gm.)	Sp. Gr. (G)	Gt	Air Void (%)	Ga	Gta	VMA (%)	VFA (%)	Unit Weight (kg/m3)	Stability (KN)		Deformation (mm)	Flow value, (1/100) in
			In Air	In water												Measured	Corrected		
8%	4.50	2.81	1280.03	712.47	35.31	1138.82	633.87	2.26	2.46	8.50	2.15	2.63	17.62	51.76	2255.32	12.28	9.95	2.40	9.45
	5.00	2.90	1283.50	715.13	36.44	1106.47	616.49	2.28	2.45	6.83	2.15	2.63	16.95	59.71	2277.20	12.90	10.45	2.48	9.75
	5.50	2.87	1198.30	689.40	36.07	1043.82	600.52	2.30	2.43	4.70	2.23	2.63	16.73	71.91	2297.80	13.09	10.60	2.55	10.05
	6.00	2.82	1277.57	720.37	35.44	1132.60	638.63	2.30	2.41	4.10	2.16	2.63	17.62	76.73	2299.50	13.02	10.55	2.62	10.33
	6.50	2.79	1273.17	713.87	35.06	1140.83	639.67	2.29	2.40	3.00	2.13	2.63	19.22	84.39	2286.35	12.74	10.32	2.76	10.87

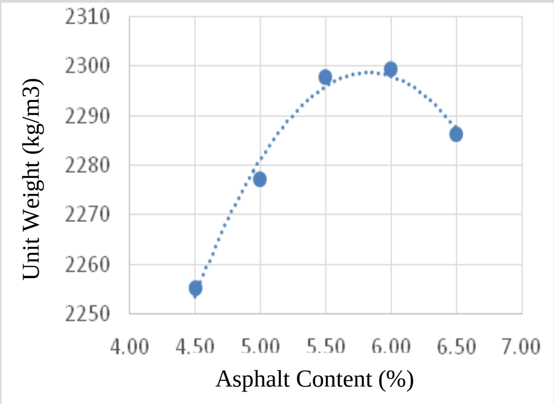

Fig. 4.5(a) Variation of Unit Weight With % of Bitumen

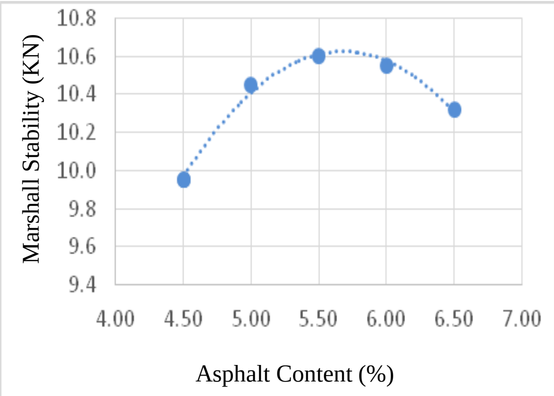

Fig. 4.5(b) Variation of Stability With % of Bitumen

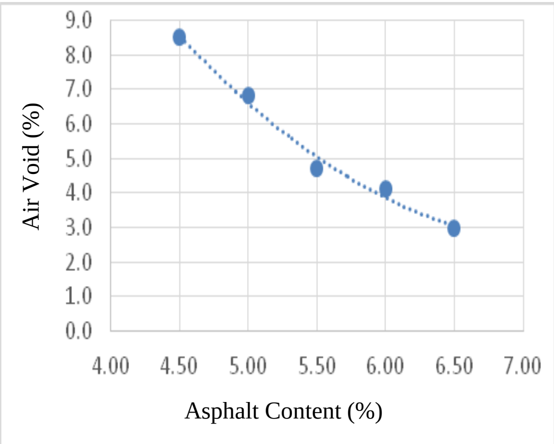

Fig. 4.5(c) Variation of Air Void With % of Bitumen

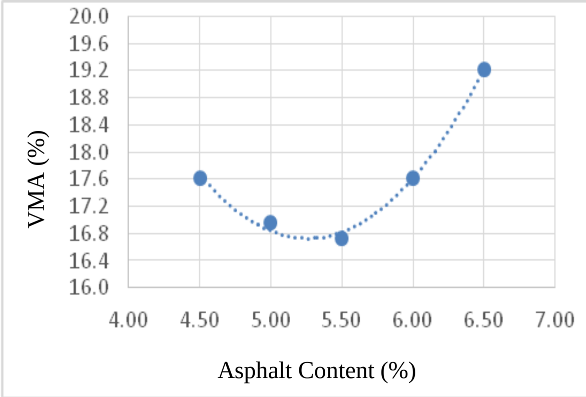

Fig. 4.5(d) Variation of VMA With % of Bitumen

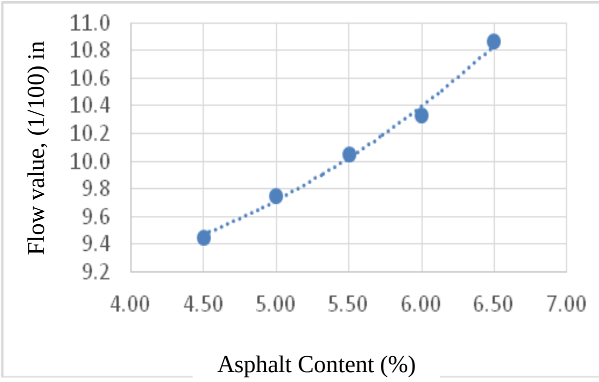

Fig. 4.5(e) Variation of Flow Value With % of Bitumen

Table 4.6 Marshall Properties of HMA using Stone Dust (4%)

<u>STONE DUST</u>

Filler (%)	AC (%)	Sample ht (in)	Mass (gm.)		Bulk volume (cc.)	Wa (gm.)	Ww (gm.)	Sp. Gr. (G)	Gt	Air Void (%)	Ga	Gta	VMA (%)	VFA (%)	Unit Weight (kg/m3)	Stability (KN)		Deformation (mm)	Flow value, (1/100) in
			In Air	In water												Measured	Corrected		
4%	4.50	2.71	1267.00	724.00	34.05	1168.82	667.90	2.27	2.46	5.12	2.23	2.63	14.22	63.97	2268.75	9.81	7.95	2.40	9.45
	5.00	2.71	1257.77	738.00	34.05	1160.30	680.81	2.29	2.44	3.30	2.30	2.63	10.90	69.72	2291.25	16.07	13.02	2.45	9.65
	5.50	2.70	1264.10	736.43	33.93	1170.46	681.88	2.30	2.42	2.15	2.26	2.63	11.27	80.92	2302.25	17.80	14.42	2.51	9.88
	6.00	2.73	1273.67	739.90	34.31	1166.36	677.56	2.30	2.41	1.45	2.24	2.63	14.66	90.11	2298.45	16.32	13.22	2.60	10.24
	6.50	2.72	1277.70	737.00	34.18	1174.36	677.39	2.28	2.39	1.17	2.21	2.63	18.94	93.83	2283.00	12.96	10.50	2.70	10.63

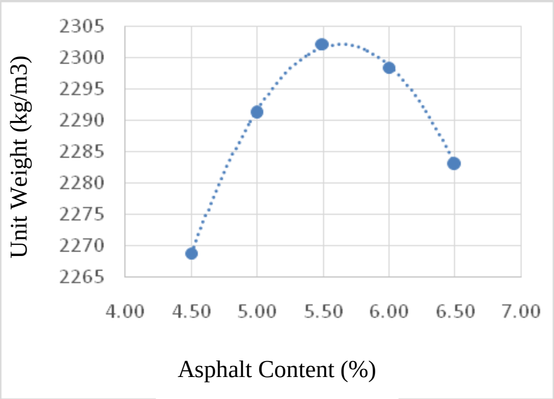

Fig. 4.6(a) Variation of Unit Weight With % of Bitumen

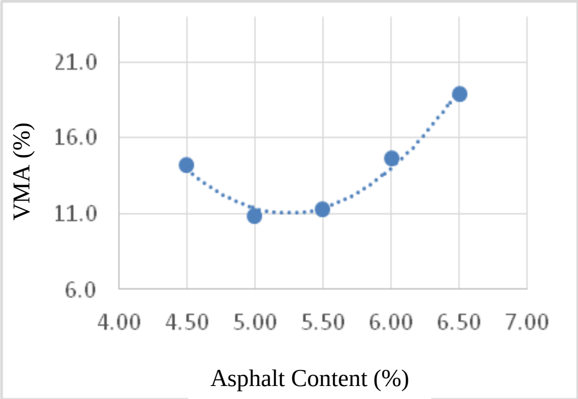

Fig. 4.6(d) Variation of VMA With % of Bitumen

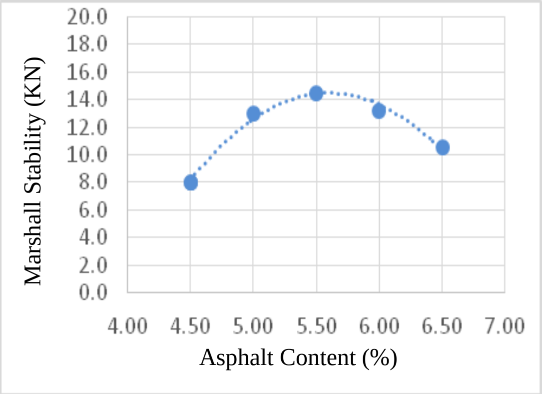

Fig. 4.6(b) Variation of Stability With % of Bitumen

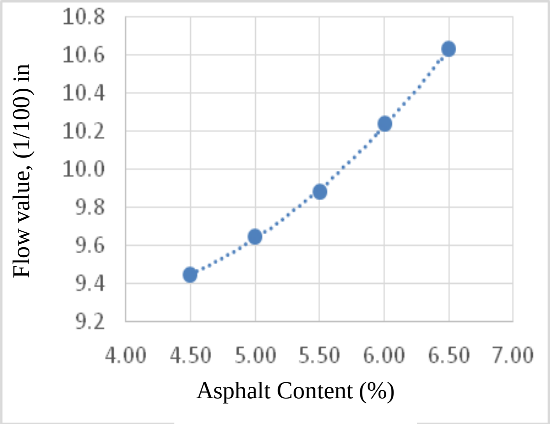

Fig. 4.6(e) Variation of Flow Value With % of Bitumen

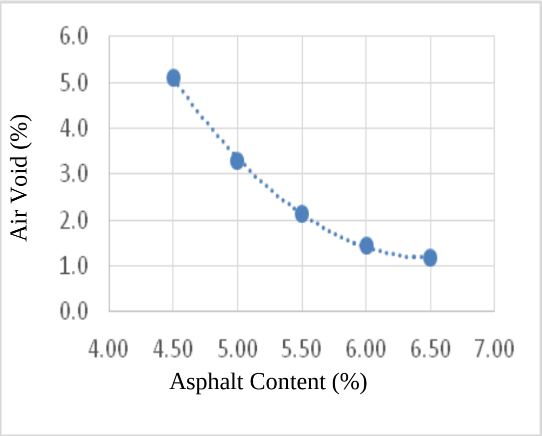

Fig. 4.6(c) Variation of Air Void With % of Bitumen

Table 4.7 Marshall Properties of HMA using Stone Dust (5%)

<u>STONE DUST</u>

Filler (%)	AC (%)	Sample ht (in)	Mass (gm.)		Bulk volume (cc.)	Wa (gm.)	Ww (gm.)	Sp. Gr. (G)	Gt	Air Void (%)	Ga	Gta	VMA (%)	VFA (%)	Unit Weight (kg/m3)	Stability (KN)		Deformation (mm)	Flow value, (1/100) in
			In Air	In water												Measured	Corrected		
5%	4.50	2.77	1276.90	719.73	34.81	1152.44	649.58	2.28	2.46	6.86	2.19	2.63	17.25	60.25	2275.76	17.28	14.00	2.12	8.35
	5.00	2.77	1269.05	715.80	34.81	1145.35	646.03	2.30	2.44	5.15	2.18	2.63	16.27	68.35	2298.25	18.05	14.62	2.16	8.52
	5.50	2.74	1285.50	733.50	34.43	1172.90	669.25	2.31	2.43	4.15	2.20	2.63	16.55	74.92	2309.25	18.46	14.95	2.25	8.85
	6.00	2.74	1294.80	736.00	34.43	1181.39	671.53	2.30	2.41	3.62	2.18	2.63	17.17	78.92	2305.45	18.36	14.87	2.35	9.25
	6.50	2.86	1265.40	708.33	35.94	1106.12	619.17	2.29	2.39	3.42	2.12	2.63	19.24	82.22	2290.00	17.89	14.49	2.46	9.69

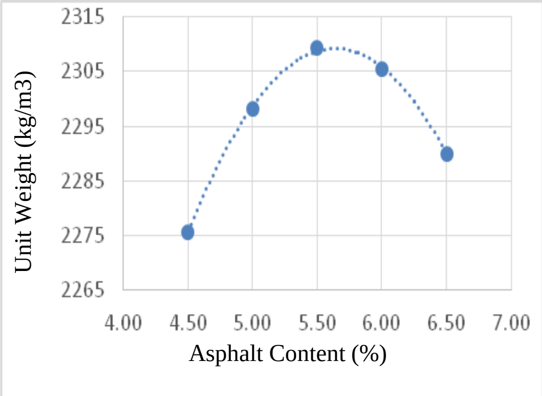

Fig. 4.7(a) Variation of Unit Weight With % of Bitumen

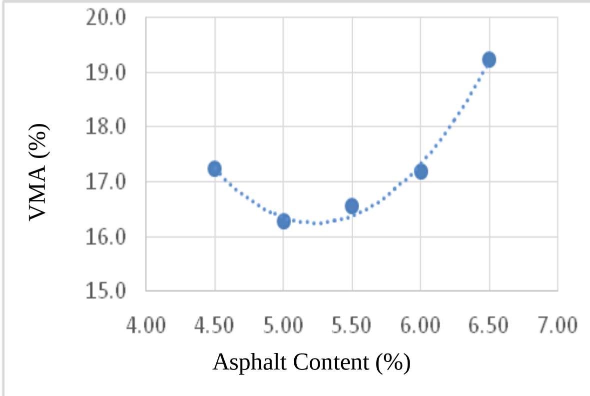

Fig. 4.7(d) Variation of VMA With % of Bitumen

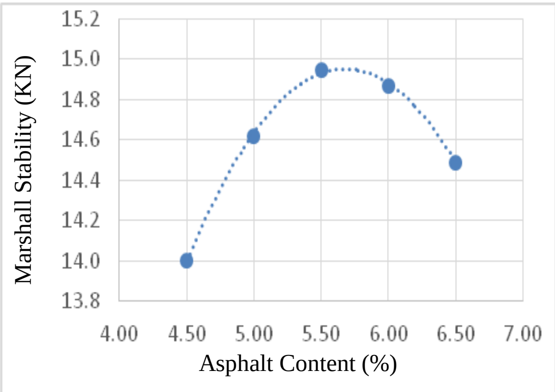

Fig. 4.7(b) Variation of Stability With % of Bitumen

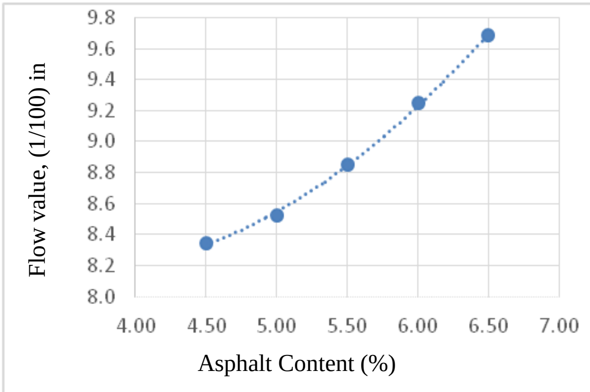

Fig. 4.7(e) Variation of Flow Value With % of Bitumen

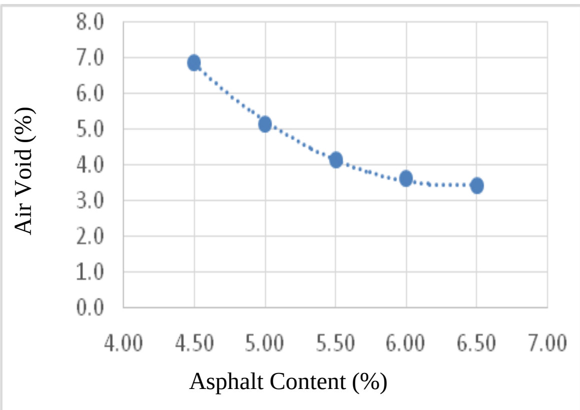

Fig. 4.7(c) Variation of Air Void With % of Bitumen

Table 4.8 Marshall Properties of HMA using Stone Dust (6%)

STONE DUST

Filler (%)	AC (%)	Sample ht (in)	Mass (gm.)		Bulk volume (cc.)	Wa (gm.)	Ww (gm.)	Sp. Gr. (G)	Gt	Air Void (%)	Ga	Gta	VMA (%)	VFA (%)	Unit Weight (kg/m3)	Stability (KN)		Deformation (mm)	Flow value, (1/100) in
			In Air	In water												Measured	Corrected		
6%	4.50	2.75	1272.17	713.40	34.56	1156.52	648.55	2.28	2.46	7.53	2.17	2.63	16.52	54.45	2276.73	11.14	9.02	2.30	9.06
	5.00	2.79	1283.83	725.80	35.06	1150.39	650.36	2.32	2.44	5.58	2.19	2.63	16.01	65.15	2318.75	17.83	14.44	2.32	9.13
	5.50	2.71	1278.60	733.57	34.05	1179.52	676.73	2.34	2.43	3.58	2.22	2.63	16.00	77.63	2343.95	20.51	16.61	2.35	9.25
	6.00	2.72	1271.20	729.13	34.18	1168.38	670.16	2.34	2.41	2.70	2.20	2.63	16.47	83.59	2340.08	19.44	15.75	2.39	9.42
	6.50	2.65	1267.80	725.57	33.30	1196.04	684.50	2.31	2.39	2.31	2.19	2.63	17.38	86.70	2312.22	15.99	12.95	2.45	9.65

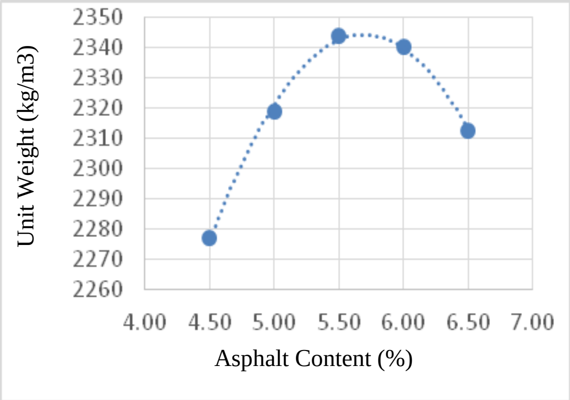

Fig. 4.8(a) Variation of Unit Weight With % of Bitumen

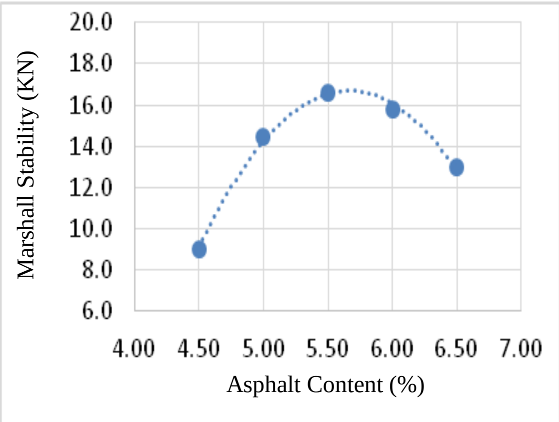

Fig. 4.8(b) Variation of Stability With % of Bitumen

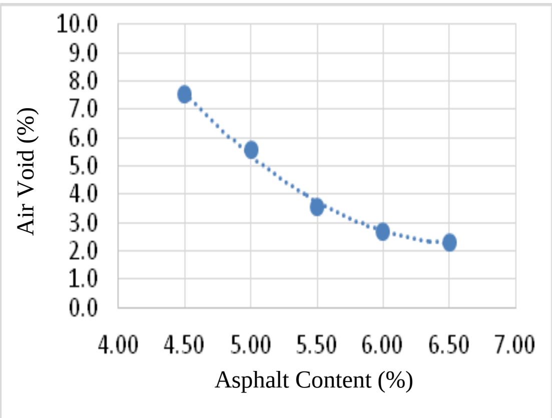

Fig. 4.8(c) Variation of Air Void With % of Bitumen

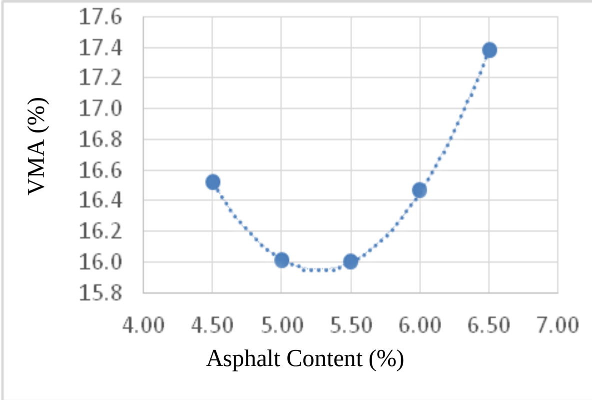

Fig. 4.8(d) Variation of VMA With % of Bitumen

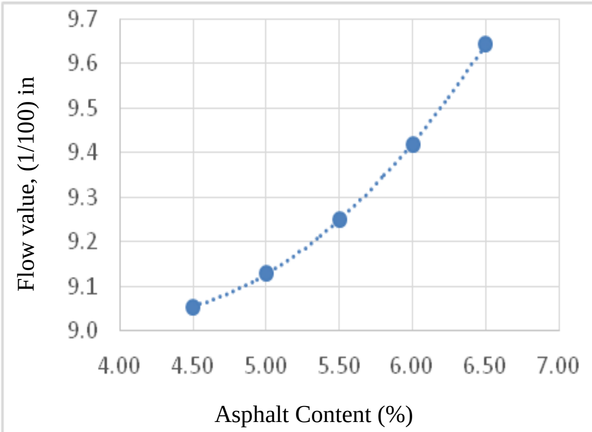

Fig. 4.8(e) Variation of Flow Value With % of Bitumen

Table 4.9 Marshall Properties of HMA using Stone Dust (7%)

<u>STONE DUST</u>

Filler (%)	AC (%)	Sample ht (in)	Mass (gm.)		Bulk volume (cc.)	Wa (gm.)	Ww (gm.)	Sp. Gr. (G)	Gt	Air Void (%)	Ga	Gta	VMA (%)	VFA (%)	Unit Weight (kg/m3)	Stability (KN)		Deformation (mm)	Flow value, (1/100) in
			In Air	In water												Measured	Corrected		
7%	4.50	2.76	1266.63	713.07	34.68	1147.31	645.90	2.29	2.46	7.12	2.19	2.63	16.02	55.58	2288.15	12.20	9.88	2.37	9.33
	5.00	2.77	1294.20	734.90	34.81	1168.05	663.27	2.32	2.45	5.40	2.20	2.63	14.45	62.66	2323.96	19.52	15.81	2.39	9.39
	5.50	2.73	1295.10	747.57	34.31	1185.99	684.59	2.34	2.43	3.62	2.24	2.63	14.75	75.46	2342.45	23.76	19.25	2.41	9.50
	6.00	2.74	1271.63	723.77	34.43	1160.25	660.37	2.34	2.41	2.45	2.18	2.63	16.70	85.33	2340.42	22.16	17.95	2.45	9.66
	6.50	2.65	1277.07	735.23	33.30	1204.78	693.61	2.32	2.39	1.58	2.20	2.63	19.31	91.81	2325.45	18.19	14.73	2.51	9.88

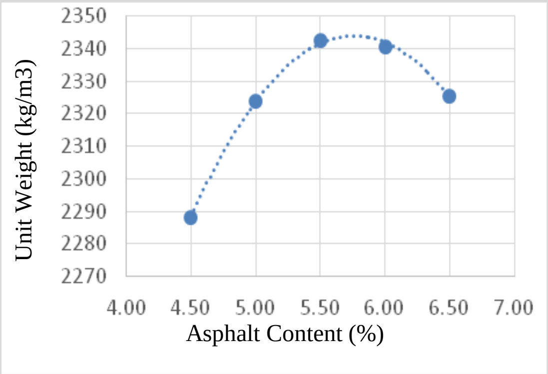

Fig. 4.9(a) Variation of Unit Weight With % of Bitumen

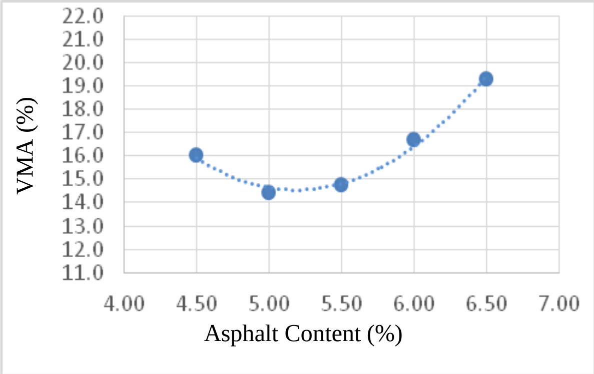

Fig. 4.9(d) Variation of VMA With % of Bitumen

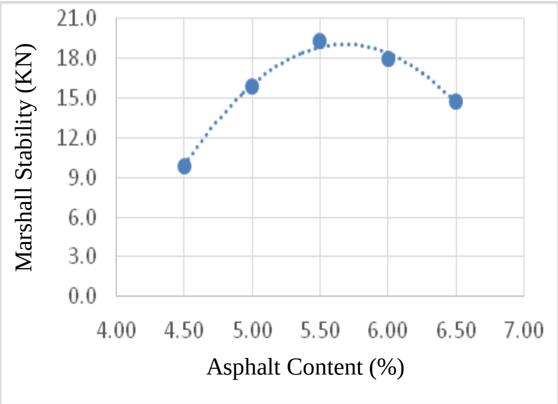

Fig. 4.9(b) Variation of Stability With % of Bitumen

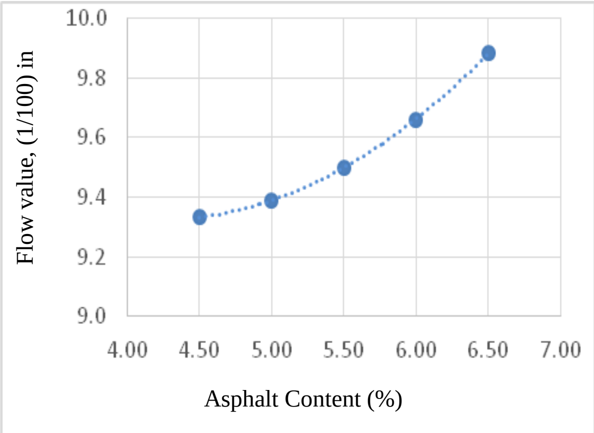

Fig. 4.9(e) Variation of Flow Value With % of Bitumen

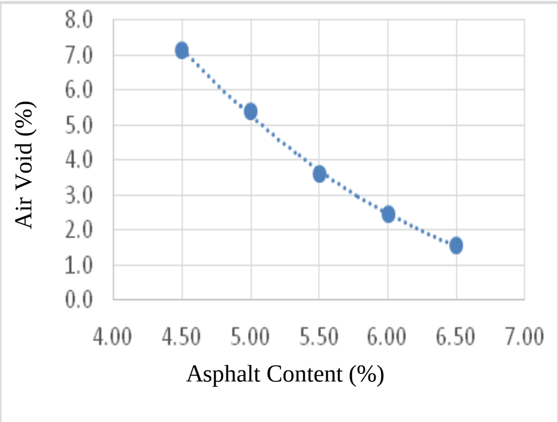

Fig. 4.9(c) Variation of Air Void With % of Bitumen

Table 4.10 Marshall Properties of HMA using Stone Dust (8%)

<u>STONE DUST</u>

Filler (%)	AC (%)	Sample ht (in)	Mass (gm.)		Bulk volume (cc.)	Wa (gm.)	Ww (gm.)	Sp. Gr. (G)	Gt	Air Void (%)	Ga	Gta	VMA (%)	VFA (%)	Unit Weight (kg/m3)	Stability (KN)		Deformation (mm)	Flow value, (1/100) in
			In Air	In water												Measured	Corrected		
8%	4.50	2.73	1267.20	701.50	34.31	1160.44	642.40	2.26	2.46	8.12	2.14	2.63	18.08	55.09	2260.06	11.20	9.07	2.37	9.35
	5.00	2.72	1257.43	730.17	34.18	1155.73	671.11	2.33	2.45	5.80	2.27	2.63	17.55	66.95	2328.32	16.31	13.21	2.40	9.45
	5.50	2.73	1284.10	740.73	34.31	1175.92	678.32	2.35	2.43	4.02	2.23	2.63	17.45	76.96	2354.22	18.09	14.65	2.45	9.66
	6.00	2.70	1273.67	727.20	33.93	1179.32	673.33	2.35	2.41	3.12	2.19	2.63	17.75	82.42	2350.24	17.55	14.22	2.52	9.93
	6.50	2.73	1277.70	736.77	34.31	1170.05	674.70	2.32	2.40	2.42	2.21	2.63	18.62	87.00	2320.45	15.06	12.20	2.63	10.35

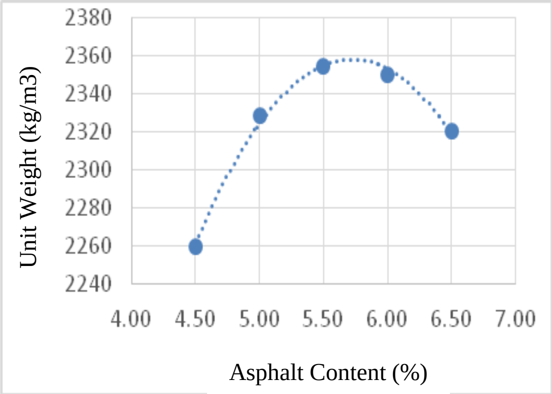

Fig. 4.10(a) Variation of Unit Weight With % of Bitumen

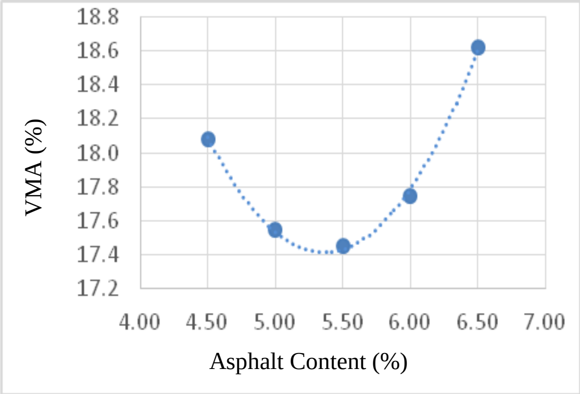

Fig. 4.10(d) Variation of VMA With % of Bitumen

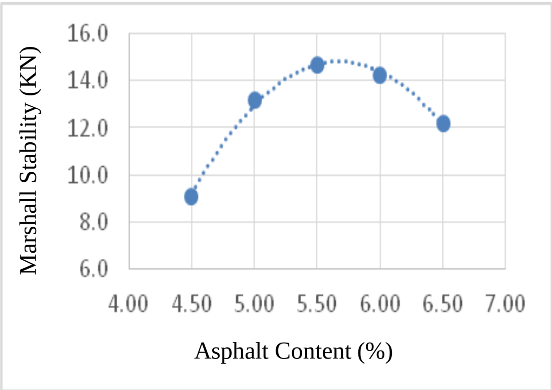

Fig. 4.10(b) Variation of Stability With % of Bitumen

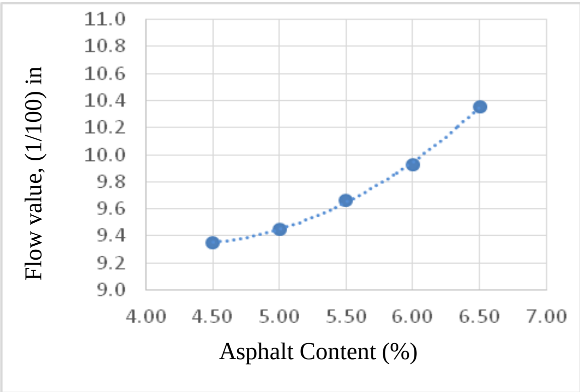

Fig. 4.10(e) Variation of Flow Value With % of Bitumen

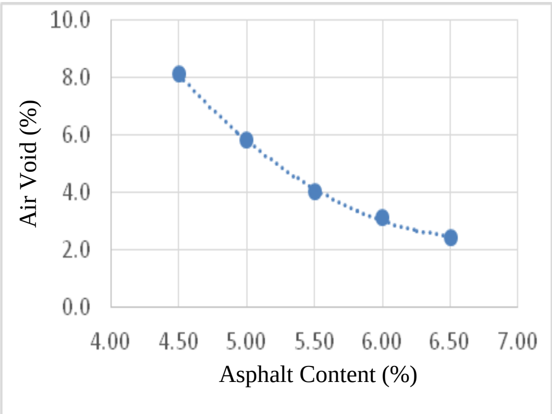

Fig. 4.10(c) Variation of Air Void With % of Bitumen

Table 4.11 Marshall Properties of HMA using Fly Ash (4%)

FLY ASH DUST

Filler (%)	AC (%)	Sample ht (in)	Mass (gm.)		Bulk volume (cc.)	Wa (gm.)	Ww (gm.)	Sp. Gr. (G)	Gt	Air Void (%)	Ga	Gta	VMA (%)	VFA (%)	Unit Weight (kg/m3)	Stability (KN)		Deformation (mm)	Flow value, (1/100) in
			In Air	In water												Measured	Corrected		
4%	4.50	2.89	1279.93	703.73	36.32	1107.21	608.76	2.22	2.46	9.68	2.12	2.63	19.62	50.68	2221.33	4.72	3.82	2.50	9.84
	5.00	2.88	1276.57	704.30	36.19	1108.13	611.37	2.23	2.44	8.65	2.12	2.63	19.37	55.36	2233.21	10.19	8.25	2.52	9.92
	5.50	2.87	1274.23	705.70	36.07	1109.96	614.72	2.24	2.42	7.56	2.12	2.63	19.42	61.04	2237.27	12.31	9.97	2.54	10.00
	6.00	2.81	1273.20	703.40	35.31	1132.74	625.80	2.23	2.41	7.20	2.10	2.63	19.82	63.70	2234.47	11.80	9.56	2.56	10.09
	6.50	2.91	1277.70	703.60	36.57	1097.68	604.47	2.22	2.39	6.92	2.08	2.63	20.37	66.04	2225.57	8.37	6.78	2.60	10.24

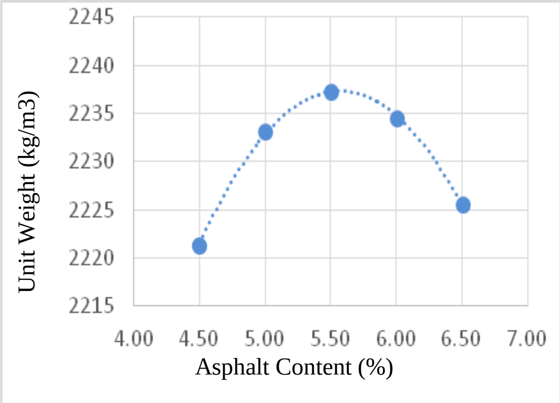

Fig. 4.11(a) Variation of Unit Weight With % of Bitumen

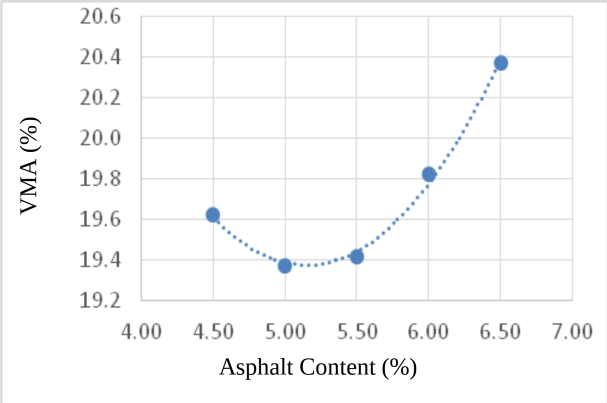

Fig. 4.11(d) Variation of VMA With % of Bitumen

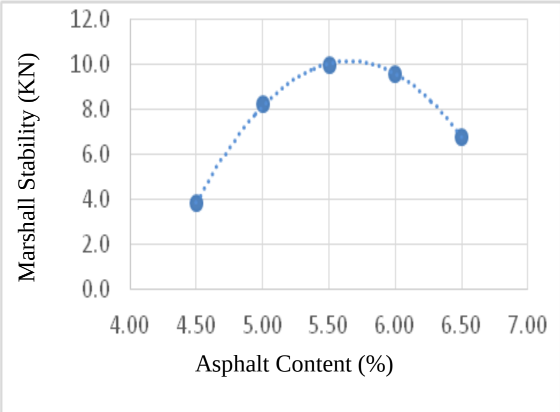

Fig. 4.11(b) Variation of Stability With % of Bitumen

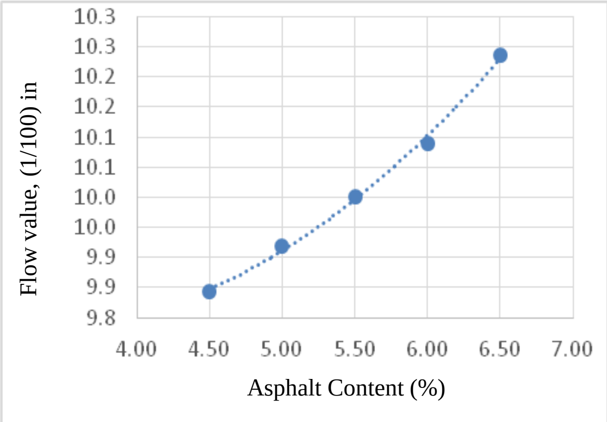

Fig. 4.11(e) Variation of Flow Value With % of Bitumen

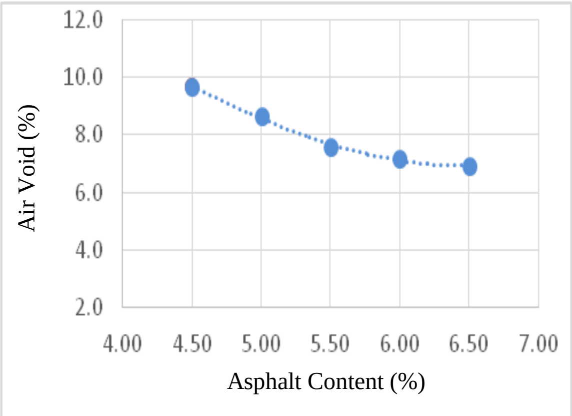

Fig. 4.11(c) Variation of Air Void With % of Bitumen

Table 4.12 Marshall Properties of HMA using Fly Ash (5%)

FLY ASH DUST

Filler (%)	AC (%)	Sample ht (in)	Mass (gm.)		Bulk volume (cc.)	Wa (gm.)	Ww (gm.)	Sp. Gr. (G)	Gt	Air Void (%)	Ga	Gta	VMA (%)	VFA (%)	Unit Weight (kg/m3)	Stability (KN)		Deformation (mm)	Flow value, (1/100) in
			In Air	In water												Measured	Corrected		
5%	4.50	2.82	1267.73	691.70	35.44	1123.87	613.21	2.20	2.46	10.55	2.10	2.63	18.88	44.10	2200.81	12.30	9.96	2.30	9.06
	5.00	2.80	1257.40	699.50	35.19	1122.68	624.55	2.25	2.44	7.74	2.14	2.63	18.45	58.02	2253.81	17.92	14.52	2.40	9.45
	5.50	2.93	1281.37	718.73	36.82	1093.32	613.25	2.28	2.43	6.12	2.15	2.63	18.58	67.08	2277.42	20.02	16.22	2.47	9.72
	6.00	2.79	1274.77	710.53	35.06	1142.27	636.68	2.27	2.41	4.95	2.12	2.63	19.02	73.97	2270.27	19.46	15.76	2.62	10.32
	6.50	2.82	1277.10	721.80	35.44	1132.18	639.89	2.24	2.39	3.86	2.15	2.63	20.08	80.80	2242.20	16.06	13.01	2.85	11.22

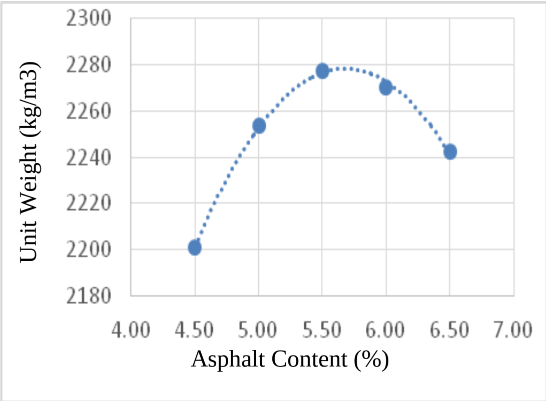

Fig. 4.12(a) Variation of Unit Weight With % of Bitumen

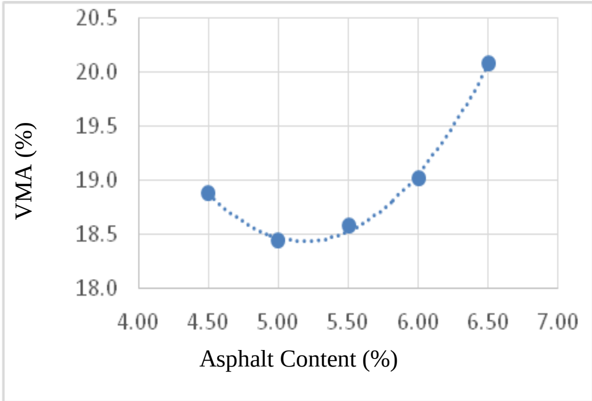

Fig. 4.12(d) Variation of VMA With % of Bitumen

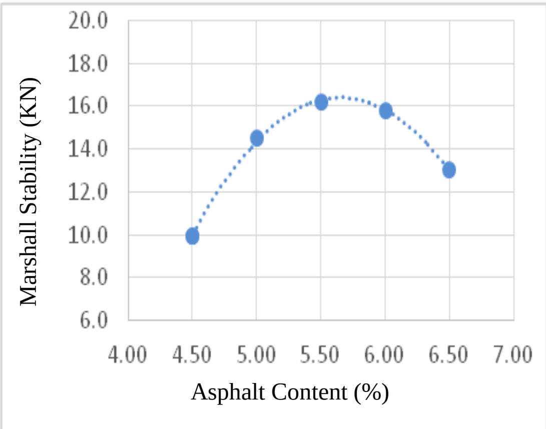

Fig. 4.12(b) Variation of Stability With % of Bitumen

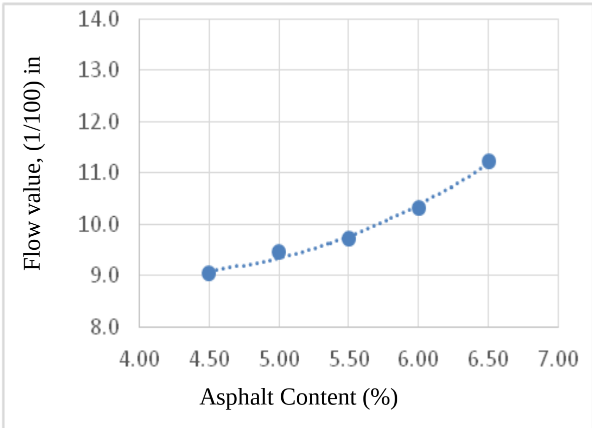

Fig. 4.12(e) Variation of Flow Value With % of Bitumen

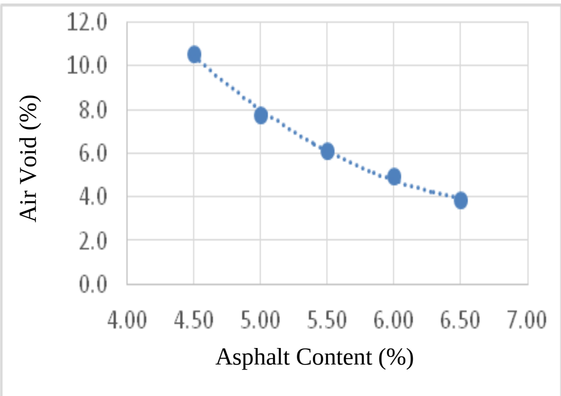

Fig. 4.12(c) Variation of Air Void With % of Bitumen

Table 4.13 Marshall Properties of HMA using Fly Ash (6%)

FLY ASH DUST

Filler (%)	AC (%)	Sample ht (in)	Mass (gm.)		Bulk volume (cc.)	Wa (gm.)	Ww (gm.)	Sp. Gr. (G)	Gt	Air Void (%)	Ga	Gta	VMA (%)	VFA (%)	Unit Weight (kg/m3)	Stability (KN)		Deformation (mm)	Flow value, (1/100) in
			In Air	In water												Measured	Corrected		
6%	4.50	2.82	1276.43	702.47	35.44	1131.59	622.76	2.22	2.46	9.67	2.12	2.63	19.29	49.87	2223.90	16.32	13.22	2.50	9.84
	5.00	2.82	1275.73	708.67	35.44	1130.97	628.25	2.25	2.44	7.97	2.14	2.63	18.78	57.58	2252.73	17.86	14.47	2.56	10.06
	5.50	2.83	1264.73	704.90	35.56	1117.25	622.70	2.26	2.43	6.63	2.13	2.63	18.87	64.87	2268.89	18.83	15.25	2.62	10.33
	6.00	2.79	1276.10	718.40	35.06	1143.46	643.73	2.27	2.41	5.17	2.15	2.63	19.26	73.16	2266.35	18.52	15.00	2.70	10.62
	6.50	2.94	1332.33	738.13	36.95	1132.93	627.66	2.24	2.39	4.32	2.10	2.63	20.33	78.75	2245.22	17.49	14.17	2.80	11.02

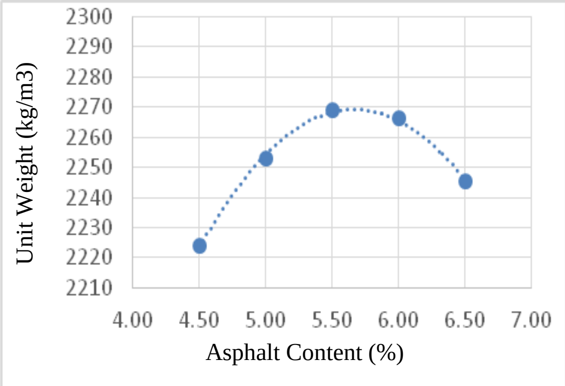

Fig. 4.13(a) Variation of Unit Weight With % of Bitumen

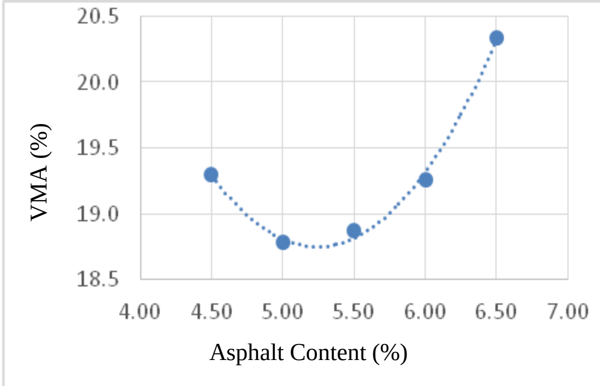

Fig. 4.13(d) Variation of VMA With % of Bitumen

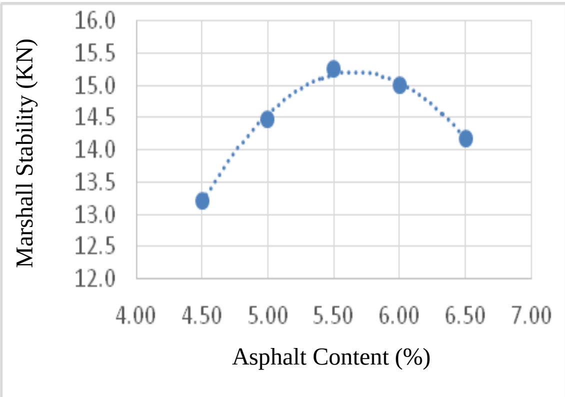

Fig. 4.13(b) Variation of Stability With % of Bitumen

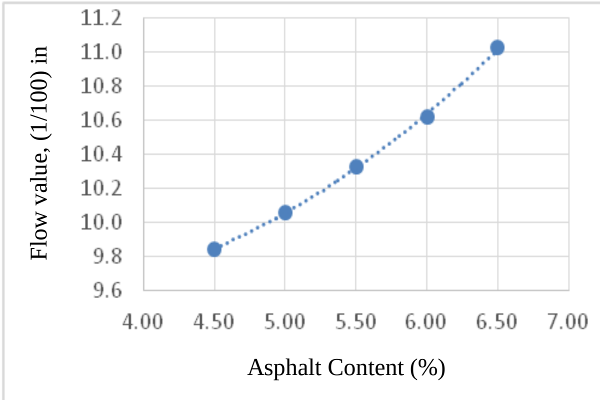

Fig. 4.13(e) Variation of Flow Value With % of Bitumen

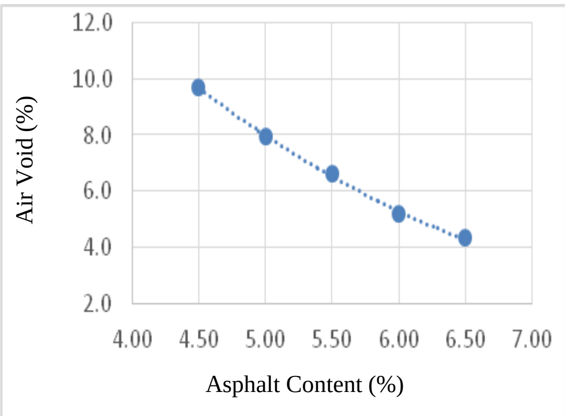

Fig. 4.13(c) Variation of Air Void With % of Bitumen

Table 4.14 Marshall Properties of HMA using Fly Ash (7%)

FLY ASH DUST

Filler (%)	AC (%)	Sample ht (in)	Mass (gm.)		Bulk volume (cc.)	Wa (gm.)	Ww (gm.)	Sp. Gr. (G)	Gt	Air Void (%)	Ga	Gta	VMA (%)	VFA (%)	Unit Weight (kg/m3)	Stability (KN)		Deformation (mm)	Flow value, (1/100) in
			In Air	In water												Measured	Corrected		
7%	4.50	2.91	1272.70	699.50	36.57	1093.38	600.95	2.20	2.46	9.87	2.12	2.63	20.62	52.15	2201.92	8.48	6.87	2.45	9.65
	5.00	2.90	1279.97	704.10	36.44	1103.42	606.98	2.22	2.45	8.93	2.11	2.63	20.10	55.57	2218.00	15.52	12.57	2.48	9.76
	5.50	2.87	1276.87	704.93	36.07	1112.26	614.05	2.22	2.43	8.17	2.11	2.63	20.18	59.51	2224.32	17.86	14.47	2.54	10.00
	6.00	2.83	1282.47	703.50	35.56	1132.92	621.47	2.22	2.41	7.55	2.08	2.63	20.78	63.67	2222.22	17.10	13.85	2.61	10.27
	6.50	2.81	1282.77	700.20	35.31	1141.25	622.95	2.21	2.39	7.25	2.06	2.63	21.65	66.51	2214.45	13.48	10.92	2.73	10.75

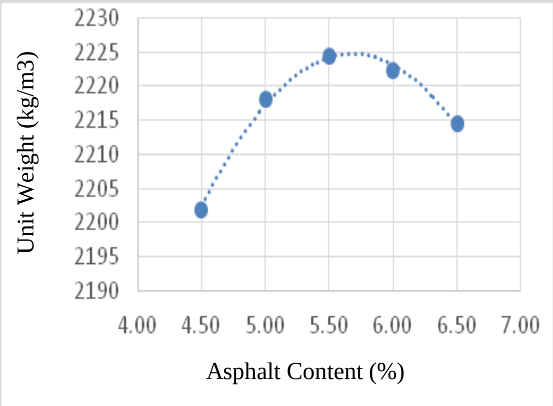

Fig. 4.14(a) Variation of Unit Weight With % of Bitumen

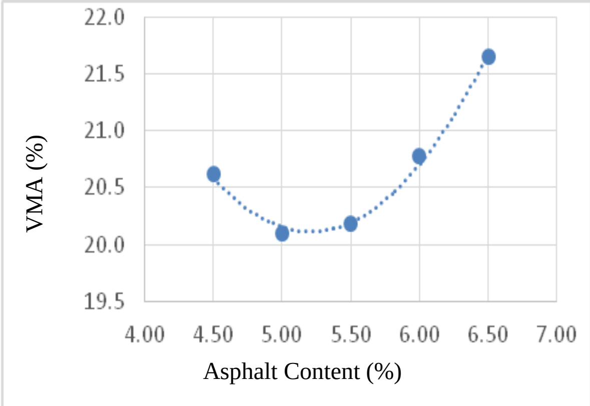

Fig. 4.14(d) Variation of VMA With % of Bitumen

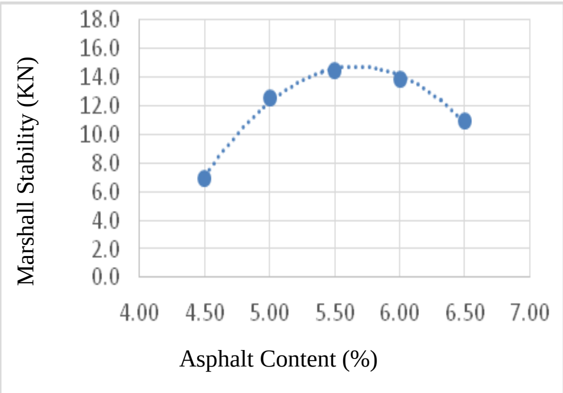

Fig. 4.14(b) Variation of Stability With % of Bitumen

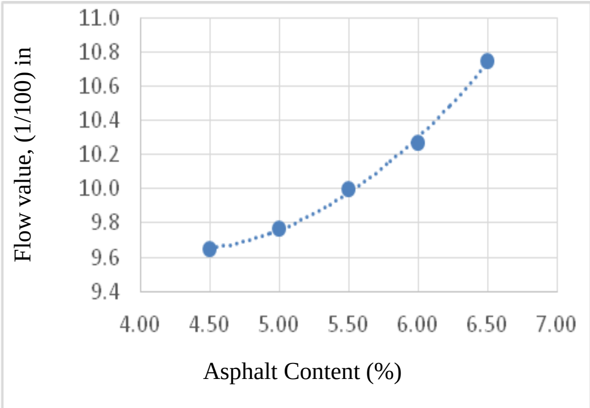

Fig. 4.14(e) Variation of Flow Value With % of Bitumen

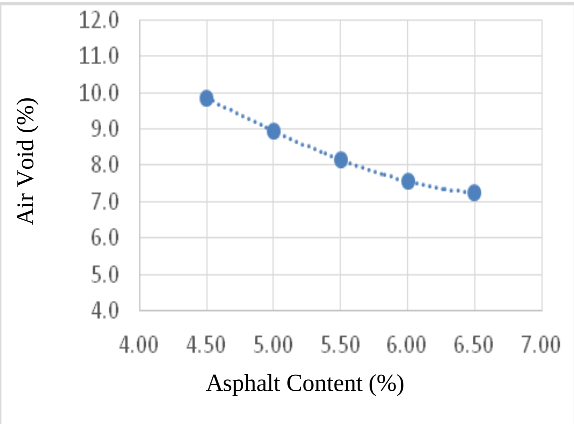

Fig. 4.14(c) Variation of Air Void With % of Bitumen

Table 4.15 Marshall Properties of HMA using Fly Ash (8%)

FLY ASH DUST

Filler (%)	AC (%)	Sample ht (in)	Mass (gm.)		Bulk volume (cc.)	Wa (gm.)	Ww (gm.)	Sp. Gr. (G)	Bulk volume (cc.)	Air Void (%)	Ga	Gta	VMA (%)	VFA (%)	Unit Weight (kg/m3)	Stability (KN)		Deformation (mm)	Flow value, (1/100) in
			In Air	In water												Measured	Corrected		
8%	4.50	2.91	1286.03	701.73	36.57	1104.84	602.86	2.20	2.46	10.71	2.10	2.63	20.23	47.08	2200.98	4.69	3.80	2.40	9.45
	5.00	2.92	1287.53	710.23	36.69	1102.34	608.07	2.23	2.45	8.87	2.12	2.63	19.87	55.37	2230.26	8.99	7.28	2.43	9.58
	5.50	2.91	1290.43	711.60	36.57	1108.62	611.34	2.24	2.43	7.95	2.11	2.63	19.82	59.89	2240.35	10.52	8.52	2.47	9.72
	6.00	2.88	1280.37	710.80	36.19	1111.43	617.01	2.24	2.41	6.93	2.11	2.63	20.05	65.44	2240.96	10.25	8.30	2.52	9.92
	6.50	2.73	1277.30	703.33	34.31	1169.69	644.08	2.22	2.40	6.52	2.08	2.63	20.55	68.27	2225.38	8.21	6.65	2.59	10.21

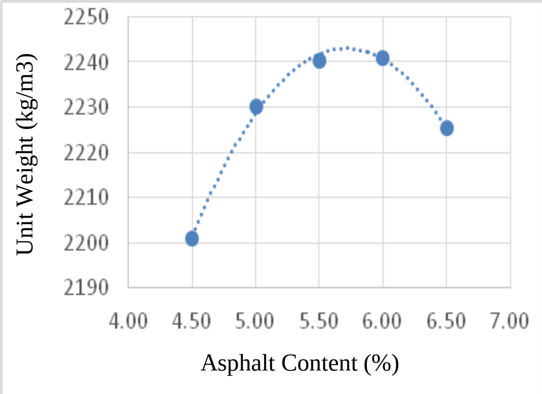

Fig. 4.15(a) Variation of Unit Weight with % of Bitumen

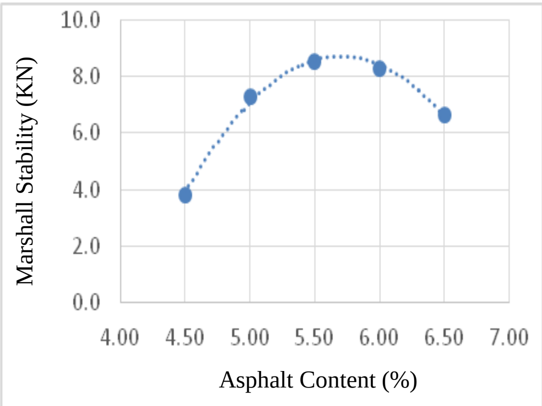

Fig. 4.15(b) Variation of Stability With % of Bitumen

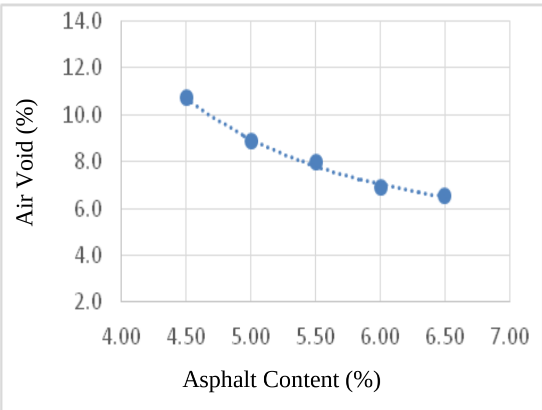

Fig. 4.15(c) Variation of Air Void With % of Bitumen

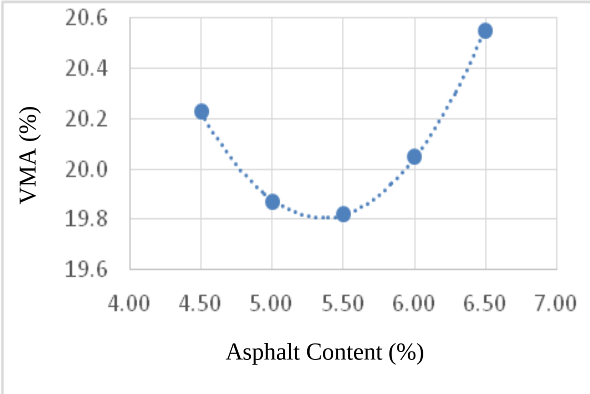

Fig. 4.15(d) Variation of VMA with % of Bitumen

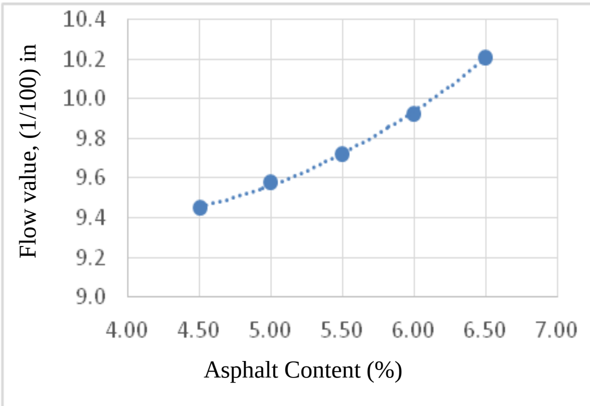

Fig. 4.15(e) Variation of Flow Value With % of Bitumen

Table 4.15 (a) Comparison Marshall Properties of HMA using 4% filler of Brick dust, Stone dust and Fly ash

Filler	Filler Type	AC	VMA (%)	Air Void (%)	Unit Weight (kg/m3)	Marshall stability (KN)	Flow value, (1/100) in
4%	Brick Dust	4.50	18.19	8.11	2259.94	8.56	9.65
		5.00	17.64	6.68	2278.71	11.96	9.80
		5.50	17.43	5.15	2299.75	13.66	10.00
		6.00	17.74	4.47	2300.09	13.15	10.18
		6.50	18.41	4.31	2288.02	11.53	10.43
	Stone Dust	4.50	14.22	5.12	2268.75	7.95	9.45
		5.00	10.90	3.30	2291.25	13.02	9.65
		5.50	11.27	2.15	2302.25	14.42	9.88
		6.00	14.66	1.45	2298.45	13.22	10.24
		6.50	18.94	1.17	2283.00	10.50	10.63
	Fly Ash	4.50	19.62	9.68	2221.33	3.82	9.84
		5.00	19.37	8.65	2233.21	8.25	9.92
		5.50	19.42	7.56	2237.27	9.97	10.00
		6.00	19.82	7.20	2234.47	9.56	10.09
		6.50	20.37	6.92	2225.57	6.78	10.24

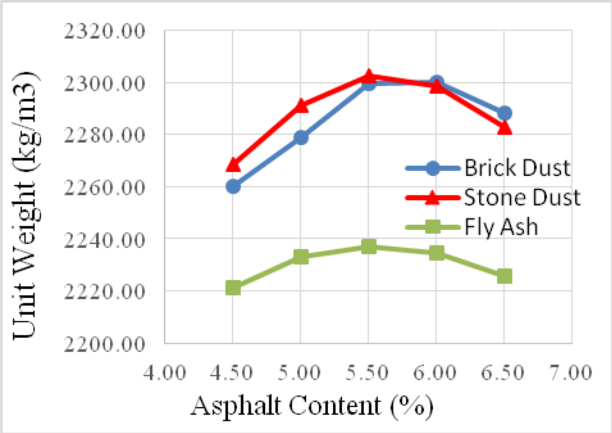

Fig: 4.15 (i) Unit weight curve using 4% filler of Brick dust, Stone dust and Fly ash

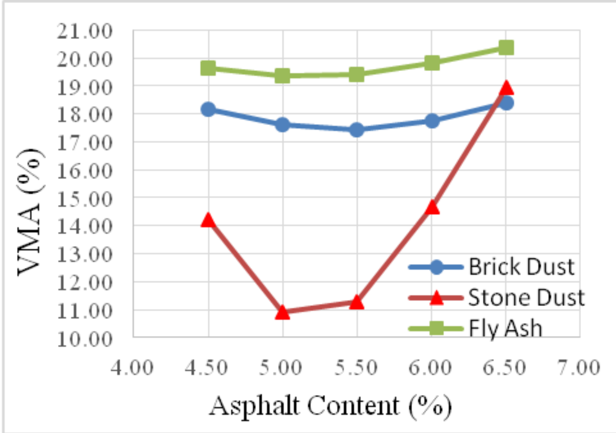

Fig: 4.15 (iv) VMA curve using 4% filler of Brick dust, Stone dust and Fly ash

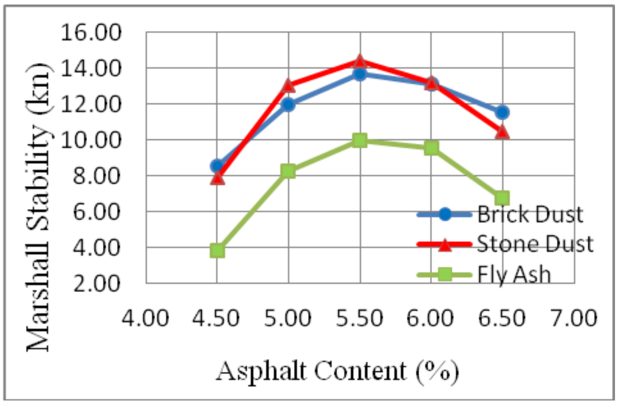

Fig: 4.15 (ii) Stability curve using 4% filler of Brick dust, Stone dust and Fly ash

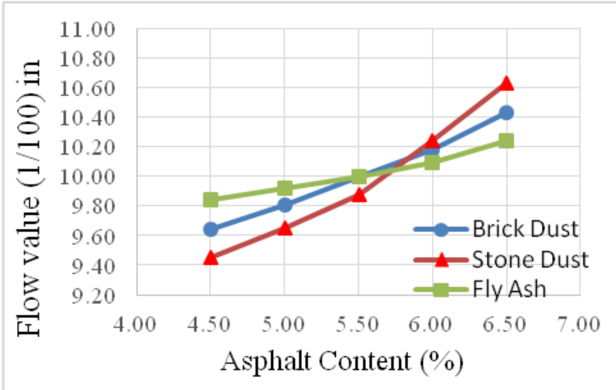

Fig: 4.15 (v) Flow value curve using 4% filler of Brick dust, Stone dust and Fly ash

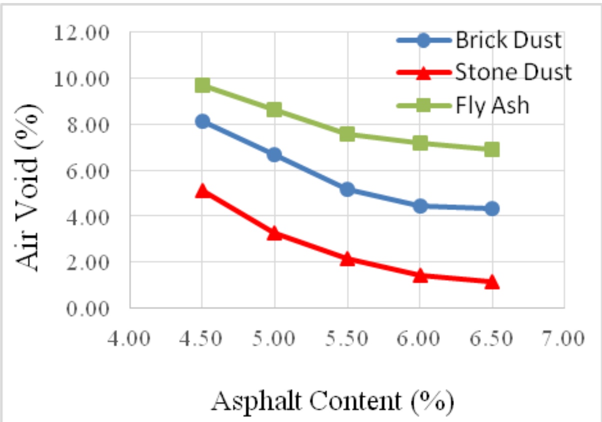

Fig: 4.15 (iii) Air void curve using 4% filler of Brick dust, Stone dust and Fly ash

Table 4.15 (b) Comparison Marshall Properties of HMA using 5% filler of Brick dust, Stone dust and Fly ash

Filler	Filler Type	AC	VMA (%)	Air Void (%)	Unit Weight (kg/m3)	Marshall stability (KN)	Flow value, (1/100) in
5%	Brick Dust	4.50	17.63	8.89	2241.80	9.20	9.06
		5.00	17.25	5.95	2310.00	12.90	9.32
		5.50	17.32	4.66	2332.00	14.20	9.54
		6.00	17.75	3.82	2330.00	13.75	10.00
		6.50	18.42	2.74	2285.00	12.30	10.35
	Stone Dust	4.50	17.25	6.86	2275.76	14.00	8.35
		5.00	16.27	5.15	2298.25	14.62	8.52
		5.50	16.55	4.15	2309.25	14.95	8.85
		6.00	17.17	3.62	2305.45	14.87	9.25
		6.50	19.24	3.42	2290.00	14.49	9.69
	Fly Ash	4.50	18.88	10.55	2200.81	9.96	9.06
		5.00	18.45	7.74	2253.81	14.52	9.45
		5.50	18.58	6.12	2277.42	16.22	9.72
		6.00	19.02	4.95	2270.27	15.76	10.32
		6.50	20.08	3.86	2242.20	13.01	11.22

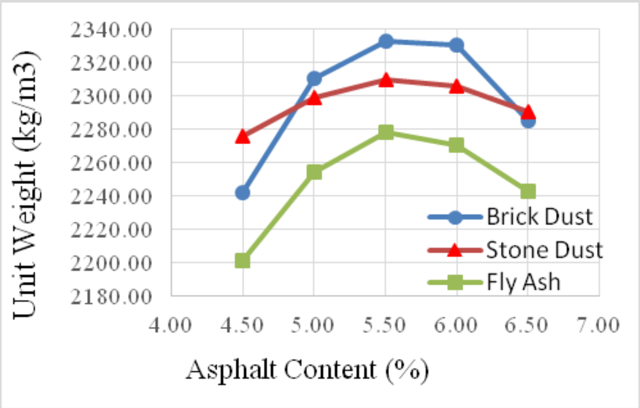

Fig: 4.16 (i) Unit weight curve using 5% filler of Brick dust, Stone dust and Fly ash

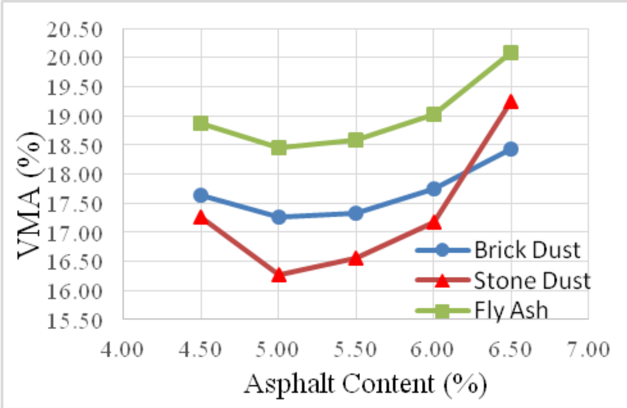

Fig: 4.16 (iv) VMA curve using 5% filler of Brick dust, Stone dust and Fly ash

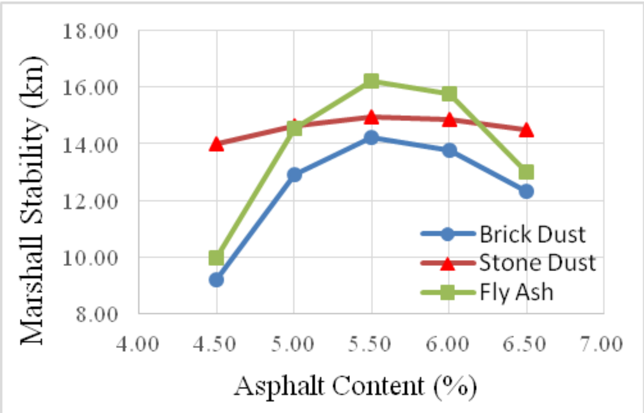

Fig: 4.16 (ii) Stability curve using 5% filler of Brick dust, Stone dust and Fly ash

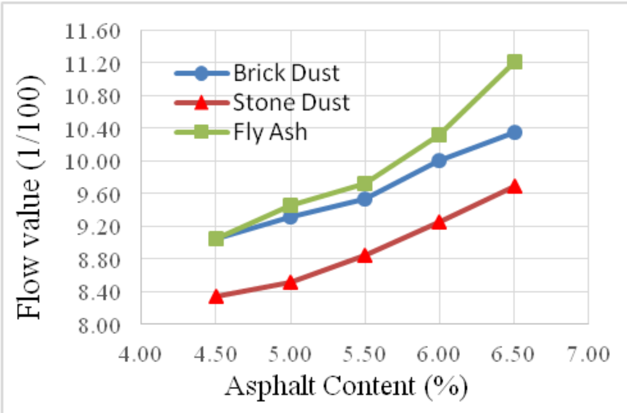

Fig: 4.16 (v) Flow value curve using 5% filler of Brick dust, Stone dust and Fly ash

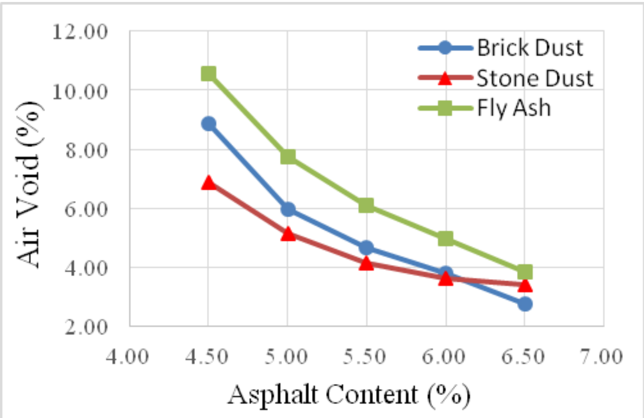

Fig: 4.15 (iii) Air void curve using 5% filler of Brick dust, Stone dust and Fly ash

Table 4.15 (c) Comparison Marshall Properties of HMA using 6% filler of Brick dust, Stone dust and Fly ash

Filler	Filler Type	AC	VMA (%)	Air Void (%)	Unit Weight (kg/m3)	Marshall stability (KN)	Flow value, (1/100) in
6%	Brick Dust	4.50	17.30	8.46	2253.58	6.40	9.45
		5.00	17.18	6.09	2285.00	9.84	9.57
		5.50	17.25	5.07	2304.21	11.65	9.84
		6.00	17.50	3.37	2310.00	10.87	10.20
		6.50	17.85	2.85	2290.00	9.65	10.63
	Stone Dust	4.50	16.52	7.53	2276.73	9.02	9.06
		5.00	16.01	5.58	2318.75	14.44	9.13
		5.50	16.00	3.58	2343.95	16.61	9.25
		6.00	16.47	2.70	2340.08	15.75	9.42
		6.50	17.38	2.31	2312.22	12.95	9.65
	Fly Ash	4.50	19.29	9.67	2223.90	13.22	9.84
		5.00	18.78	7.97	2252.73	14.47	10.06
		5.50	18.87	6.63	2268.89	15.25	10.33
		6.00	19.26	5.17	2266.35	15.00	10.62
		6.50	20.33	4.32	2245.22	14.17	11.02

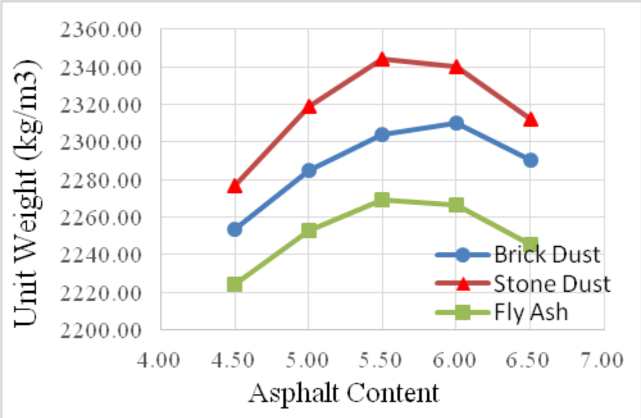

Fig: 4.17 (i) Unit weight curve using 6% filler of Brick dust, Stone dust and Fly ash

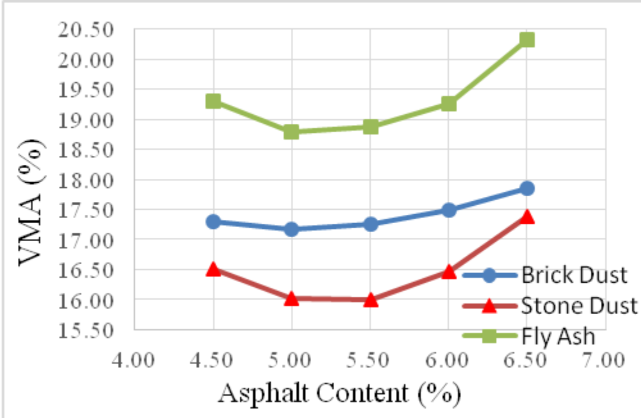

Fig: 4.17 (iv) VMA curve using 6% filler of Brick dust, Stone dust and Fly ash

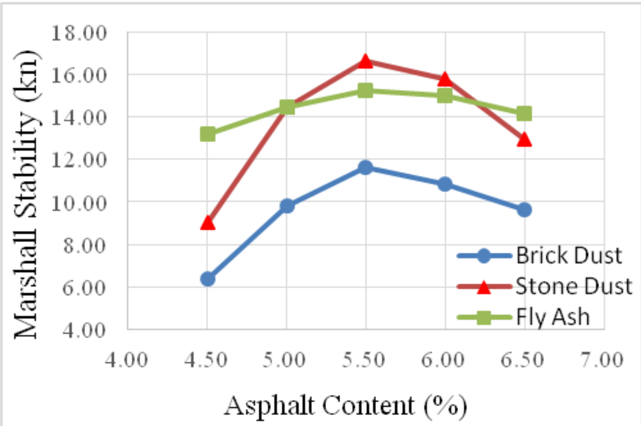

Fig: 4.17 (ii) Stability curve using 6% filler of Brick dust, Stone dust and Fly ash

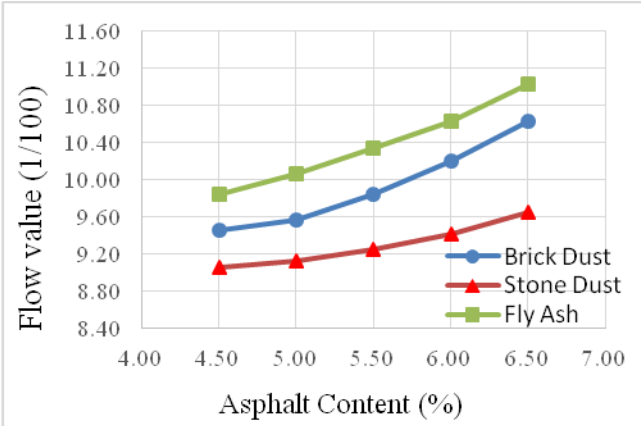

Fig: 4.17 (v) Flow value curve using 6% filler of Brick dust, Stone dust and Fly ash

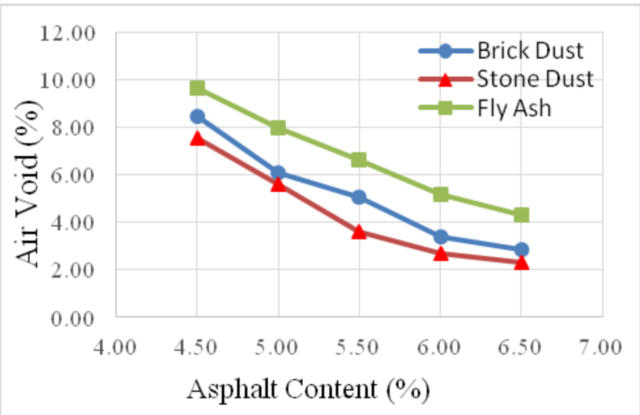

Fig: 4.17 (iii) Air void curve using 6% filler of Brick dust, Stone dust and Fly ash

Table 4.15 (d) Comparison Marshall Properties of HMA using 7% filler of Brick dust, Stone dust and Fly ash

Filler	Filler Type	AC	VMA (%)	Air Void (%)	Unit Weight (kg/m3)	Marshall stability (KN)	Flow value, (1/100) in
7%	Brick Dust	4.50	19.48	9.87	2230.00	7.15	9.63
		5.00	18.47	7.95	2260.00	13.40	9.75
		5.50	18.03	5.81	2287.61	16.60	10.03
		6.00	18.62	4.95	2292.00	16.00	10.43
		6.50	20.24	4.97	2275.00	13.26	10.75
	Stone Dust	4.50	16.02	7.12	2288.15	9.88	9.33
		5.00	14.45	5.40	2323.96	15.81	9.39
		5.50	14.75	3.62	2342.45	19.25	9.50
		6.00	16.70	2.45	2340.42	17.95	9.66
		6.50	19.31	1.58	2325.45	14.73	9.88
	Fly Ash	4.50	20.62	9.87	2201.92	6.87	9.65
		5.00	20.10	8.93	2218.00	12.57	9.76
		5.50	20.18	8.17	2224.32	14.47	10.00
		6.00	20.78	7.55	2222.22	13.85	10.27
		6.50	21.65	7.25	2214.45	10.92	10.75

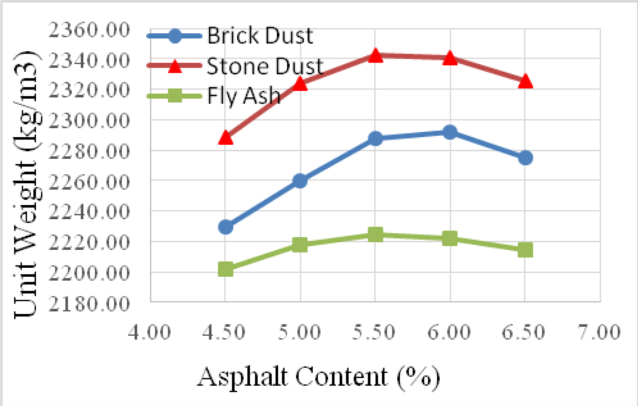

Fig: 4.18 (i) Unit weight curve using 7% filler of Brick dust, Stone dust and Fly ash

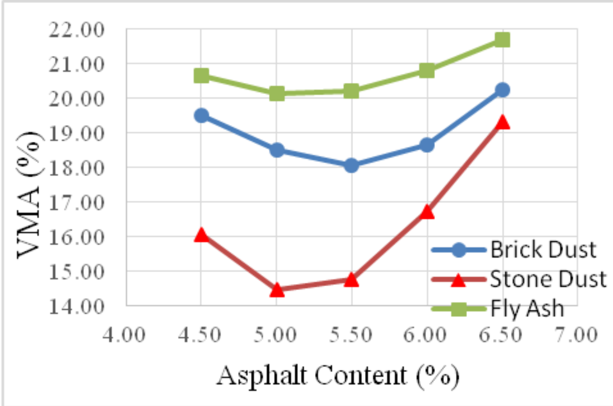

Fig: 4.18 (iv) VMA curve using 7% filler of Brick dust, Stone dust and Fly ash

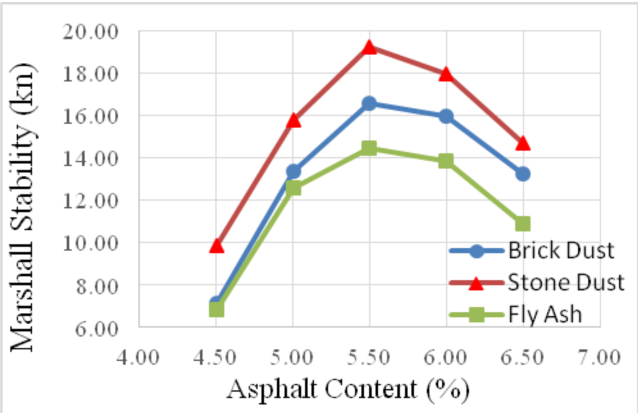

Fig: 4.18 (ii) Stability curve using 7% filler of Brick dust, Stone dust and Fly ash

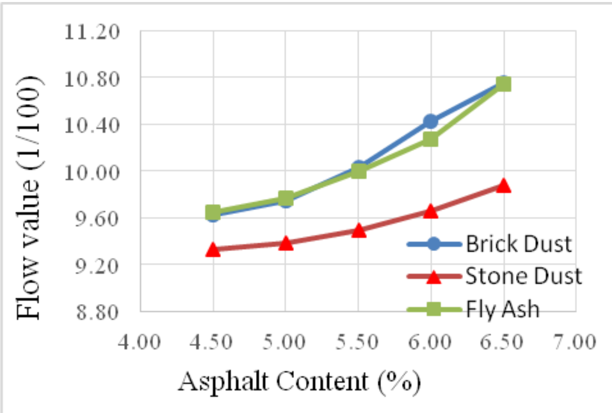

Fig: 4.18 (v) Flow value curve using 7% filler of Brick dust, Stone dust and Fly ash

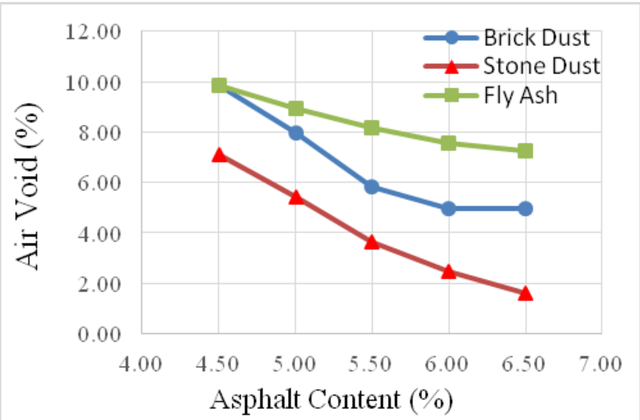

Fig: 4.18 (iii) Air void curve using 7% filler of Brick dust, Stone dust and Fly ash

Table 4.15 (e) Comparison Marshall Properties of HMA using 8% filler of Brick dust, Stone dust and Fly ash

Filler	Filler Type	AC	VMA (%)	Air Void (%)	Unit Weight (kg/m3)	Marshall stability (KN)	Flow value, (1/100) in
8%	Brick Dust	4.50	17.62	8.50	2255.32	9.95	9.45
		5.00	16.95	6.83	2277.20	10.45	9.75
		5.50	16.73	4.70	2297.80	10.60	10.05
		6.00	17.62	4.10	2299.50	10.55	10.33
		6.50	19.22	3.00	2286.35	10.32	10.87
	Stone Dust	4.50	18.08	8.12	2260.06	9.07	9.35
		5.00	17.55	5.80	2328.32	13.21	9.45
		5.50	17.45	4.02	2354.22	14.65	9.66
		6.00	17.75	3.12	2350.24	14.22	9.93
		6.50	18.62	2.42	2320.45	12.20	10.35
	Fly Ash	4.50	20.23	10.71	2200.98	3.80	9.45
		5.00	19.87	8.87	2230.26	7.28	9.58
		5.50	19.82	7.95	2240.35	8.52	9.72
		6.00	20.05	6.93	2240.96	8.30	9.92
		6.50	20.55	6.52	2225.38	6.65	10.21

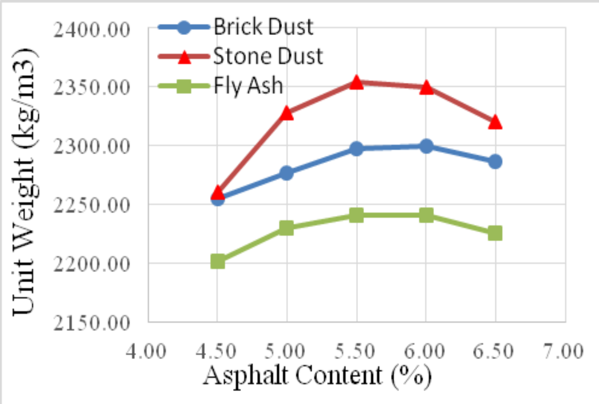

Fig: 4.19 (i) Unit weight curve using 8% filler of Brick dust, Stone dust and Fly ash

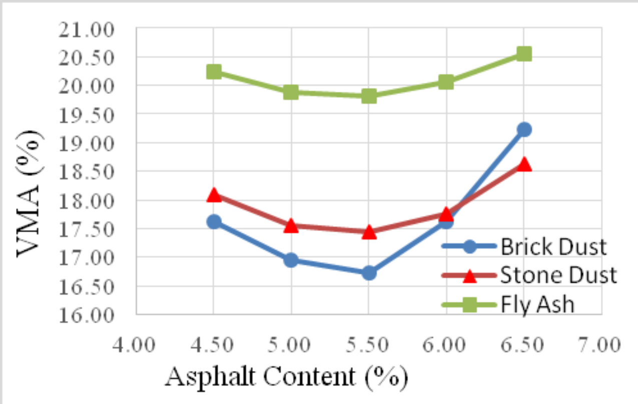

Fig: 4.19 (iv) VMA curve using 8% filler of Brick dust, Stone dust and Fly ash

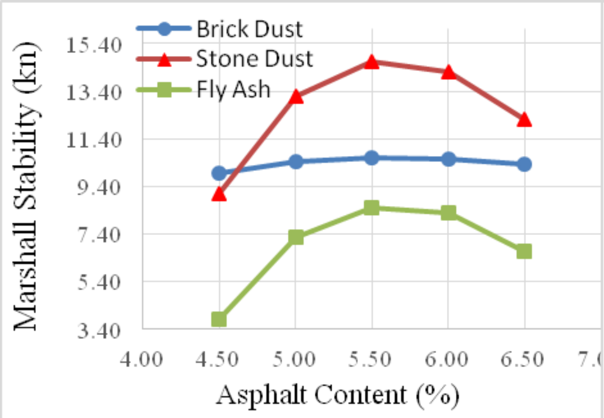

Fig: 4.19 (ii) Stability curve using 8% filler of Brick dust, Stone dust and Fly ash

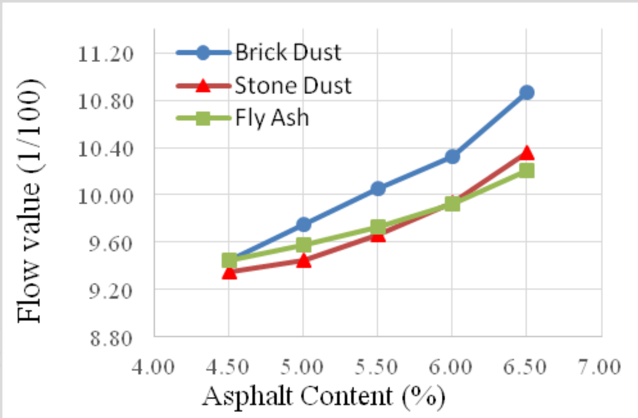

Fig: 4.19 (v) Flow value curve using 8% filler of Brick dust, Stone dust and Fly ash

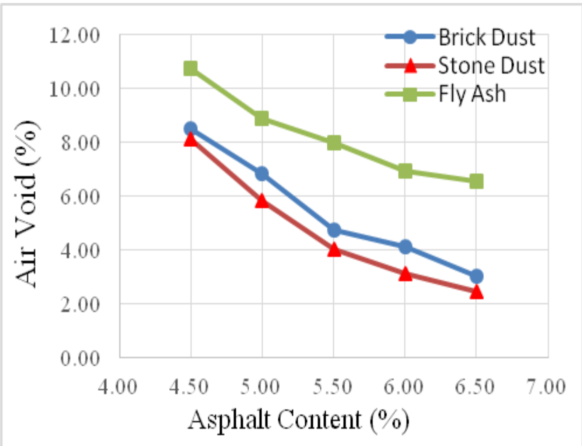

Fig: 4.19 (iii) Air void curve using 8% filler of Brick dust, Stone dust and Fly ash

Table 4.16 Marshall Properties of Bituminous Mix Design

Marshall Content Property	Filler type	Filler Content (%)				
		4%	5%	6%	7%	8%
Optimum asphalt Content, %	Brick Dust	5.72	5.67	5.73	5.70	5.65
	Stone Dust	5.65	5.68	5.67	5.72	5.73
	Fly Ash	5.65	5.65	5.65	5.70	5.70
Air Voids, %	Brick Dust	4.90	4.20	4.15	5.46	4.68
	Stone Dust	1.92	3.88	3.30	3.13	3.65
	Fly Ash	7.47	5.63	6.15	7.87	7.48
Marshall Stability, (KN)	Brick Dust	13.67	14.35	11.55	16.72	10.63
	Stone Dust	14.46	14.96	16.70	19.04	14.83
	Fly Ash	10.13	16.40	15.20	14.73	8.73
Flow Value, (1/100) in	Brick Dust	10.07	9.70	9.97	10.18	10.13
	Stone Dust	9.97	8.97	9.31	9.58	9.74
	Fly Ash	10.03	9.93	10.41	10.10	9.82
Bulk Density, (Kg/m^3)	Brick Dust	2300.00	2337.00	2308.00	2289.00	2298.00
	Stone Dust	2302.50	2309.30	2344.20	2343.40	2357.80
	Fly Ash	2237.60	2280.00	2269.20	2224.80	2243.00
VFA, (%)	Brick Dust	72.61	75.50	75.70	70.55	74.12
	Stone Dust	85.25	76.75	80.45	80.15	79.50
	Fly Ash	62.25	70.32	68.85	61.35	62.46
VMA, (%)	Brick Dust	17.52	17.40	17.35	18.24	16.95
	Stone Dust	11.82	16.60	16.12	15.33	17.50
	Fly Ash	19.52	18.63	18.92	20.35	19.88

4.3. Effect on Optimum Asphalt Content

Figure 4.2 shows that 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 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. Consequently, this decreases the voids in the mineral aggregate. As a result, lower space is available for asphalt. However, at higher (7% and 8%) filler content, the overall surface area of aggregate is increased and requires higher asphalt content to fulfill the Marshall requirements.

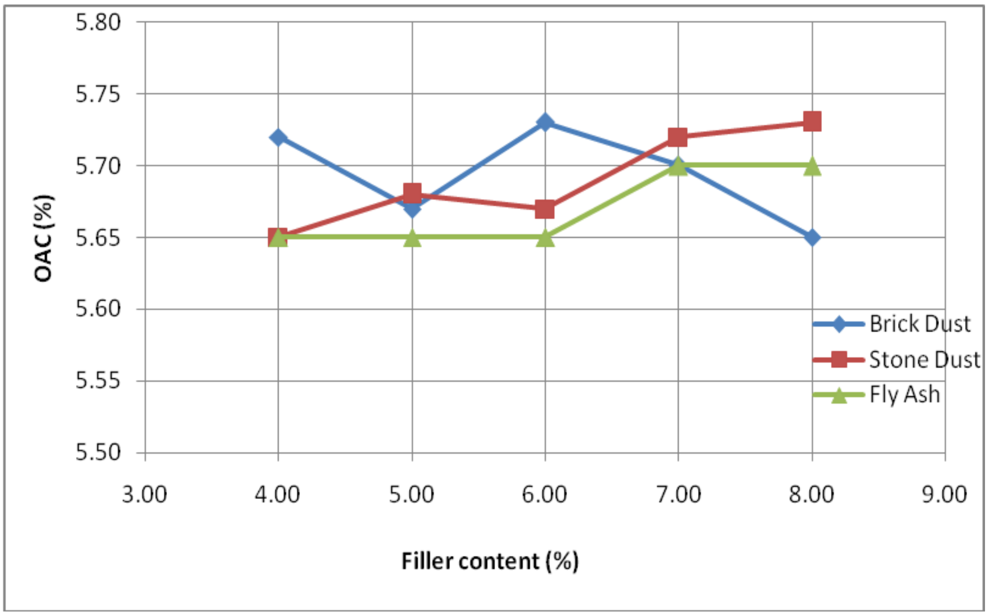

Figure 4.2 Effect of Filler type and Content on Optimum Asphalt Content

It is seen in the Figure 4.2 that the individual effect of different types of mineral fillers in the optimum binder content, mixtures using stone dust possess higher asphalt content than the mixes using brick dust and fly ash fillers. The mixes using stone dust have higher asphalt cement absorption than other filler types. 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 stone dust and brick dust and fly ash fillers show similar optimum binder content for 4% and 7% filler content. The optimum bitumen content for mixes using 4% stone dust and fly ash filler is 5.65%, while it is 5.73% for mixes using brick dust filler. The highest value of optimum asphalt content (5.74%) was obtained with 8% stone dust filler, while the lowest value (5.62%) was obtained with 6.0% stone dust filler. The increase was about 8%. This is indicated the effect of fillers on the voids in mineral aggregates.

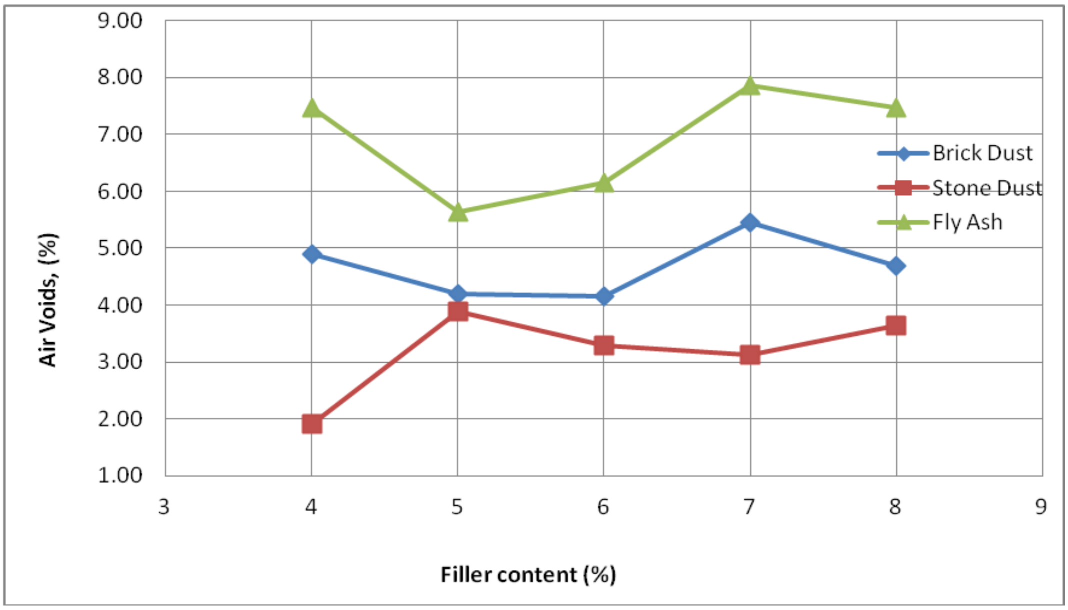

Figure 4.3 Effect of filler type and content on Air Voids, (%) at OBC

4.4 Effect on Unit Weight

The effect of all the filler type and their content on the unit weight of compacted mixes is shown in Figure 4.4. Mixes made with brick dust, stone dust, and fly ash filler showed same trend of increase in unit weight as filler content increases, then decreases as filler content increases and again increases with increase of filler content. It is shown that at 4% filler content, mixes made with all of the filler contents possessed lower unit weight (2300 Kg/m^3, 2300 Kg/m^3 and 2238 Kg/m^3 for Brick dust, stone dust and Fly ash, respectively) and highest unit weight value for mixes made with stone dust (2358 Kg/m^3) with 8% filler content. The lowest unit weight value of 2225 kg/m^3 for mixes made with fly ash with 7% filler content was observed.

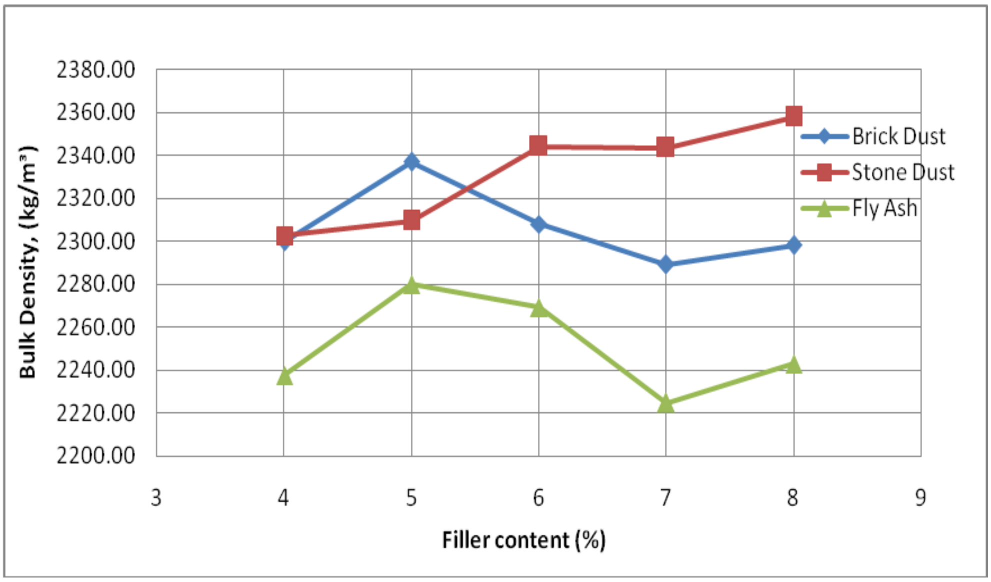

Figure 4.4 Effect of filler type and content on unit weight at OBC

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.

The effect of filler content on unit weight for mixes made by stone dust, brick dust and fly ash fillers is that the values increase and then decrease. This is because while filler content increases in the mix, it fills the voids hence increase unit weight. The unit weight for mixes also increases after decrease the value. This is difficult to explain why this happening. But it may be due to the voids in the mineral aggregate decreases as the filler content increases. Hence increase the unit weight.

4.5 Effect on Marshall Stability

Figure 4.5 shows the effect of filler type and their contents on Marshall Stability. Stone dust and fly ash fillers have the similar trend on their effect on Marshall Stability by content. But the brick dust filler have different trend than other two.

Marshall Stability increases up to maximum then decreases the mixtures with stone dust and fly ash. This is due to the fact that voids at lower filler content are too high and the aggregate tends to be finer as filler content increases. Hence reduce the stability values.

Moreover, anything that increases the viscosity of the asphalt binder increases the Marshall stability. Thus, a small addition of fine material (filler) in the mixture may have the effect of making the asphalt cement mixture act as a more viscous binder thus increasing the Marshall stability. However, if the dust is extremely fine, act like higher asphalt content, and lower the stability.

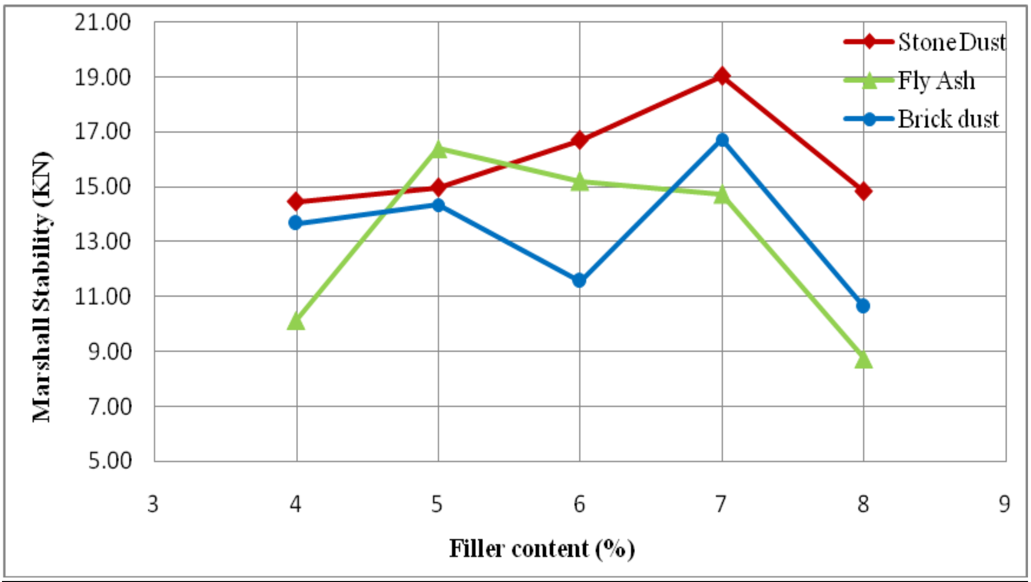

Figure 4.5 Effect of filler type and content on Marshall Stability at OBC

The test results obtained for individual filler type revealed that fly ash filler is finer than other types of fillers. Thus the finer the material the more it modifies the asphalt mixtures, hence gives lower stability values. On the other hand, the stability values obtained by mixes made with stone dust filler are relatively higher than all mixes made with either brick dust or fly ash fillers. It may be related with the effective asphalt content and voids in mineral aggregate in the mixture.

The mixtures prepared with stone dust relatively lower effective asphalt cement content and voids in mineral aggregate than the mixtures prepared either with brick dust or fly ash fillers. The effective asphalt 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 also shows that 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 7%, higher stability values were obtained using stone dust whereas lower values using brick dust and fly ash fillers.

4.6 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 4.6. 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 it is seen in Figure 4.6 that the mixtures using both the fillers of Brick dust and fly ash exhibit same manner, but mixtures made using stone dust filler, the voids in mineral aggregate keeps decreasing as the filler content in the mix increases from 5 to 7 percent.

Higher voids in mineral aggregate were obtained from mixes prepared by fly ash. This may be due to the fly is coarser than the stone dust and brick dust filler types. Lowest voids in mineral aggregates were obtained on mixes prepared using 4% and 8% of stone dust, where these mixtures possess higher optimum binder content relative to mixes prepared by brick dust and fly ash fillers. Moreover, effect of filler content is found to be more considerable than that of effect of filler type.

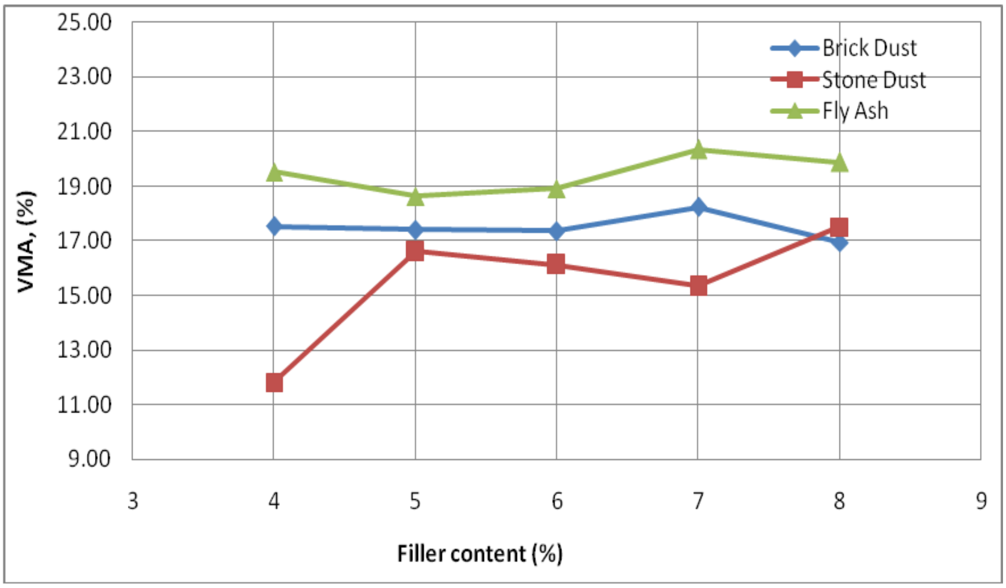

Figure 4.6 Effect of filler type and content on VMA at OBC

It is also seen that 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 stone dust filler and hence, results lower effective asphalt content. These mixes could be less durable than that of containing brick dust fillers.

4.7 Effect on Voids Filled with Asphalt (VFA)

Figure 4.7 shows the effect of filler types on the voids filled with asphalt (VFA) property of the mixture. Voids filled with asphalt values are ranges 60% to 85% for all types of fillers and contents, where the Marshall Criteria for VFA is 65% to 78%. 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 as well as 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 4% and 6% filler content of stone dust filler type, the voids filled with asphalt is greater than the maximum limit set by Marshall Criteria. The mixtures prepared by 4% and 7% filler content of fly ash filer type, the voids filled with asphalt is lower than the minimum limit set by Marshall Criteria.

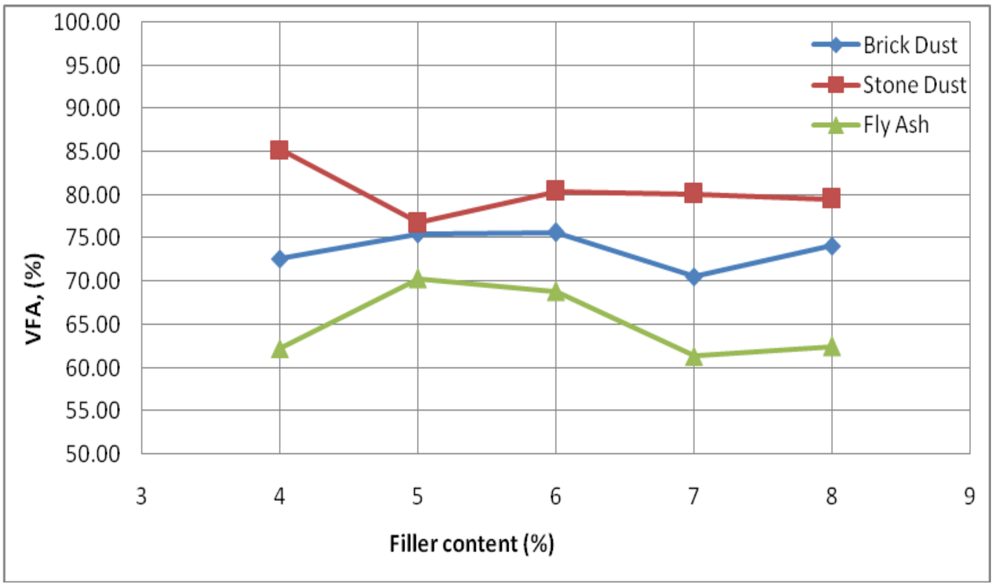

Figure 4.7 Effect of filler type and content on VFA at OBC

4.8 Effect on Marshall Flow

As it is clearly shown in Figure 4.8 that the Marshall Flow values obtained from the laboratory prepared mixes using all filler types, meet the Marshall criteria (8 to14)1/100in. For mixes prepared using 4% and 8% stone dust and fly ash fillers, the flow values obtained are relatively the same. Higher values of flow were also obtained for mixtures prepared using 8% brick dust and 6% fly ash fillers. At higher filler content using crushed stone, lower flow values were obtained. It may be due to the crushed stone filler are finer and stiffens the mixture more than other types of fillers.

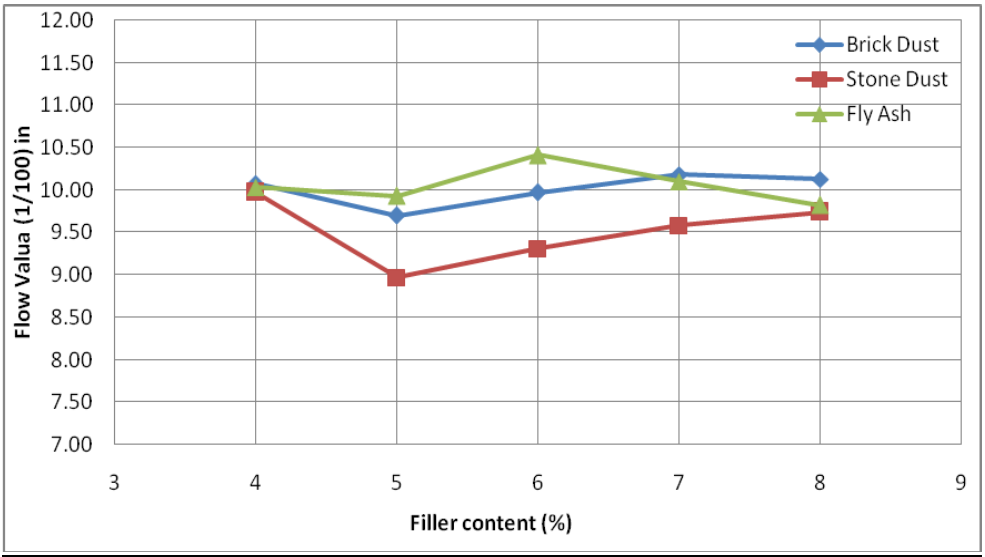

Figure 4.8 Effect of filler type and content on Flow Values at OBC

4.9 Effect of Fillers on Moisture Susceptibility of HMA

From the Marshall 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 4.17 and Figure 4.9 respectively. The figure is provided here for comparison between values obtained using different 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 8% brick dust filler provide highest retained stability as compared to mixes prepared with stone dust or fly ash fillers. This indicates that mixes prepared using brick dust 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 fly ash, followed by mixes with brick dust and the lowest using crushed stone dust filler

Table 4.17 Retained Stability Results from Marshall Immersion Test

Filler Type	Filler Content %	OBC, %	Stability (KN)		Retained Stability, % Soaking period 24 hrs. at 60˚c
			Control	Conditioned	
Brick Dust	4	5.72	13.67	12.80	93.64
	6	5.73	11.55	9.24	80.00
	8	5.65	10.63	9.72	91.44
Stone Dust	4	5.65	14.46	10.01	69.23
	6	5.67	16.70	11.56	69.22
	8	5.73	14.83	10.78	72.69
Fly Ash	4	5.73	9.00	6.93	77.00
	6	5.50	15.30	12.96	84.70
	8	5.67	8.30	7.70	92.77

For all the tests carried out to determine the moisture susceptibility showed that mixes using brick dust and fly ash fillers provide better resistance to moisture effect than mixtures using crushed stone filler.

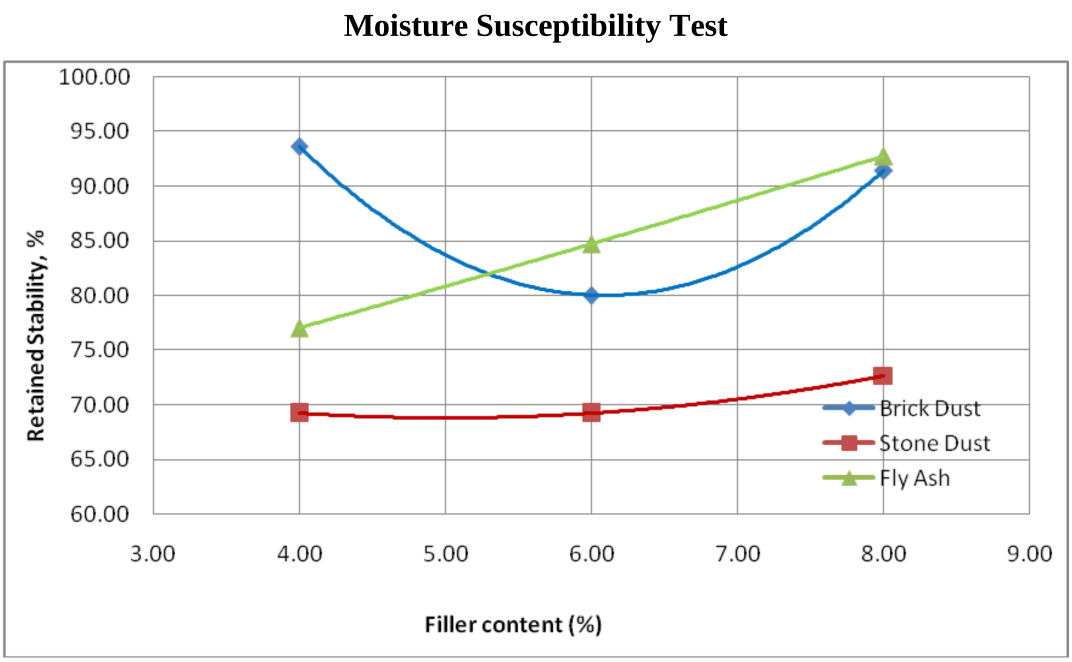

Figure 4.9 Effects of Filler Type and Content on Moisture Susceptibility at OBC

CHAPTER V

Conclusions and Future Scope

5.1 Conclusions

- Bituminous mixes containing Brick dust as fillers are found to have Marshall Properties almost similar as of stone dust and fly ash fillers.
- Bituminous mixes containing brick dust as filler displayed maximum unit weight at 5.50% content of bitumen having an increasing trend up to 5.50%. In case of stone and fly ash also maximum unit weight at 5.50% content of bitumen was achieved.
- Bituminous mixes containing brick dust as filler showed maximum stability at 5.50% content of bitumen. Also in case of stone and fly ash as filler maximum stability is attained at 5.50% content of bitumen.
- It is found that bituminous mixes containing 5.50% of bitumen content and 6% of filler gives the satisfactory results in all brick dust, stone dust and fly ash as fillers.
- These mixes were seen to display higher air voids than required for normal mixes.
- Problem of disposal of industrials waste can be reduced by using these waste materials.
- It is found that with further tests on brick dust, stone dust and fly ash generated as waste materials can be used effectively in the making of bitumen concrete blend for paving purposes.
- The cost effectiveness of these non conventional filler specimens can be realized after performing a cost analysis of these non conventional materials against the conventional specimens resulting in reduction of the construction costs considerably.

5.2 Future Scope

- Pavement mixes with silt, concrete dust, cement, limestone dust can also be used as fillers to improve the quality of pavement mixes.
- Creep test, Indirect tensile test of bituminous mixes can give us an idea about the tensile strength of the bituminous mixes.

- We can also use the different types of binders and additives like rubber, plastic waste, polymers etc.
- We can also use the different types of fibers like synthetic fiber and natural fiber to improve the quality of pavement mixes.

REFFERENCES

1. Ali, N., Chan, J.S., Simms, S., Bushman, R. and Bergan, A.T. (1996). Mechanistic evaluation of fly ash asphalt concrete mixture. J. Mater. Civ. Eng. 8(1).

2. Al-Sayed, M.H. (1988). The effect of funeral filler performance of tolled Asphaltic Mixes. PhD Thesis, University of Leeds, UK.

3. Anderson, D.A., Bahia, H.U., and Dongre, R. (1992). Rheological properties of mineral filler asphalt mastics and their relationship to pavement performance, ASTM, STP 1147, Richard C. Meininger Ed., ASTM, Philadelphia.

4. Anderson, D. A., Bahia, H. U., and Dongre, Raj,1992 "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.

5. Anderson, D. A., Dongre, R., Christensen, D. W. III, and Dukatz, E. L. 1992 "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.

6. Asphalt Institute Manual Series (1993). Marshall Methods for asphalt concrete and hot mix types. Lexington KY.

7. Berhanu A. Feyissa,2001 Strength Characteristics of Bituminous Concrete With Different Types of Fillers.

8. Brian D. prowell, B.D., Zhang, J., and Brown, E. R.2005 "Aggregate Properties and the Performance of Superpave- Designed Hot Mix Asphalt" NHCRP Report 539, WASHINGTON, D.C.

9. Brown, E.R., McRae, J.L. and Crawley, A.B. (1989).Effects of aggregates on performance of bituminous concrete, implication of aggregates in design, construction and performance of flexible pavement. STP 1016, ASTM, Philadelphia, 34-63.

10. Elliot, R.P.; Ford, M.C.; Ghanim, M.; and Tu, Y.P. (1991). Effect of aggregate gradation variation on Asphalt concrete mix properties. Transportation Research Board, 1317, National Research Council, Washington D.C., USA.

11. Fwa, T. F. and Tan, S. A.1992 "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.

12. Harries, B.M. and Stuart, K.D. (1995). Analysis of mineral fillers and mastics used in stone matrix asphalt. Journal of Association Asphalt Paving Technology.

13. Kandhal, P.S. (1981). Evaluation of bag house fines in Bituminous paving mixture. Proceedings of the Association of Asphalt Paving Technologists, 50:150-210.

14. Kandhal, P.S., C.Y. Lynn, and F. Parker, Jr.1998 Characterization Tests for Mineral Fillers Related to Performance of Asphalt Paving Mixtures. NCAT Report No.98-2. Auburn University, AL., January.

15. Kim, Y.R., Daniel, J.S., and Wen, H. (2002). Fatigue performance evaluation of WesTrack asphalt mixtures using viscoelastic continuum damage approach, Rep. No. FHWA/NC/2002-2004, Federal Highway Administration/North Carolina Dept. of Transportation, Raleigh, NC.

16. Kim, Y. R., Kim, N., and Khosla, N. P.1992 "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.

17. Matthews, J. M. and Monismith, C. L.1992 “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.

18. Mogawer, W.S. and Stuart, K.D. (1996). Effects of mineral fillers on properties of stone matrix asphalt mixtures. Transportation Research Records, 1530, Transportation Research Board, National Research Council, Washington, D.C. USA

19. Ramzi Taha, A. M. ASCE, Amer Al-Rawas, and Ali Al-Harthy; and Ahmed Qatan,2002 Use of Cement Bypass Dust as Filler in asphalt Concrete Mixtires, Journal of Matrials in Civil Engineering / July/August,

20. Ready, J. and Whiteoak, D. (2003). The Shell Bitumen Handbook, Thomas Telford Publishing, London.

21. Roberts F.L., P.S. Kandhal, E.R. Brown, D. Lee, and T. W. Kennedy, 1996 Hot Mix Asphal Materials, Mixture Design, and Construction. Second Edition, National Asphalt Pavement Association, Lanham, MD.

22. Sadoon, O.E. (2010). The influence of filler type on asphalt mastic and performance properties of asphalt paving materials. M.Sc. Thesis, College of Engineering, University of Anbar.

23. Sharrour, A. M., and Saloukeh, G.B.1992 “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.

24. Shuler, T. S., and Huber, G. A.1992 “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,

25. Sofia, G.G. (1986). The effect of dust fines on the properties of asphalt paving mixtures. M.Sc.Thesis, College of Engineering, University of Mosul.

26. **Su**haibani, A.A., and Mudaiheem, J.A. (1992). Effect of filler type and Content on properties of asphalt concrete mixes. ASTM, Philadelphia

27. Tayebali, A.A., Malpass, G.A., and Khosla, N. P. (1998). Effect of mineral filler type and amount on design and performance of asphalt concrete mixtures. Transportation Research Record, 1609 (1), 36-43.

28. Taylor, R. (2007). Surface interaction between mineral fillers and their effects on the rheology of bitumen filler mastics. PhD Thesis, University of Nottingham, UK.

29. The Asphalt Institute, 1993 Construction of Hot Mix asphalt Pavements, MS- 22, Sixth Edition.

30. The Asphalt Institute, 1993 Mix Design Methods for Asphalt Concrete and other Hot Mix Types, MS-2, Sixth Edition.

31. Vavrik, W.R., Pine, W. J., Carpenter, S.H., and Bailey, R. (2002). Bailey method for gradation selection in hot-mix asphalt mixture design. Transportation Research Board, Washington, D.C.

32. Zulkali, A.; Diew, W.Y.; and Detai, D.S. (2012). Effects of fillers on the properties of asphalt concrete mixture. Journal of Transportation Engineering, ASCE, Vol. 138, No. 7, pp. 902-910.