



**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
INSTITUTE OF TECHNOLOGY
COMPARATIVE LABORATORY STUDY ON FLY ASH AND WOOD ASH
AS FILLER MATERIAL IN HOT MIX ASPHALT**

A Thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the Degree of
**MASTERS OF SCIENCE IN CIVIL ENGINEERING
(ROAD AND TRANSPORT ENGINEERING)**

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BY

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Declaration

This thesis is my original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been duly acknowledged.

Candidate's name _____

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Date of submission: June, 2016

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LIST OF ABBREVIATIONS

AACRA	Addis Ababa City Roads Authority
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Content
ACV	Aggregate Crushing Value
ASTM	America Society for Testing and Materials
CBR	California Bearing Ratio
CMA	Cold Mix Asphalt
D10	Particle size at 10 percent passing
D30	Particle size at 30 percent passing
D60	Particle size at 60 percent passing
ERA	Ethiopian Road Authority
ERCC	Ethiopian Road Construction Corporation
Gmb	Bulk specific gravity of the compacted mix
Gmm	Maximum theoretical specific gravity of the mixture
HMA	Hot Mix Asphalt
LAA	Los Angeles Abrasion
MDD	Maximum Dry Density
NP	Non Plastic
OBC	Optimum Binder Content
OFC	Optimum Filler Content
OMC	Optimum Moisture Content
PG	Penetration Grade
SG	Specific Gravity
SGC	Superpave Gyrotory Compactor
SMA	Stone Matrix Asphalt
SP	Softening Point
SSD	Saturated Surface Dry
TMD	Theoretical Maximum Density

Va	Air Void
VFA	Voids Filled with Asphalt
VMA	Voids in the Mineral Aggregate
Vv	Volume of Void
WMA	Warm Mix Asphalt

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ABSTRACT

Mineral fillers have crucial effect on the mechanical property of asphalt concrete pavements. Some of the newly constructed highway pavements in Ethiopia have shown failures with consequential negative impacts on roadway safety, performance and economy. Fillers materials suspected to be one of the major contributors to these failures. This research is focused on the investigation of two types of mineral fillers effects in hot-mix-asphalt performance. The mineral fillers that were used for the study are crushed basaltic rock, fly ash and wood ash with different percentage by total weight of the mixture. A detailed laboratory study was carried out by preparing asphalt mixtures specimens using aggregates and (85/100) grade bitumen collected from Akaki new asphalt plant, and two different types of fillers (wood ash and Fly ash) were tested in the laboratory. Marshall Mix design test was conducted using all types of fillers and different content to evaluate the Marshall properties of different types and filler quantities in the asphalt mixture. Three different trials had been prepared with three filler types at different content.

The results of this study indicate that the traditional filler material (Crushed Basaltic Rock) fulfills all the design requirements at 7.85% filler content. This implies that Crushed Basaltic rock which has being used as a filler material in hot mix asphalt has a good performance in the construction of bituminous pavements in Ethiopia. Similarly comparing of fly ash with Crushed Basaltic rock, it has relative and optimum Marshall Property that fulfills design requirements. Therefore overlooking of the test result of fly ash it has a good Marshall test result as the traditional filler material which indicates it can be used as a substitute filler material in Asphalt paving.

On the other hand wood ash shows inconsistent test results of Marshall Property comparing with other filler materials. Even if higher bitumen content is consumed in the specimens, the VFA value for the wood ash is less compared with the basaltic rock filler and fly ash. Similarly the VMA, Stability and Bulk Density are very low in comparison with the other mineral filler materials. The consistent Marshall Property result for wood ash is the flow which increases its value with the increment of bitumen content. But wood ash at 7.85% and 7% of filler content, it fulfills the design requirements of asphalt pavement construction even if the VFA value is at the lowest margin at 7%. Generally the test result for wood ash entails deep investigation shall be deemed to increase the Marshall Properties in advance to provide durable pavement construction. Considering their cost AC prepared by the Fly ash and Wood ash filler materials have less cost than the traditional filler. But comparing the two new filler types Wood Ash have a higher cost of construction than Fly Ash at 7.85% of filler content since its lesser cost than 7% filler content for both types of the new filler materials.

Therefore this research work is hoped to be used as a basis for future studies about different types of mineral fillers in provision of strong durable bituminous pavements from industrial and household waste materials.

1. INTRODUCTION

Ethiopia is one of the fast economic growing developing countries in the world. Infrastructure like road has a huge contribution for such rapid economic growth of the country by facilitating the transportation system. Currently the Ethiopian government began a sustained effort to improve these infrastructures nationwide since the need of the society to transportation is getting higher and higher currently and in the last decades.

Construction of highway involves huge outlay of investment. A precise engineering design may save considerable investment as well a reliable performance of the in-service highway can be achieved. Two things are of major considerations in flexible pavement engineering—pavement design and the mix design. The present study is related to the mix design considerations using different kinds of fillers. And all filler types can be applicable in the production of bituminous mixture for paving of asphalt concrete roads.

A good design of bituminous mix is expected to result in a mix which is adequately strong, durable, and resistive to fatigue and permanent deformation, environment friendly, economical and so on. A mix designer tries to achieve these requirements through a number of tests on the mix with varied proportions and finalizes with the best one. And that proportion shall be fitted with the Marshall Properties of design requirements in all circumstances.

Pavement systems in Ethiopia are exposed to a multitude of severe environmental factors, mainly the heavy axle load applied on the road, the high traffic and the excessive high temperature. Road usually show excessive failures at an early stage of the pavement life. A major step in the improvement of the existing performance of roads starts with modification of mix design. Fillers fill voids between coarse aggregates in the mixture and alter properties of the binder. The addition of fillers is known to stiffen asphalt. The degree of stiffening is a function of several filler and asphalt properties, which are not well understood.

Therefore deep laboratory studies shall be deemed considering filler materials at different contents with different types to provide a good mix design for strong and economical pavement structure.

1.2. STATEMENT OF THE PROBLEM

Decades have been counted since distress in pavement structures become a chronic problem in the country. The one reason behind this problem is selection of poor filler materials type and content for hot mix asphalt concrete mixture. Mineral filler may increase the stiffness of the asphalt mortar matrix, improving the rutting resistance of pavements. Mineral filler also help reduce the amount of asphalt drain down in the mix during construction which improves durability of the mix by maintaining the amount of asphalt initially used in the mix. Filler type and content have a considerable effect on the bituminous mixture making it act as a much stiffer, and thereby affect the HMA pavement performance including its fracture behavior.

Therefore, application of new filler materials shall be studied to alleviate the existence of poor Marshall Properties in asphalt concrete mix. Strong, durable, resistive to fatigue and permanent deformation, environment friendly and economical pavement construction can be achieved through application of new filler materials in aggregate gradation. Hence a good design of bituminous mixes shall be studied in laboratories for the provision of strong pavement structure that fulfills the contentious transportation demand of the people. And this can be done using industrial and household process wastages such as fly ashes and wood ash as filler material in hot mix asphalt aggregate mixing gradation.

1.3. OBJECTIVES OF THE STUDY

The general aim of this research is to investigate and determine the effect of both filler type and content on mechanical properties of asphalt concrete paving mixture. It aims to study the effects of filler materials (fly ash and wood ash) on asphalt for comparison with the traditional filler (Crushed Basaltic Rock).

Studying the impacts of these filler materials on asphalt mixture performance, it will help in advance to improve the performance of asphalt concrete pavements in the country.

The other scope of this research, it will create an introduction for wood ash to be a new filler material in marshal mix design. And this can imply wood ash will never be a wastage material from its sources which directly relate with the concept of income generation and job opportunity creation for the peoples who will involve in the business.

Based on the above mentioned idea this research will open a new basis to study the logistic system that will be generated due to supply of these filler materials from their sources till the end hot mix asphalt producer.

THE SPECIFIC OBJECTIVE

- To determine the content of Fly ash in HMA aggregate gradation and study the effect on the mechanical properties of asphalt mixtures using marshal mix design method which depends on stability and flow of the mix.
- To determine the content of Wood ash in HMA aggregate gradation and study the effect on the mechanical properties of asphalt mixtures using marshal mix design method which depends on stability and flow of the mix.
- To compare the two filler types with the traditional filler type which has been used in preparation of HMA.
- To evaluate the economy of the asphalt concrete mixture of both fly ash and wood ash fillers with the basaltic rock filler.

2. LITERATURE REVIEW

2.1. TYPES OF ASPHALT CONCRETE

(Hot Mix Asphalt Concrete Pavements, 2003) The HMA is typically applied in 4-8 inch (10.16 - 20.32 cm) thick layers, with the lower layers acting to support the top layer, known as the surface or friction course. The aggregates in the lower layer are chosen to prevent rutting and failure while the aggregates in the surface coarse are chosen for their friction properties and durability. When designing HMA pavement the aggregate used must be strong and durable and have a good angular shape, to help resist rutting. The fine aggregate (mineral filler) is used to fill in the voids between the coarse particles, which increases the density of the asphalt concrete and provides load transfer between the large particles.

The asphalt binder is typically 5 – 6 % of the mixture, and serves to bind the aggregates together. Asphalt binder is a petroleum derivative, though additional materials are often added to modify the properties of the binder.

Asphalt is a viscous liquid or solid, consisting essentially of hydrocarbons and their derivatives, which is soluble in trichloroethylene and is substantially non-volatile and softens gradually when heated. It is black or brown in color and possesses water proofing and adhesive properties. As discussed earlier, it is obtained by refining process from petroleum and is also found as a natural deposit or as component of naturally occurring asphalt, in which it is associated with mineral matter. Asphalt binders are classified (graded) based on their physical properties as measured through testing. The most common asphalt binder classifications are: penetration grade, viscosity grade and performance grade (from super pave). These asphalt grades are what is generally specified in HMA mix design.

(DebashishKar, 2012) have briefly explained different types of asphalt mixes by his research paper called “A laboratory study of bituminous mixes using a natural fiber” which is listed below.

Asphalt concrete is a composite material commonly used in construction projects such as road surfaces, airports and parking lots. It consists of asphalt (used as a binder) and mineral aggregate mixed together, then are laid down in layers and compacted. Mixing of asphalt and aggregate is accomplished in one of several ways:

- **Hot mix asphalt concrete** (commonly abbreviated as HMAC or HMA) is produced by heating the asphalt binder to decrease its viscosity, and drying the aggregate to remove moisture from it prior to mixing. Mixing is generally performed with the aggregate at about 150 °C for virgin asphalt and 166 °C for polymer modified asphalt, and the asphalt cement at 150 °C. Paving and compaction must be performed while the asphalt is sufficiently hot. In many countries paving is restricted to summer months because in winter the compacted base will cool the asphalt too much before it is packed to the optimal air content. HMAC is the form of asphalt concrete most commonly used on highly trafficked pavements such as those on major highways, racetracks and airfields.
- **Warm mix asphalt Concrete** (commonly abbreviated as WMA) is produced by adding zeo-lites waxes, asphalt emulsions, or sometimes even water to the asphalt binder prior to mixing. This allows significantly lower mixing and laying temperatures and results in lower consumption of fossil fuels, thus releasing less carbon dioxide, aerosols and vapors. Not only are working conditions improved, but the lower laying-temperature also leads to more rapid availability of the surface for use, which is important for construction sites with critical time schedules. The usage of these additives in hot mixed asphalt (above) may afford easier compaction and allow cold weather paving or longer hauls.
- **Cold mix asphalt** (commonly abbreviated as CMA) concrete is produced by emulsifying the asphalt in water with (essentially) soap prior to mixing with the aggregate. While in its emulsified state the asphalt is less viscous and the mixture is easy to work and compact. The emulsion will break after enough water evaporates and the cold mix will, ideally, take on the properties of cold HMAC. Cold mix is commonly used as a patching material and on lesser trafficked service roads.
- **Cut-back asphalt concrete** is produced by dissolving the binder in kerosene or another lighter fraction of petroleum prior to mixing with the aggregate. While in its dissolved state the asphalt is less viscous and the mix is easy to work and compact. After the mix is laid down the lighter fraction evaporates. Because of concerns with pollution from the volatile organic compounds in the lighter fraction, cut-back asphalt has been largely replaced by asphalt emulsion.

- **Mastic asphalt concrete** or sheet asphalt is produced by heating hard grade blown bitumen (oxidation) in a green cooker (mixer) until it has become a viscous liquid after which the aggregate mix is then added. Then bitumen aggregate mixture is cooked (matured) for around 6-8 hours and once it is ready the mastic asphalt mixer is transported to the work site where experienced layers empty the mixer and either machine or hand lay the mastic asphalt content on to the road. Mastic asphalt concrete is generally laid to a thickness of around $\frac{3}{4}$ – $1\frac{3}{16}$ inches (20–30 mm) for footpath and road applications and around $\frac{3}{8}$ of an inch (10 mm) for flooring or roof applications. In addition to the asphalt and aggregate, additives, such as polymers, and antistripping agents may be added to improve the properties of the final product.
- **Natural asphalt concrete** can be produced from bituminous rock, found in some parts of the world, where porous sedimentary rock near the surface has been impregnated with upwelling bitumen.

2.2. EFFECTS OF FILLERS IN BITUMINOUS MIXTURE

Many researchers had conducted different studies on the properties of HMA using minor changes on the aggregate gradation and filler content of the mixture. In general the primary aims of the researches were to dig out different filler materials which had a positive impact on the performance of asphalt pavements. Among the various studies conducted, some of them were concerned on investigation of effects of mineral fillers on mechanical characteristics of bituminous mixtures. The filler is the very fine material that passes 0.075mm sieve size which had a significant effect on pavement performance.

The filler plays a major role in the properties and behavior of bituminous paving mixtures (Ilan Ishai, et al, 1980). The mechanical properties of bituminous road pavement depend upon the properties of its filler-bitumen property (S.Huschek, et al, 1980). For modification of asphalt paving materials, the high quality additives are quite expensive for the mass production of bituminous mixtures; a solution to this problem can be obtained by considering the influence of natural mixture ingredients, such as filler (Ilan Ishai, Joseph Craus, 1980). Mineral fillers were originally added to dense-graded HMA paving mixtures to fill the voids in the aggregate skeleton and to reduce the voids in the mixture (Brian D. Prowell, et al, 2005). Filler used in the asphalt mixture are known to

affect the mix design, especially the optimum asphalt content. The term (filler) is often used loosely to designate a material with a particle size distribution smaller than #200 sieve. The filler theory assumes that "the filler serves to fill voids in the mineral aggregate and thereby create dense mix", (I.Abdulwahhab, 1981). Filler particles are beneficial because of increased resistance to displacement resulting from the large area of contact between particles. It was found that fillers increase compactive effects required to compact specimens to the same volume or air void content. This effect becomes more pronounced with increasing concentration of fillers. An early study made by (Clifford Richardson), concluded that the role of the filler was more than void filling, implying that some sort of physical –chemical interaction occurred. Increasing amount in excess of upper limits produced pavements that cracked and checked while being rolled. In warm weather traffic tests, the pavement with excessive filler showed more cracking and checking under load. The cold weather tests showed no detrimental effects resulting from the excessive filler (Ervin L. Dukatz, et al, 1980). It is believed that the filler had a dual role: (a) a portion participates in the particle to particle contact, and (b) the rest floats in the asphalt, forming a high consistency binder. High filler concentration introduced non Newtonian flow behavior. (Ervin L. Dukatz, et al, 1980). The addition of filler to the mixture can improve adhesion and cohesion substantially. The effect of the addition of filler is directly related to their characteristics and the degree of concentration of the filler in the bitumen-filler system. The reduction of filler might cause the reduction of hardening by age and improve the property of flow at low temperature. The function of mineral filler is essentially to stiffen the binder. A higher percentage of very fine filler may stiffen the mixture excessively, making it difficult to work with and resulting in a crack susceptible mixture. According to various studies, the properties of mineral filler especially the material passing 0.075mm (No. 200) sieve (generally called P200 material) have a significant effect on the performance of asphalt paving mixtures in terms of permanent deformation, fatigue cracking, and moisture susceptibility. (Brown, McRae and Crawley, 1989) evaluate the effect of mineral filler, maximum aggregate size, aggregate gradation, crushed particles and stripping tendencies on the performance of asphalt concrete by gathered information from various laboratory and field studies. The authors come up with a conclusion of that the quality and amount of filler greatly affected the asphalt concrete performance. They also stated that uncrushed aggregates such as sands and gravels produce mixtures with lower stability and decreased pavement performance. Their investigation was that additional minus No. 200 material produced a lower optimum asphalt content, a higher stability and

a very sensitive asphalt mixture. Furthermore, some filler is required for stability, but an excessive amount (greater than 6 percent) produced unsatisfactory mixtures. The authors also stated that the maximum aggregate size greatly affected the pavement performance and that larger maximum aggregate sizes produce higher stability, better skid resistance, and lower optimum asphalt contents.

(Herrin and Goetz, 1954) conducted a laboratory evaluation to determine the effect of aggregate shape on the stability of asphalt concrete mixtures. This study focused on crushed and uncrushed gravel, crushed limestone for the coarse aggregate (plus No. 4), and natural sand and crushed limestone sand for the fine aggregate (minus No. 4). The investigation proves that the strength of the mixture, regardless of the type of coarse aggregate, increased substantially when the fine aggregate was changed from rounded sand to crushed limestone. A major finding was that the strength of the asphalt mixture was affected more by a change in fine aggregate shape than a change in the coarse aggregate shape. Similarly (Kalcheff and Tunnicliff, 1982) conducted a laboratory study to determine the effects of crushed aggregate size and shape on properties of asphalt concrete mixtures. Specifically they evaluated the effect of coarse aggregate gradations, shape effects of fine aggregates, and effects of high mineral filler content.

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

Mineral fillers have a deep relation with the asphalt mixture characteristics. A study was made by (Dah-yinn Lee, 1964) to investigate the relationships of asphaltic binder and filler, as expressed in terms of simple, universally adopted tests, were studied. The author Emphasize on the filler particle size which has been included in current specifications and which could be used conveniently in defining the filler. Furthermore, most of the other important properties of filler such as specific surface area, voids, void diameter, degree of compaction, and bulk density are found directly or indirectly related to particle size.

The investigation concludes that:

For all filler-asphalt mastics when the filler content increases:

- Penetration decreases uniformly throughout the filler contents.
- Softening point increases, first slowly, then very rapidly and shows large diversion among fillers.
- Ductility drops, very rapidly up to 10% filler content, and then flattens out.
- Viscosity at all temperatures increases, proportional to filler content up to about 10%, and rapidly and continuously after 40-50% filler.
- Penetration index decreases slightly at first, then increases at different rates continuously throughout the filler content range studied. This means that the temperature susceptibility decreases and the consistency of the mastic increases.
- The softening point changes reflect the viscosity changes in a definite manner.
- For mastics of equal consistency or penetration, those containing softer asphalt and higher proportion of filler have the higher softening point and lower ductility.

For all mastics studied, the penetration and ductility are decreased, and the softening point and viscosity are increased, in addition to the increase of filler content, by the following factors, two or more of them may operate simultaneously:

- Increase in the fineness of the filler or decrease in the particle size of the filler;
- Increase in the consistency of the asphalt; and
- Decrease in the specific gravity of the filler.

It appears that the relationships between the penetration index, ductility, softening point and viscosity of the mastic and the nature and proportion of the filler are most consistent and informative, thus, when very well controlled, they can be best adopted as evaluation tests for filler used in asphaltic paving mixtures.

It is suggested that the function of filler in an asphaltic mix is to increase the viscosity of the binder, reduce the temperature susceptibility and increase the plasticity of the mastic. The end effects on the paving mix are:

- Increases the stability or rigidity of the mix while still allowing it to retain the necessary flexibility;
- Reduces the amount of binder required as a filler of the voids in the aggregate ;
- Enables a softer binder to be used without bleeding in summer and brittle in winter; and
- Gives toughness to the paving mix.

The essential properties of filler used in asphaltic paving mixture can be summarized as:

- To be able to become suspended in the binder, when the latter is in the fluid as well as the semi-solid or solid state.
- To be chemically inert.

With regard to the suspendibility of filler in asphalt, two important properties of the filler should be emphasized: (a) the fineness of the particle, and (b) the specific gravity of the filler. The joint result is: the smaller the particle size, the lower the specific gravity the longer or the more will the particles remain in the suspension.

From the test results that the finer the filler particle, the more effective is the filler! This can readily be seen because (a) the smaller the particle size the greater is its surface-area which provides greater area for adsorption that leads to consistency change (b) the finer the filler particles the greater is their capability of remaining in suspension in the binder.

In relation to specific gravity of the filler, two points of practical importance should be brought up: (a) other properties being equal, the use of low specific gravity filler is more desirable than high specific gravity filler. (b) In specifying the proportion of filler to be used in an asphaltic paving mix, either the amount should be expressed in volume (in addition to fineness) or the quantity in weight should be adjusted according to the specific gravity of the kind of filler to be used.

Another researcher called (Yong-Rak Kim, 2003) studies that the mineral filler increase the stiffness of the asphalt mortar matrix, improving the rutting resistance of pavements. Mineral filler also help reduce the amount of asphalt drain down in the mix during construction which improves durability of the mix by maintaining the amount of asphalt initially used in the mix. The addition of fillers is known to stiffen asphalt.

Also researchers called (R Muniandy*, E Aburkaba and R Taha, 2013) investigates the effectiveness of new filler materials. The main objective of this study was to facilitate decisions

concerning the effectiveness of using new filler types which are byproducts of other industries. The various experimental fillers possessed different particle sizes and were expected to improve the engineering properties of paving mixtures, thereby enhancing pavement performance. The reported improvement in the engineering properties of the paving mixtures containing Ceramic waste filler, Coal fly ash, and Steel sludge filler can be attributed to the bonding and cementation properties of the fillers. These properties tend to increase the viscosity of the filler-asphalt mastic and the texture of the filler particles which consequently increases the frictional resistance among the aggregate particles, increasing the stability of the mix.

From the investigations conducted in this study using different types of fillers with different particle sizes, it can be concluded that

- Filler type and particle size directly affect the engineering properties of the asphalt mixtures.
- In addition to filling the voids, the fillers' components interact with the binder present in the mix, potentially making it stiff and brittle. The change in mix properties is strongly related to the properties of the filler.
- The major finding of this study is that Ceramic waste filler and Steel sludge filler used as filler were found to be effective in improving the Marshall stability, resilient modulus, and Marshall Stiffness index, as compared to Lime stone filler. Coal fly ash had the lowest Optimum asphalt content. It did little to improve the Marshall Stability or resilient modulus value as compared with to reference filler.
- The results of the laboratory tests show that Ceramic waste filler and Steel sludge filler fillers improve the overall mixture properties of asphalt. The use of these special fillers improves pavement performance, thus reducing the maintenance and rehabilitation costs of the pavement.
- It can be concluded that utilization of industrial wastes and byproducts in SMA results in the improvement of the engineering properties and a reduction in the Optimum asphalt content. The reduction in Optimum asphalt content would result in significant cost saving.

2.3. STUDIES ON FILLER EFFECTS

Among different studies made on filler material in our country, researcher (ZemichaelBerheMehari, 2007) studies the effect of mineral fillers in the properties of asphalt concrete and different results were obtained. For mixtures prepared with volcanic crushed rock at higher filler contents (5% - 8%), higher optimum asphalt content values were required to fulfill the Marshal requirements. This is probably due to the fact that there is higher asphalt cement absorption when mixes prepared with volcanic crushed rock. In practice, one of the main objectives in bituminous mix design is to obtain a mixture that satisfies all the criteria provided that it is economical and practical.

However, in this study, mixes with volcanic crushed rock filler requires higher asphalt content that makes them to be costly from practical point of view. Whereas, mixtures prepared with limestone or crushed stone filler, optimum asphalt content are relatively the same. For 2% filler content in the mixture, the effect due to filler type is less. The bulk density increases up to some point and then decreases with increasing filler content in the mixture using crushed stone and volcanic crushed rock. While for mixtures with limestone filler, the bulk density keeps increasing with the filler content.

Stability values of mixes prepared with crushed stone and limestone were found to be increasing up to maximum and then decreasing with the increase in the amount of filler content starting from 4%. Whereas, the stability values of mixes containing volcanic crushed rock keeps increasing with the filler content.

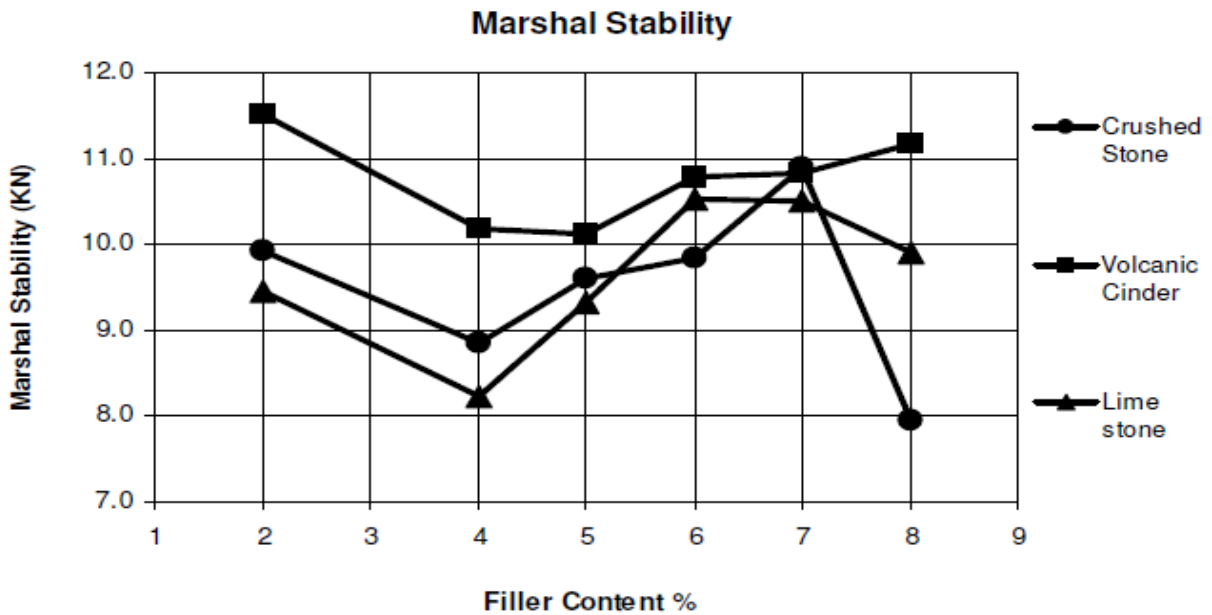


Figure 1 Effect of Filler Content on Marshall Stability (Zemichael Berhe Mehari, 2007)

Higher stability values were obtained from mixtures containing volcanic crushed rock for all filler contents. Mixes prepared with crushed stone provide higher stability values than the mixes containing limestone for all fillers content except 6% and 8%.

The voids in mineral aggregate values obtained indicate relatively similar decreasing trend despite of the filler type used. Voids filled with asphalt (VFA) values of mixtures using 2% of all types of mineral fillers and 4% of crushed stone were found to be higher than the maximum value of Marshall Criteria.

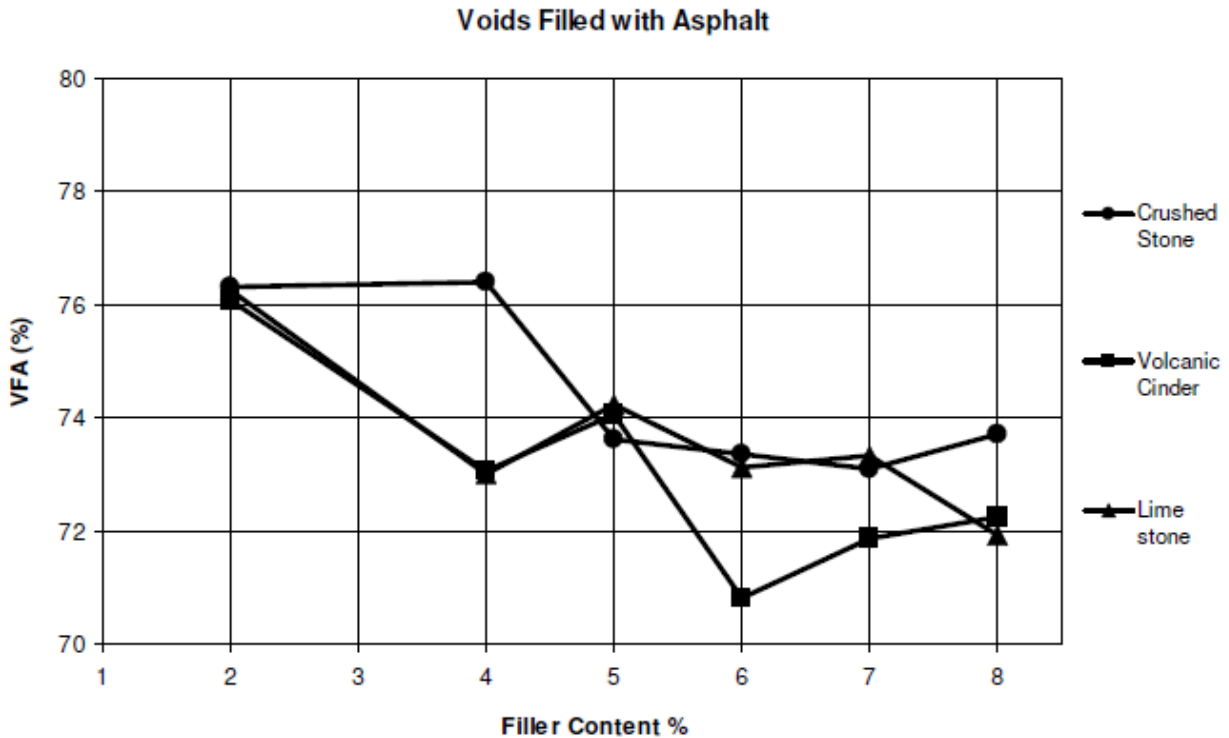


Figure 2 Effect of Filler Content on VFA (Zemichael Berhe Mehari, 2007)

The effective asphalt content in the mix provides the required film thickness around the aggregate particles. It is the available film thickness that determines flexibility and durability of mixtures. Mixes made with volcanic crushed rock have lower effective asphalt content as compared to mixes containing limestone and crushed stone fillers. Thus, mixtures containing volcanic crushed rock have lower film thickness around aggregate particles than mixes containing either limestone or crushed stone fillers and may be less durable.

The dynamic modulus values increases with the fillers content for all mixtures. Higher retained stability values were obtained from mixtures prepared with limestone and volcanic crushed rock as compared to crushed stone.

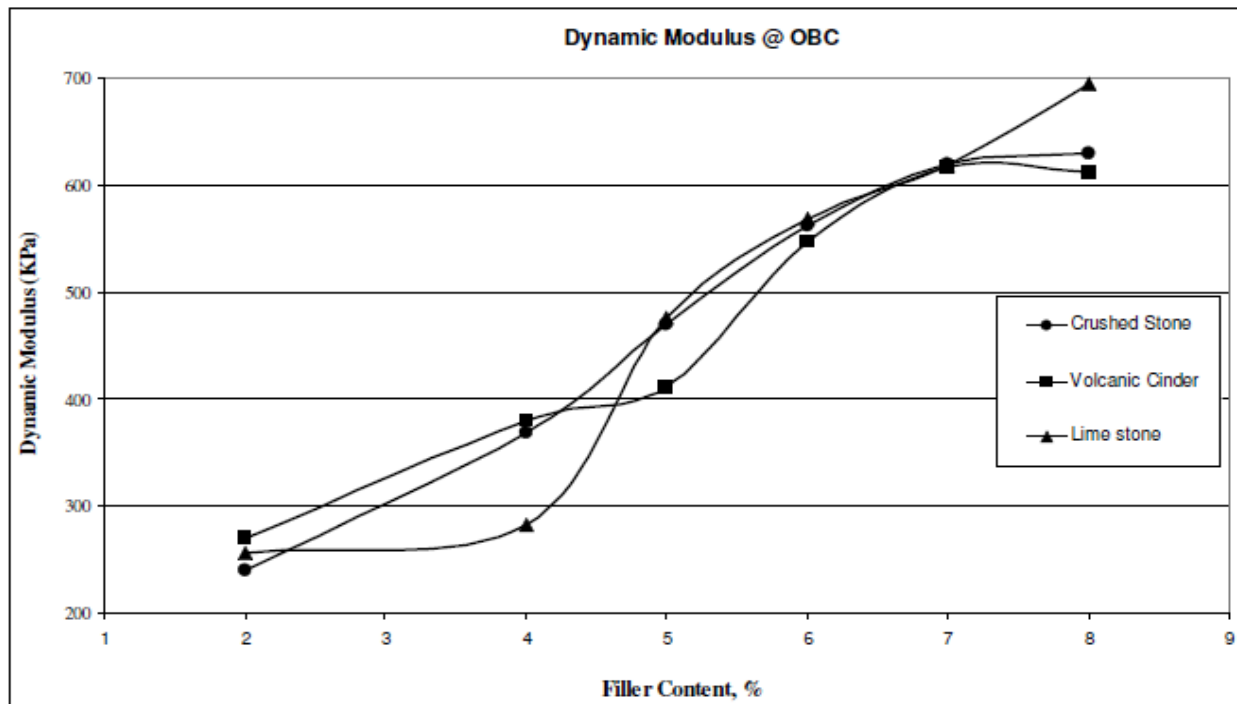


Figure 3 Effect of Filler Content on Dynamic Modulus (Zemichael Berhe Mehari, 2007)

From this study, the test results obtained from mixes with limestone have relatively similar trend with that of using crushed stone fillers as compared to mixes with volcanic crushed rock. Besides, better stability was obtained from mixes using crushed stone when compared to limestone fillers. As a result, this shows us that limestone fillers can be used as alternative filler type in bituminous mixtures to the widely used crushed stone. However, this study is limited when considering the tests conducted and even not verified in the field. Therefore, further investigation is important in the subject matter so as to characterize limestone filler in relation with mixture properties not only in the laboratory but also in the field.

The statistical data analysis indicated that there exists relationship between the filler properties and mixture test results. In most cases, the gradation parameters such as D10, D30 and D60 have more correlation with the properties of asphalt concrete. D10 and fineness modulus have high correlation with the moisture susceptibility values. D60 and fineness modulus have better relationship with the effective asphalt content results.

(Berhanu A. Feyisa, 2001) conducted Marshal Stability tests on bituminous mixes with 60/70 grade bitumen and mineral fillers such as stone filler, marble, and limestone. Generally, Marshal Stability values of all mixes were improved with addition of fillers. This attributes to the fact that lower air voids can be achieved as filler content in the mix increases. The conclusions made in the study were:

- The content of fillers in the mixture have greater influence on determination of optimum asphalt content and strength where, better results could be found in a range of 5 - 7.5 percent filler content.
- Higher values of stability and modulus of elasticity was achieved by mixes prepared using marble filler as compared to lime and stone filler.
- From the low temperature tensile strength test, higher values were exhibited by mixes prepared using marble filler. This shows better performance can be achieved by using marble filler in paving mixtures when compared to others.

Similarly a study carried out by (Shahrour and Saloukeh, 1992) to evaluate the effects of different types and quantity of mineral fillers on asphalt mixtures. The authors have pointed out that, different types of mineral fillers result different stiffening effect on asphalt binder. At higher field temperatures, the deformation behavior of asphalt pavement becomes critical. For this reason, the highest possible viscosity for the filler-bitumen mixture is desirable because this has a favorable influence upon the deformation resistance of the pavement. Thus, at a certain temperature an increase in the viscosity can be achieved either with more filler or with the use of effective filler. In this study, the Marshal parameters were not significantly affected by changing the type of filler at specific filler contents. However, the type of filler significantly affected the filler-bitumen properties by stiffening the binder to different degrees. It was also indicated that hydrated lime filler has shown superior stiffening properties when mixed with the binder compared to all other filler types.

Considering all the studies performed on mineral fillers, it's possible to generalize that the effect of mineral fillers on asphalt pavement performance is huge. The performance of asphalt surface roads is directly affected by the quality of the asphalt concrete. Therefore deep studies shall be conducted for a better and durable provision of asphalt pavements to the society.

2.4. VOLUMETRIC PROPERTIES

In HMA mixture volumetric properties are the one which shall be determined to create sufficient performance for the pavement. Different researchers studied the effect of mineral fillers on the volumetric property of bituminous mixtures. Most of all concluded that mineral fillers have a strong relation with the overall volumetric property of HMA mixture.

Among them (Vivian Silveira dos Santos B., José Leomar F., Luis Miguel Gutiérrez K., 2013) studies that HMA volumetric properties are necessary requirements to ensure a good performance, and these properties are directly influenced by the mixture grading, aggregates surface characteristics and compaction energy. The research also evaluated the mineral filler influence on the volumetric properties of HMA, the Voids in Mineral Aggregates (VMA) and Voids Filled with Asphalt (VFA). During the procedure the researcher first prepare HMA specimen with an asphalt binder of 60/70 (0.1mm) penetration, varying mineral aggregate (basalt and granite), filler type (hydrated lime, Portland cement, limestone and silica) and filler content (6%, 9% and 12 % in the HMA grading). The results showed that, HMA with 4% of Air Voids, the VMA and the VFA decreases when the filler content increases and is dependent on filler content. Also, it was noted that the optimum asphalt binder content increases as the filler in the HMA content increases and it is greatly influenced by the filler type.

(Roberts, F. L.; Kandhal, P.S.; Brown, E.R.; Lee, D.Y.; Kennedy, T.W., 1991)conduct a study on Marshall and Super pave methods, determine the optimum asphalt binder using HMA volumetric properties (Vv, VMA and VFA). The Super pave method also evaluates the filler content in the mixture and the percentages of initial and maximum compaction as a function of the number of gyrations in the Super pave Gyrotory Compactor (SGC).

They found that the mixture should be formed by aggregates sizes, shapes, angularity and surface textures that allow enough space for the addition of the adequate amount of asphalt to ensure durability and flexibility of the mixture.

The Super pave method suggests the volumetric parameters of Vv, VMA and VFA to design of asphalt mixtures. It is established a Vv of 4% as the main parameter to select the optimum asphalt binder content. Excessive Vv or VFA and inadequate VMA suggest potential durability problems.

And this all volumetric parameters are highly influenced by the content of mineral fillers in the overall aggregate gradation.

Also (Nathem A .H. AL- Saffar, 2013) conduct different experiments to relate mineral fillers content with volumetric and performance parameters of asphalt mixture. The researcher summarizes the theoretical and experimental results of the study as follow:

- Adding glass powder of 6 % by total weight of aggregates on the hot asphalt concrete mixtures leading to increase the Marshall stability by 15.5 % and 9.2 % compared with ordinary Portland cement and lime stone powder respectively. While, the Flow decreases by 14.5 %, and increased by 4.4 % compared with ordinary Portland cement and lime stone powder respectively.
- Adding glass powder of 8 % by total weight of aggregates on the hot asphalt concrete mixtures leading to increase the Marshall stability by 11.7 % and 14.3 % compared with ordinary Portland cement and lime stone powder respectively. While, the Flow decreased by 21.6% and 44.3% compared with ordinary Portland cement and lime stone powder respectively.
- The(VTM) and (V.M.A) decreased as the percentage of ordinary Portland cement and lime stone powder increase, and (V.F.A)increased as the percentage of glass powder decreased.

Based on the different studies made by different researchers, it's clear to see that type and content of mineral fillers had a high effect on the volumetric parameters of bituminous mixes

3. RESEARCH METHODOLOGY

The methodology employed for this research ensures the alignment of the result with the objective of the study. This study involves collecting of materials for the preparation of bituminous mixtures. The materials used in the mixture includes: coarse and fine aggregates, two types of mineral fillers, and asphalt binder.

3.1. SCOPE

The study area selected for this research is only the aggregate gradation part which is focused on filler type and content determination in HMA marshal mix design preparation. The two filler types that will be investigated in this research are fly ash and wood ash as a substitute for the Basaltic Rock Filler in paving of asphalt concrete.

3.2. STUDY DESIGN

To conduct the studies of the research effectively, a well-organized design is shaped step by step for a successful result. Based on that to limit the scope of the study, the subjects are defined before sampling of all input material for the laboratory tests. After sampling of materials, sample size shall be determined enough to get the final output.

This all processes will lead us to the beginning of testing of materials collected from their quarries to prepare the HMA specimens. And after preparation of the HMA mixes, Marshall Design requirements criteria shall be meet by the specification. The trials will be repeated with different filler content of the design requirements are not meet. Finally, comparison of the two filler types (Fly Ash and Wood Ash) will be checked.

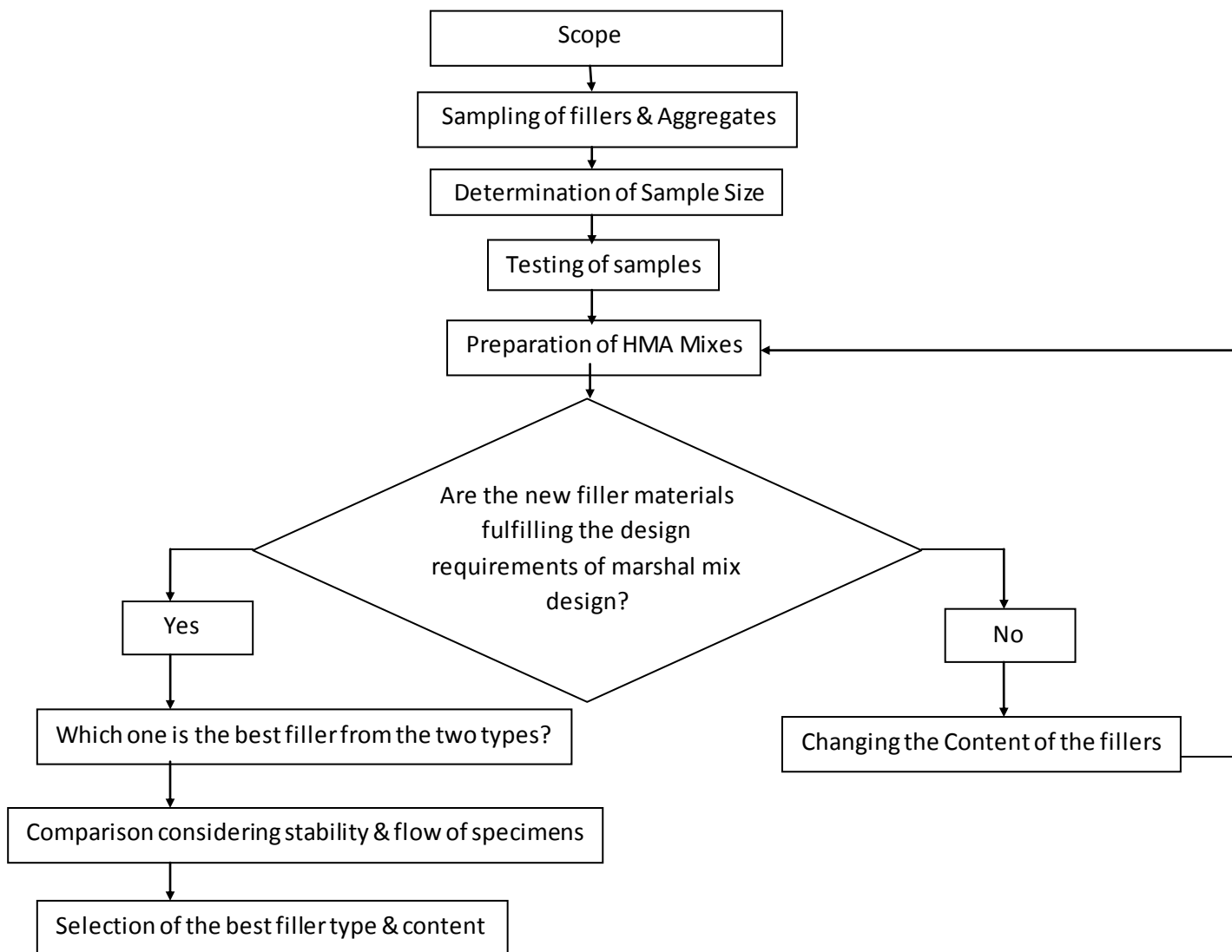


Figure 4 Study design of research

3.3. DATA COLLECTION TECHNIQUES

Different types of data collected for the purpose of accomplishing this research. The sources of the data are primary and secondary sources. The primary data include aggregate bitumen and filler collection from their sources. The secondary data will be collected through interviews made with experienced material engineers and laboratory technicians who had analyze the effect of fillers in marshal mix design.

3.4. DATA COLLECTION

To attain the objective of this research, different types of quantitative data namely aggregate, fillers and bitumen are collected.

3.4.1. *FILLERS*

There are two types of fillers selected which are the main reason to conduct this research. These fillers are wood ash and fly ash. Wood ash will be collected from households and fly ash will be collected from beauty spas which use coal for sauna bath.



Figure 5 Wood Ash Source



Figure 6 Coal Fly Ash

3.4.2. AGGREGATES

Aggregates for HMA are usually classified by size as coarse aggregates, fine aggregates, or mineral fillers. ASTM defines coarse aggregates as particles retained on No.4 (4.75 mm) sieve, fine aggregate as that passing a No.4 sieve (4.75 mm), and mineral filler as material with at least 70 percent passing the No. 200 (75 micrometer) sieve. For this research, aggregates collected from the AACRA quarry site found at Akaki Kality. Forty kilograms of fine aggregates, intermediate aggregates and coarse aggregates are taken with two bags for each size which is a total of 80 kilograms are collected based on their size.



Figure 7 Course Aggregate



Figure 8 Intermediate Aggregate



Figure 9 Fine Aggregate

3.4.3. BITUMEN

Bitumen type selection was based on current AACRA source for asphalt production. They have used penetration of 85/100 bitumen grade for the production of HMA. Therefore for this research 85/100 PG bitumen collected from AACRA Akaki asphalt production new plant which is the same site where the aggregates collected.



Figure 10 Akaki Asphalt Plant Production Site



Figure 11 Akaki Asphalt Storage Tank

3.5. SAMPLING

In conducting this research a different materials had been sampled from different sources which could help as an input for the laboratory tests.

3.5.1. *FILLERS*

Among the ingredients for preparation of HMA, filler materials are the backbone of this research. Therefore 5 Kilograms of Fly ash and 2killogrames of wood ash are collected from their source and stored in laboratory.

3.5.2. *BITUMEN*

In construction of Asphalt pavement bitumen is the crucial and expensive material in our country since it's imported. Considering these 20 liters of bitumen had sampled from the quarry site I have been referred and permitted to collect the bitumen by AACRA bureau.

3.5.3. AGGREGATES

The best aggregate gradation is the one that have the maximum gradation density. Based on that, three different sizes of aggregates had sampled from the stockpiled production at the quarry site. Each aggregate weigh 80 kilograms to prepare the necessary specimens.

3.6. SAMPLING SIZE

In conducting this research the sample size shall be quantified enough to execute the necessary trials in fulfilling the Marshall property design requirements for all filler types. Based on that, three types of fillers are selected. Using those 45 HMA specimens will be prepared in first trial to determine the optimum filler and bitumen content. The controlled variable will be the traditional HMA specimen with fine material collected from the quarry site in which 15 specimen can be produced for a single trial. While the other 30 specimens are prepared by using wood ash and fly ash as a filler material which is 15 specimens for each. If the first trial specimens shows less flow and stability result from the design requirements, a second trial will be prepare with different filler content which is 30 specimens preparation for the trial. And the trial will continue to the third one if the result doesn't fulfill a design requirement that implies a total of 105 specimens will be prepared to complete the research.

3.7. LABORATORY TESTS

The Marshall Mix design method consists of the following basic steps

- Aggregate selection
- Asphalt binder selection
- Sample preparation (including compaction)
- Stability determination using the Marshall Stability and flow test
- Volumetric calculations.
- Finally the required Optimum asphalt binder content selection from 4% air void is calculated.

3.7.1. AGGREGATE SELECTION AND EVALUATION

A typical aggregate evaluation for use with Marshall Mix Design methods includes three basic steps

- Determine Aggregate Physical Properties.
- Determine Other Aggregate Descriptive Physical Properties
- Perform Blending Calculations To Achieve The Mix Design Aggregate Gradation

- DETERMINE AGGREGATE PHYSICAL PROPERTIES: - Consists operation of various tests to determine properties such as:
 - TOUGHNESS AND ABRASION

In order to know the resistance to degradation of small-size coarse aggregate by abrasion and impact we conduct LAA (Los Angles Abrasion) and ACV (Aggregate crushing value) test.

- LAA

I. Purpose: The test is to determine the ability of coarse aggregate smaller than 37.5mm (1-1/2") and retained on 1.7mm to resist abrasion, using the Los Angeles Testing Equipment.

II. Computations and Data Collection: Calculate the difference between the original sample weight and that retained on the 1.7mm (No.12) sieve. Express that value as a percentage of the original sample weight. This value is considered as the percentage of wear.

- DURABILITY AND SOUNDNESS
- CLEANLINESS AND DELETERIOUS MATERIALS
- PARTICLE SHAPE AND SURFACE TEXTURE

To know the particle shape and surface texture the main test we carried out in the laboratory is Flakiness and Elongation test. The Purpose of these tests is for the determination of the percentages of flat or elongated particles in coarse aggregates.

- DETERMINE OTHER AGGREGATE DESCRIPTIVE PHYSICAL PROPERTIES

If the aggregate is acceptable according to step one, additional tests are run to fully characterize the aggregate. These tests determine:

- GRADATION AND SIZE

Sieve Analysis of Fine and Coarse Aggregates

Purpose: Determination of the particle size distribution of fine and coarse aggregates by sieving.

Computations:

- Sieve Analysis for Fine and Coarse Aggregate,
- Calculate percentages on the basis of the total weight of the sample.
- Compute the percent of material retained on each sieve and the per cent of material finer than for each sieve size for both the coarse and the fine aggregates.

- SPECIFIC GRAVITY AND ABSORPTION

Purpose: Determine the bulk, apparent, and effective specific gravities, and absorption of coarse and fine aggregates. Absorption is the process by which water is drawn into and tends to fill the permeable pores in a porous solid body. The effective specific gravity was determined since the absorption of asphalt cement is an important factor in asphalt mixtures.

i. Coarse Aggregate: -it is the aggregate most of which is retained 4.75mm sieve and contains only so much finer as is permitted by specification.

Computations

A = weight of oven-dry sample in air, grams

B = weight of saturated-surface-dry sample in air, grams

C = weight of saturated sample in water, grams

a. Bulk Specific Gravity = $A / (B - C)$

b. Apparent Specific Gravity = $A / (A - C)$

c. Absorption in Percent = $\{(B - A) \times 100\} / A$

ii. Fine Aggregate: - it is the aggregate most of which passes 4.75mm sieve and contains only so much coarser as is permitted by specification.

Computations:

A = weight of oven-dry sample in air, grams

B = weight of pycnometer filled with water, grams

C = weight of pycnometer with sample and water, grams

a) Bulk Specific Gravity = $A / \{B + 500 - C\}$

b) Apparent Specific Gravity = $A / \{B - C + A\}$

c) Absorption, Percent = $\{(500 - A) \times 100\} / A$

PERFORM BLENDING CALCULATIONS TO ACHIEVE THE MIX DESIGN AGGREGATE GRADATION

Often, aggregates from more than one source or stockpile are used to obtain the final aggregate gradation used in a mix design. Trial blends of these different gradations are usually calculated until an acceptable final mix design gradation is achieved.

Typical considerations for a trial blend include:-

- All gradation specifications must be met. Typical specifications will require the percent retained by weight on particular sieve sizes to be within a certain band.
- The gradation should not be blend in a way to decrease the VMA percentage very much.

3.7.2. BITUMEN EVALUATION

Rheology is a science which deals about deformation and flow of matter. In this case Asphalt which is the main constituent of HMA, Deformation and flow of the asphalt binder in HMA is important in determining HMA pavement performance. HMA pavements that deform and flow too much may be susceptible to rutting and bleeding, while those that are too stiff may be susceptible to fatigue or thermal cracking. HMA pavement deformation is closely related to asphalt binder rheology. Since the rheological properties of asphalt binder vary with temperature, rheological characterization involves two key considerations:

- To compare different asphalt binders, their rheological properties must be measured at some common reference temperature.
- To fully characterize an asphalt binder, its rheological properties must be examined over the range of temperatures that it may encounter during its life.

The penetration grade selected for this project is 85/100 in which the AACRA uses for production of asphalt at quarry sites. Since the temperature of Addis Ababa is not high causes the viscosity of

the bitumen to increase and this increase in *viscosity* will further imply the increase in the *stiffness* of the bitumen. Bleeding and deformation will not be major effects. So by selecting this appropriate penetration grade of bitumen to be 85/100 we can minimize the effects of temperature so in our case the grade is 91.



Figure 12 Penetration test

3.7.3. SAMPLE PREPARATION (INCLUDING COMPACTION)

For these research 15 blends with 3 filler samples each for a total of 45 specimens, each with different asphalt binder content prepared on first trial. Then, by evaluating each trial blend's Marshall Properties, optimum asphalt binder content can be selected. In order for this concept to work, the trial blends must contain a range of asphalt contents from the minimum to the maximum optimum asphalt content which is 4 – 6 percent. Therefore, the first step in sample preparation is to *estimate optimum asphalt content*. Trial blend asphalt contents are then determined from this estimate.



Figure 13 Trial optimum Asphalt sample

3.7.4. COMPACTION WITH MARSHALL HAMMER

Each sample is then heated to the anticipated compaction temperature and compacted with a Marshall hammer, a device that applies pressure to a sample through a tamper foot (see Figure 14). Some hammers are automatic and some are hand operated. Since this research laboratory test is done in core consulting the Marshall hammer is automatic.



Figure 14 Marshall Hammer

3.7.5. MARSHALL STABILITY AND FLOW TEST

The Marshall Stability and flow test provides the performance prediction measure for the Marshall Mix design method. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute (2 inches/minute). Basically, the load is increased until it reaches a maximum then when the load just begins to decrease, the loading is stopped and the maximum load is recorded.

During the loading, an attached dial gauge measures the specimen's plastic flow as a result of the loading (see Figure 15). The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time the maximum load is recorded.



Figure 15 Marshall Stability and Flow Test Equipment

3.7.6. DENSITY AND AIR VOIDS

All mix design methods use density and voids to determine basic HMA physical characteristics. Two different measures of densities are typically taken:

i. BULK SPECIFIC GRAVITY (GMB)

It is calculated as the ratio of the mass in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the mass in air (of equal density) of an equal volume of gas-free distilled water at a stated temperature.

ii. THEORETICAL MAXIMUM SPECIFIC GRAVITY (GMM)

The ratio of the mass of a given volume of void less ($V_a = 0$) HMA at a stated temperature (usually 25°C) to a mass of an equal volume of gas-free distilled water at the same temperature.

These densities are then used to calculate the volumetric parameters of the HMA.

iii. AIR VOIDS (VA), SOMETIMES EXPRESSED AS VOIDS IN THE TOTAL MIX (VTM)

The total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture. The amount of air voids in a mixture is extremely important and closely related to stability and durability.

iv. VOIDS IN THE MINERAL AGGREGATE (VMA)

The volume of inter granular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume of the specimen. When VMA is too low, there is not enough room in the mixture to add sufficient asphalt binder to adequately coat the individual aggregate particles. Also, mixes with a low VMA are more sensitive to small changes in asphalt binder content. Excessive VMA will cause unacceptably low mixture stability therefore a minimum VMA is specified and a maximum VMA may or may not be specified.

v. VOIDS FILLED WITH ASPHALT (VFA)

The portion of the void in the mineral aggregate that contain asphalt binder. This represents the volume of the effective asphalt content. It can also be described as the percent of the volume of the VMA that is filled with asphalt cement. VFA is inversely related to air voids: as air voids decrease, the VFA increases.

3.7.7. SELECTION OF OPTIMUM BINDER CONTENT

The optimum asphalt binder content is finally selected based on the combined results of Marshall Stability and flow, density analysis and void analysis). Optimum asphalt binder content can be arrived at in the following procedure.

Plot the following graphs:

- Asphalt binder content vs. density. Density will generally increase with increasing asphalt content, reach a maximum, and then decrease. Peak density usually occurs at higher asphalt binder content than peak stability.
- Asphalt binder content vs. Marshall Stability. This should follow one of two trends:
 - Stability increases with increasing asphalt binder content, reaches a peak, then decreases.
 - Stability decreases with increasing asphalt binder content and does not show a peak. This curve is common for some recycled HMA mixtures.
- Asphalt binder content vs. flow. Flow should be increase with increasing asphalt binder content.

- Asphalt binder content vs. air voids. Percent air voids should decrease with increasing asphalt binder content.
- Asphalt binder content vs. VMA. Percent VMA should decrease with increasing asphalt binder content, reach a minimum, and then increase.
- Asphalt binder content vs. VFA. Percent VFA increases with asphalt binder content.

Above all the main step we have to do to know the optimum binder content is to follow the following crucial steps.

- I. Determine the asphalt binder content that corresponds to the specifications median 4 percent air void content, maximum stability and maximum density. The average of the three values is the optimum asphalt binder content.
- II. Determine properties at this optimum asphalt binder content by referring to the plots. Compare each of these values against specification values and if all are within specification, then the preceding optimum asphalt binder content is satisfactory. Otherwise, if any of these properties are outside the specification range the mixture should be redesigned by changing filler content.

4. LABORATORY TEST RESULTS AND DISCUSSIONS

4.1. AGGREGATE SELECTION

4.1.1. DETERMINE AGGREGATE PHYSICAL PROPERTIES

From the Laboratory results we get the following data:-

Table 1 Aggregate Physical Property

Coarse aggregate	No	AASH TO T-104 Soundness loss magnesium	BS 812 Part 111 TFV, Wet (KN)	BS 812 Part 111 TFV, Dry (KN)	AASHTO T-96 LAA (%)	BS 812 Part 110 ACV (%)	AASHTO T-96 Coating and Stripping	BS 812 Part 105.1 Flakiness Index (%)	AASH TO T-90 PI (MAX)	AASHTO T-84 Specific Gravity	AASHTO T-85 Water Absorption (%)
	1	1.3	297.9	355	15.4	11.8	>95	33	NP	2.627	1.2
	Spec. limit	1-2	-	-	10-17	Max -30	Min-95	Max-40	-	-	Max-2
Fine Aggregate	No	Specific Gravity of Filler		AASH TO T-84 Specific Gravity Oven-dry	AASHTO T-85 Bulk Specific Gravity						
	1	-	2.697	2.697							

4.1.2. DETERMINATION OF GRADATION AND SIZE

After determination of physical property of the aggregates and gradation, blending calculation will be done to meet specification requirement of gradation for wearing course from Asphalt Institute Standards. Based on that, Table 2 found below states the percentage passing of aggregate at each sieve size with the specification limit.

Table 2 Aggregate Gradation

No	Sieve Size (mm)	Sample no-1	Sample no-2	Sample no-3	Specification Limit (Asphalt Institute 1997)
		Aggregate No 1 (%)	Aggregate No 2 (%)	Aggregate No 3 (%)	
1	37.50	100	100	100	100
2	25.00	100	100	92.2	90-100
3	19.00	100	100	80.3	71-95
4	12.50	100	99.7	61.2	-
5	9.50	99.7	99.3	40	56-80
6	4.75	78.7	29.2	1.8	35-65
7	2.36	55.8	18.6	1.3	23-49
8	1.180	41.2	14.4	1.3	-
9	0.60	29.7	11.4	1.2	14-27
10	0.300	21.9	9.4	1.2	5-19
11	0.150	17.3	8.2	1.2	-
12	0.075	14.8	7.5	1.2	2_8

Based on the existing percentage passing, blending calculation will be done to meet the specification limit band. Table 3 shown below clearly states the percentage blending of the three types of aggregated to meet the specification.

Table 3 Aggregate blending trial#3

Determine Aggregate Proportions to meet Specification Requirements									
Trial No 3									
	Sieve Size (mm)	Aggregate No 1 (%)		Aggregate No 2 (%)		Aggregate No 3 (%)		Total Blend	Specification Limit
			Blend 35%		Blend 30%		Blend 35%		
1	37.50	100	35	100	30	100	35	100	100
2	25.00	100	35	100	30	92.2	32.27	97.27	90-100
3	19.00	100	35	100	30	80.3	28.105	93.105	71-95
4	12.50	100	35	99.7	29.91	61.2	21.42	86.33	-
5	9.50	99.7	34.895	99.3	29.79	40	14	78.685	56-80
6	4.75	78.7	27.545	29.2	8.76	1.8	0.63	36.935	35-65
7	2.36	55.8	19.53	18.6	5.58	1.3	0.455	25.565	23-49
8	1.180	41.2	14.42	14.4	4.32	1.3	0.455	19.195	-
9	0.60	29.7	10.395	11.4	3.42	1.2	0.42	14.235	14-27
10	0.300	21.9	7.665	9.4	2.82	1.2	0.42	10.905	5-19
11	0.150	17.3	6.055	8.2	2.46	1.2	0.42	8.935	8-15
12	0.075	14.8	5.18	7.5	2.25	1.2	0.42	7.85	2-8

As you have seen it, 35% of coarse aggregate, 30% of intermediate aggregate and 35% of fine aggregate blending can meet the specification limit. Therefore from the total blend of percentage of passing, Table 4 below describes the gram required to mould a single HMA specimen for each sieve.

Table 4 Total weight of mass required to mould single specimen (Trial No.1)

No	Sieve Size (mm)	% Pass	% Retain	Weight Required in Size (gm)
		Pass in %	Pass in %	
1	37.50	100	0	
2	25.00	97.27	2.73	32.76
3	19.00	93.105	4.165	49.98
4	12.50	86.33	6.775	81.3
5	9.50	78.685	7.645	91.74
6	4.75	36.935	41.75	501
7	2.36	25.565	11.37	136.44
8	1.180	19.195	6.37	76.44
9	0.60	14.235	4.96	59.52
10	0.300	10.905	3.33	40.0
11	0.150	8.935	1.97	23.6
12	0.075	7.85	1.085	13.0
Filler			7.85	94.2
		Single Specimen gram		1200

From table4 it is shown that 94.2 gm of filler material required to prepare a single HMA specimen. Note that the percentage of filler content for this trial is 7.85%.

Typical specifications will require the percent pass by weight on particular sieve sizes to be within a certain band as shown below.

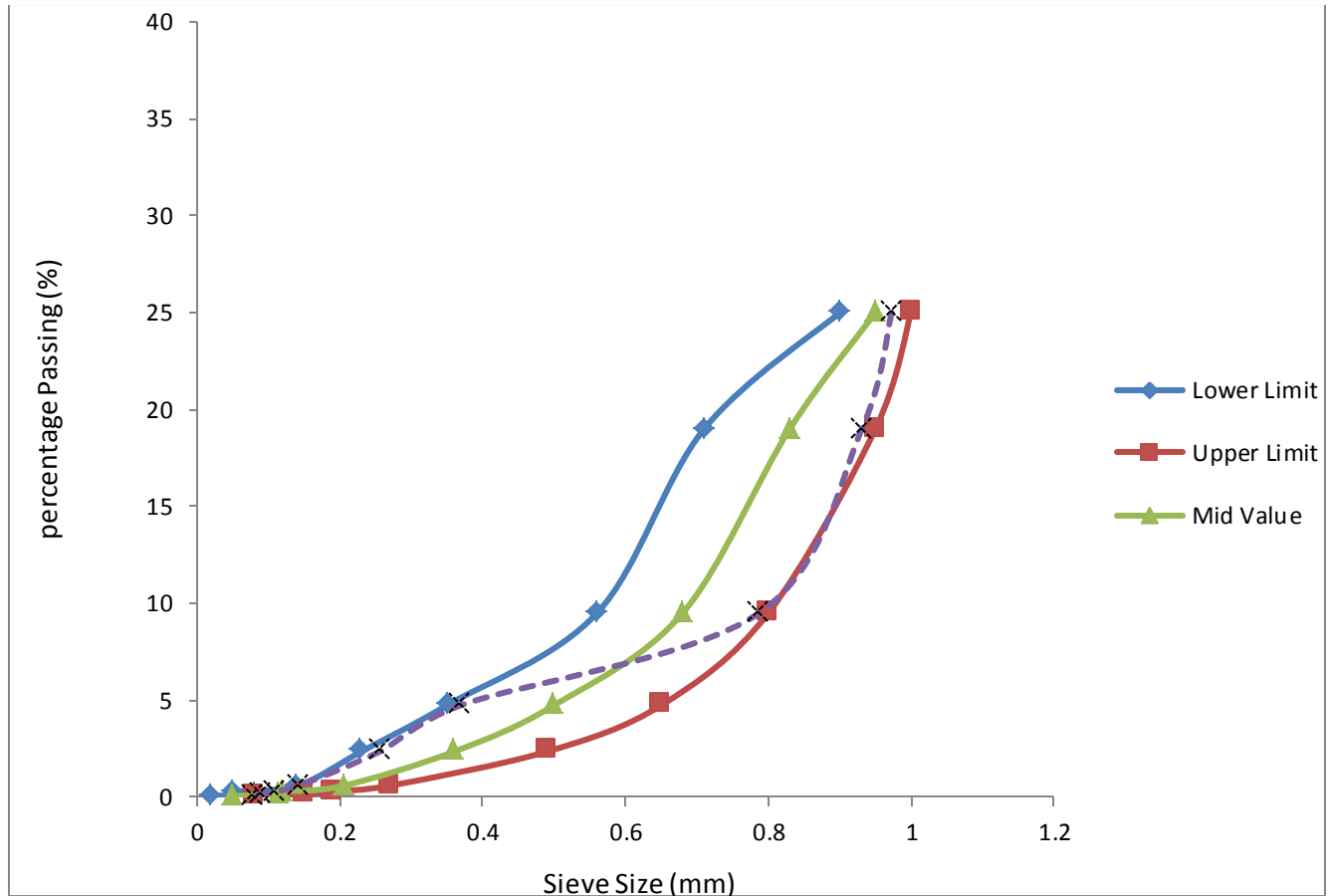


Figure 16 Limit for combined aggregate proportion

From Figure 16 it's possible to say that the gradation of aggregate is in the middle of the upper and lower values of the specifications. But it's difficult to say that the gradation is well graded because it almost touches upper and lower boundaries at some sieves.

4.2. BITUMEN TEST RESULT

The blended aggregate was heated to a temperature of 176.67°C and asphalt binder was heated to a temperature of 150 °C. The result shows a penetration grade of 91 which is in the range of 85-100.

Table 5 Bitumen Test Result

No	AASHTO T - 44 Solubility in Trichloroethylene (%)	AASHTO T - 47 Loss on Heating (%)	AASHTO T - 48 Flash point °C	AASHTO T - 49 Penetration at 25 °C, 100g, 5sec	AASHTO T - 51 Ductility at 25 °C, (cm)	Ductility of Residue, cm	AASHTO T - 53 Softening °C	AASHTO T 228-06 SPECIFIC GRAVITY at 25 °C, (kg/m ³)
1	99.9	-0.3	220	91	100+	100+	48	1011

4.3. MARSHAL PROPERTIES

4.3.1. FIRST TRIAL TEST RESULT

Based on the three tables shown below, all filler types show the same Marshall Property characteristics relation in the range of bitumen content values. When the bitumen content increases, the air void, VMA, and stability decreases in reverse the VFA, unit weight and flow increases. In comparison with the design requirements, all filler types fulfill the specification limits at 7.85% of filler content. But the wood ash shows less value of VMA, VFA, unit weight and stability. And this implies further amendment of mix design with different filler content.

Table 6 Marshall Test result trial No.1 (Crushed Basaltic Rock)

% AC by weight of total mix	Air Void	% V.M.A	% V.F.A	Unit Weight (mg/m ²)	Stability (KN)	Flow (mm)
4.00	9.19	18.53	50.40	2411.9	13.10	2.42
4.50	7.23	18.26	60.41	2432.4	12.05	2.51
5.00	5.25	18.03	70.87	2452.1	11.03	2.61
5.50	2.84	17.81	84.04	2472	10.01	2.71
6.00	1.11	17.57	93.70	2492	8.99	2.81

Table 7 Marshall Test result trial No.1 (Fly Ash)

% AC by weight of total mix	Air Void	% V.M.A	% V.F.A	Unit Weight (mg/m ²)	Stability (KN)	Flow (mm)
4.00	8.50	17.45	51.28	2400.0	12.98	1.82
4.50	6.53	17.19	62.04	2420.0	11.95	2.02
5.00	4.51	16.95	73.42	2439.9	10.95	2.22
5.50	2.41	16.70	85.57	2460	9.93	2.42
6.00	0.28	16.47	98.30	2480	8.95	2.62

Table 8 Marshall Test result trial No.1 (Wood Ash)

% AC by weight of total mix	Air Void	% V.M.A	% V.F.A	Unit Weight (mg/m ²)	Stability (KN)	Flow (mm)
4.00	9.56	16.01	40.29	2360.5	11.26	1.90
4.50	6.99	14.97	53.32	2402.2	10.36	2.02
5.00	5.63	14.87	62.14	2417.8	9.35	2.26
5.50	4.01	14.67	72.68	2436	8.47	2.68
6.00	2.04	14.20	85.63	2463	8.08	3.00

Table 9 below shows the result of Marshall Mix design at optimum binder content for a filler content of 7.85%. For the given filler content the optimum binder content of Fly ash is a little bit lower than that of the other filler types which result in less cost of construction from the others. While the Wood ash shows a little higher value than both filler types which is not recommended considering cost. While the air void has a better value for the Fly ash rather than the other filler types even if it's not 4%. And this can lead to a pavement for higher moisture susceptibility and less durability due to higher air voids in the compacted mix. Even if the flow shows optimum value for all filler types, Wood ash have lower marginal value of VMA and stability at optimum binder content for this trial. On the other hand the unit weight of the mix is high for the Basaltic rock filler while it's marginal for the Fly ash and lower for the Wood ash. But it can fulfill the design requirements even though further upgrading of this Marshall Properties is needed.

Table 9 Marshall Test result at OBC (trial No.1)

First Trial Summarized Test Result of Marshall Method									
Trial No	Filler Type	Filler Content (%)	Optimum Binder Content (%)	Air Void (%)	VMA (%)	VFA (%)	Unit Weight (mg/m ²)	Stability(KN)	Flow (mm)
1	Basaltic Rock Dust	7.85	5.1	5.26	17.9	72.45	2456.6	10.9	2.62
	Fly Ash	7.85	5.0	4.51	16.95	73.42	2439.9	10.95	2.22
	Wood Ash	7.85	5.2	5.00	14.79	66.38	2425.1	8.89	2.43
Specification Limits			4-6	4%	14% (Min)	60%-80%	-----	8 KN (Min)	2-4

4.3.2 SECOND TRIAL TEST RESULT

Since higher filler content is used for the first trial, in the second trial our filler content is decreased to 5%. Table 10 below shows for 5% filler content, 60 grams of filler were needed to produce a single specimen and it increases the 0.075mm sieve size to 47.2 gm from 13gm.

Table.10 Total Weight of Mass required to mould single specimen (Trial No.2)

No	Sieve Size (mm)	% Pass	% Retain	Gram Required in Size
		Pass in %	Pass in %	
1	37.50	100	0	
2	25.00	97.27	2.73	32.76
3	19.00	93.105	4.165	49.98
4	12.50	86.33	6.775	81.3
5	9.50	78.685	7.645	91.74
6	4.75	36.935	41.75	501
7	2.36	25.565	11.37	136.44
8	1.180	19.195	6.37	76.44
9	0.60	14.235	4.96	59.52
10	0.300	10.905	3.33	40.0
11	0.150	8.935	1.97	23.6
12	0.075	5	3.935	47.2
Filler			5	60.0
		Single Specimen gram		1200

Based on the two tables shown below, like the first trial all filler types show the same Marshall Property characteristics relation in the range of bitumen content values. When the bitumen content increases, the air void, VMA, and stability decreases in reverse the VFA, unit weight and flow increases. In comparison with the design requirements, both filler types shows less Marshall Property from the previous trial. Even if Fly ash fulfills the specification limits at 5% of filler content, the Wood ash exhibits lesser value of VMA and stability from the design requirements. Therefore at this filler content both types of materials are not acceptable for the construction of Asphalt road.

Table 11 Marshall Test result trial No.2 (Fly Ash)

% AC by weight of total mix	Air Void	% V.M.A	% V.F.A	Unit Weight (mg/m ²)	Stability (KN)	Flow (mm)
4.00	7.84	15.68	50.04	2427.6	9.81	1.85
4.50	5.99	15.42	61.16	2448.1	9.84	2.16
5.00	4.12	15.17	72.87	2468.1	9.14	2.54
5.50	1.93	14.70	86.89	2495	8.44	2.83
6.00	0.17	14.65	98.86	2510	8.29	2.99

Table 12 Marshall Test result trial No.2 (Wood Ash)

% AC by weight of total mix	Air Void	% V.M.A	% V.F.A	Unit Weight (mg/m ²)	Stability (KN)	Flow (mm)
4.00	8.87	15.34	42.15	2379.3	8.96	1.95
4.50	6.43	13.98	54.04	2430.1	8.11	2.14
5.00	5.21	13.79	62.20	2448.3	7.77	2.75
5.50	3.86	13.50	71.40	2470	7.36	2.93
6.00	2.54	13.25	80.79	2490	7.24	3.04

Table 13 shows the result of Marshall Mix design at optimum binder content for a filler content of 5%. For the given filler content the optimum binder content of Fly ash is the same result with that of the Wood Ash which results in higher cost of construction from the previous trial. While the Wood ash shows the same value of OBC with the previous trial which is not recommended considering cost. While the air void has a lesser value for the Fly ash rather than the Wood ash which has a higher value than the optimum 4%. Even if the flow shows optimum value for all filler types, Wood ash have lower value of VMA and stability at optimum binder content for this trial.

On the other hand the unit weight of the mix is high for the Fly ash than the Wood ash. But for both filler types 5 % content is not recommended for construction.

Table 13 Marshall Test result at OBC (trial No.2)

Second Trial Summarized Test Result of Marshall Method									
Trial No	Filler Type	Filler Content (%)	Optimum Binder Content (%)	Air Void (%)	VMA (%)	VFA (%)	Unit Weight (mg/m²)	Stability (KN)	Flow (mm)
2	Fly Ash	5.0	5.2	3.32	15.01	78.47	2478.8	9.00	2.66
	Wood Ash	5.0	5.2	5.16	13.67	66.00	2457.1	7.57	2.82
Specification Limits			4-6	4%	14% (Min)	60%-80%	-----	8 KN (Min)	2-4

4.3.3 THIRD TRIAL TEST RESULT

Since higher filler content is used for the first trial and lower for the second, in the third trial 7% of filler content is taken as a marginal. Table 14 below shows for 7% filler content, 84 grams of filler were needed to produce a single specimen and it decreases the 0.075mm sieve size to 23.2gm from 47.2gm.

Table 14 Total Weight of Mass required to Mould a Single Specimen (Trial No.3)

No	Sieve Size (mm)	% Pass	% Retain	Gram Required in Size
		Pass in %	Pass in %	
1	37.50	100	0	
2	25.00	97.27	2.73	32.76
3	19.00	93.105	4.165	49.98
4	12.50	86.33	6.775	81.3
5	9.50	78.685	7.645	91.74
6	4.75	36.935	41.75	501
7	2.36	25.565	11.37	136.44
8	1.180	19.195	6.37	76.44
9	0.60	14.235	4.96	59.52
10	0.300	10.905	3.33	40.0
11	0.150	8.935	1.97	23.6
12	0.075	7	1.935	23.2
Filler			7	84.0

Considering the two tables shown below, like the first and second trials all filler types show the same Marshall Property characteristics relation in the range of bitumen content values. When the bitumen content increases, the air void, VMA, and stability decreases in reverse the VFA, unit weight and flow increases. In comparison with the design requirements, both filler types fulfill the specification limits at 7% of filler content, even if the Wood ash exhibits minimum marginal value of VMA from the design requirements. But the stability of both fillers shows better result. Therefore at this filler content both types of materials are acceptable for the construction of Asphalt road.

Table 15 Marshall Test result trial No.3 (Fly Ash)

% AC by weight of total mix	Air Void	% V.M.A	% V.F.A	Unit Weight (mg/m ²)	Stability (KN)	Flow (mm)
4.00	9.39	17.61	46.69	2386.7	13.05	1.80
4.50	7.47	17.26	56.72	2409.5	12.56	2.07
5.00	5.71	17.09	66.61	2427.1	12.05	2.30
5.50	3.62	16.68	78.30	2452	11.89	2.67
6.00	1.90	16.64	88.56	2466	10.28	3.06

Table 16 Marshall Test result trial No.3 (Wood Ash)

% AC by weight of total mix	Air Void	% V.M.A	% V.F.A	Unit Weight (mg/m ²)	Stability (KN)	Flow (mm)
4.00	11.15	16.45	32.21	2338.4	12.00	1.87
4.50	9.43	16.24	41.95	2356.7	11.54	2.00
5.00	7.64	16.01	52.30	2375.6	11.02	2.22
5.50	5.43	15.45	64.86	2404	10.58	2.68
6.00	3.51	15.21	76.92	2424	9.60	2.89

Table 17 shows the result of Marshall Mix design at optimum binder content for a filler content of 7%. For the given filler content the optimum binder content of Fly ash is lower than that of the Wood Ash which results in lesser cost of construction from the previous trial. While the Wood ash shows the higher value of OBC from the previous trials which is not recommended considering cost. While the air void has a higher value for the Wood ash compared with the Fly ash which also has a higher value than the optimum 4%. Even if the flow shows optimum value for all filler types,

Wood ash have minimum marginal value of VMA at optimum binder content for this trial. On the other hand the unit weight of the mix is high for the Fly ash than the Wood ash. But for both filler types 7 % content can be recommended for construction.

Table 17 Marshall Test result at OBC (trial No.3)

Third Trial Summarized Test Result of Marshall Method									
<i>Trial No</i>	<i>Filler Type</i>	<i>Filler Content (%)</i>	<i>Optimum Binder Content (%)</i>	<i>Air Void (%)</i>	<i>VMA (%)</i>	<i>VFA (%)</i>	<i>Unit Weight (mg/m²)</i>	<i>Stability (KN)</i>	<i>Flow (mm)</i>
3	Fly Ash	7.0	5.1	5.28	17.01	64.11	2432.5	12.02	2.37
	Wood Ash	7.0	5.3	6.31	15.67	59.86	2389.6	10.80	2.72
Specification Limits			4-6	4%	14% (Min)	60%-80%	-----	8 KN (Min)	2-4

4.3.4 MARSHALL PROPERTY AT OBC

Generally Table 18 shown below entails about the overall Marshall Properties of the tests conducted with different types of fillers at different content. Based on the result it's possible to say that considering Marshall Properties of the mixes with the design requirement 7% and 7.85% can be recommendable for the construction of Asphalt Concrete roads.

Table 18 Marshall Test results of Bituminous mixes at OBC

Marshall Property of HMA at Optimum Bitumen Content							
Filler Type	Basaltic Rock Filler	Fly Ash			Wood Ash		
Filler Content(%)	7.85	7.85	7.00	5.00	7.85	7.00	5.00
Optimum Binder Content(%)	5.1	5.0	5.1	5.2	5.2	5.3	5.2
Air Void(%)	5.26	4.51	5.28	3.32	5.00	6.31	5.16
VMA(%)	17.9	16.95	17.01	15.01	14.79	15.67	13.67
VFA(%)	72.45	73.42	64.11	78.47	66.38	59.86	66.00
Unit Weight (mg/m²)	2456.6	2439.9	2432.5	2478.8	2425.1	2389.6	2457.1
Stability(KN)	10.9	10.95	12.02	9.00	8.89	10.80	7.57
Flow(mm)	2.62	2.22	2.37	2.66	2.43	2.72	2.82

4.4. DISCUSSION

4.4.1. EFFECT OF FILLER TYPE AND CONTENT ON OBC

As indicated in Figure 17 below, the optimum binder content (OBC) of mixtures prepared with two mineral fillers by type and amount vary over a range of 5% - 7.85%. Both of the fillers show different characteristics. When the content of Fly ash increases from 5% to 7.85%, the OBC decreases rapidly but the Wood Ash shows an increment up to 7% and decreases till 7.85% filler content. Generally OAC decreases due to the fact that when the void space between aggregates filled by filler materials, there will be a small room for the bitumen to occupy. Therefore when the filler content increases it's obvious that OAC decreases. But for the Wood Ash in a range of 5%-7% when the filler content increases, the OAC increases. This is due to the fact that when the filler content is getting higher; the overall surface area of aggregate is increased that implies higher asphalt content is needed to fulfill the Marshall Property requirements.

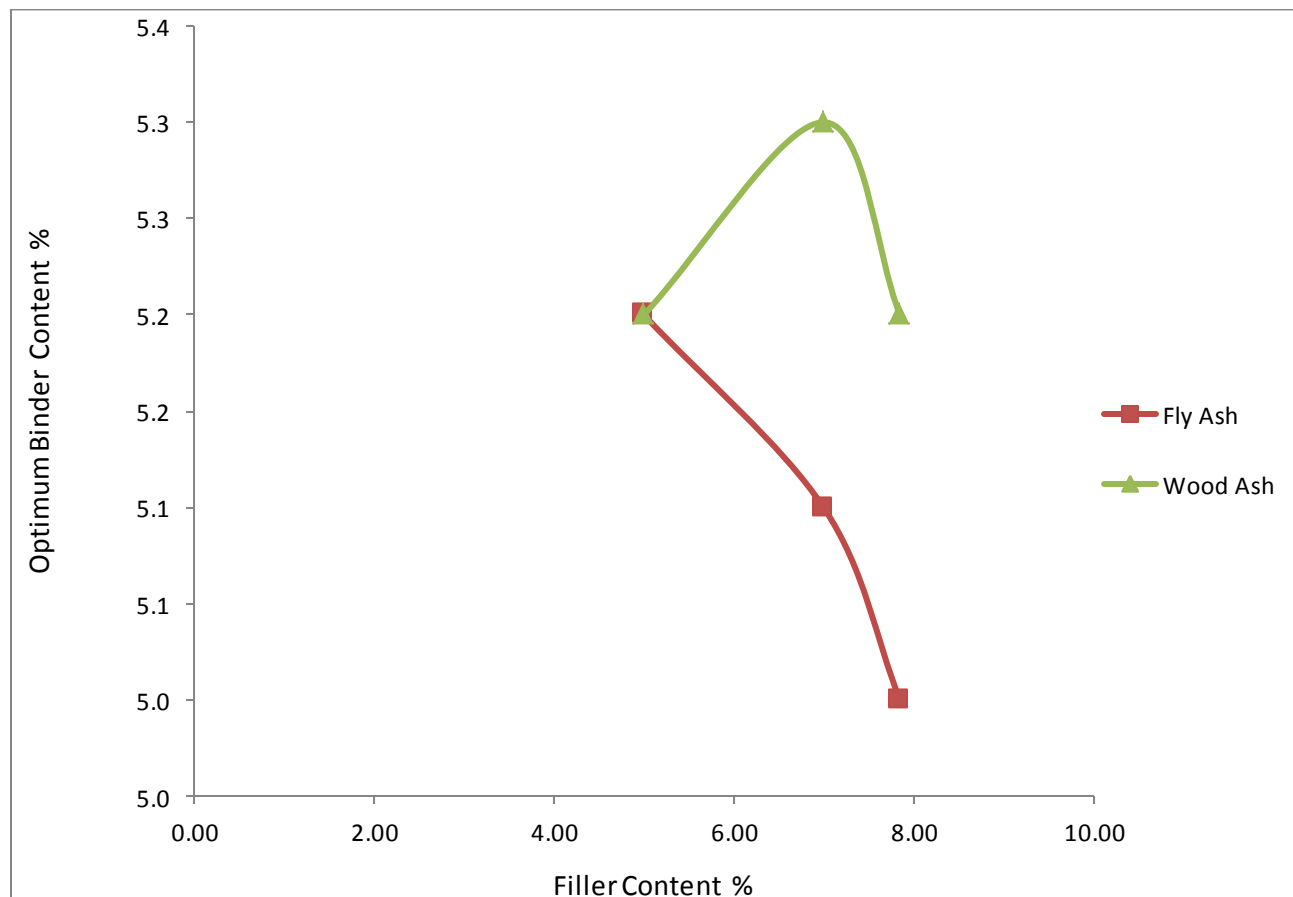


Figure 17 Effect of filler type and content on optimum binder content

Comparing of the two filler types, Wood Ash has higher asphalt cement absorption than Fly Ash. This may be due to the fact that Wood Ash has lower specific gravity than that of Fly Ash. 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.

4.4.2. EFFECT OF FILLER TYPE AND CONTENT ON AIR VOID

The effect of both filler type and their content on air void of the compacted mix shows in Figure 18 below. It's clearly shown that both filler materials have the similar characteristics of Air Void. Which is from 5%-7% filler content Air Void increases, while from 7%-7.85% filler content Air Void decreases. The reason behind this scenario is, at lower filler content the OBC for both filler types is not enough to cover the void spaces. But at higher filler contents which an increased in amount of filler content in the mixture fills the voids in the aggregate. This, subsequently, decreases the air voids in the mineral aggregate lower space is available for air. In comparison with the two filler types, Air Void in Wood Ash mixture is higher than Fly Ash mixture because Wood Ash has smaller particle size than that of Fly Ash which tends to minimize the volume covered by single filler aggregate that allows extra space for Air Void.

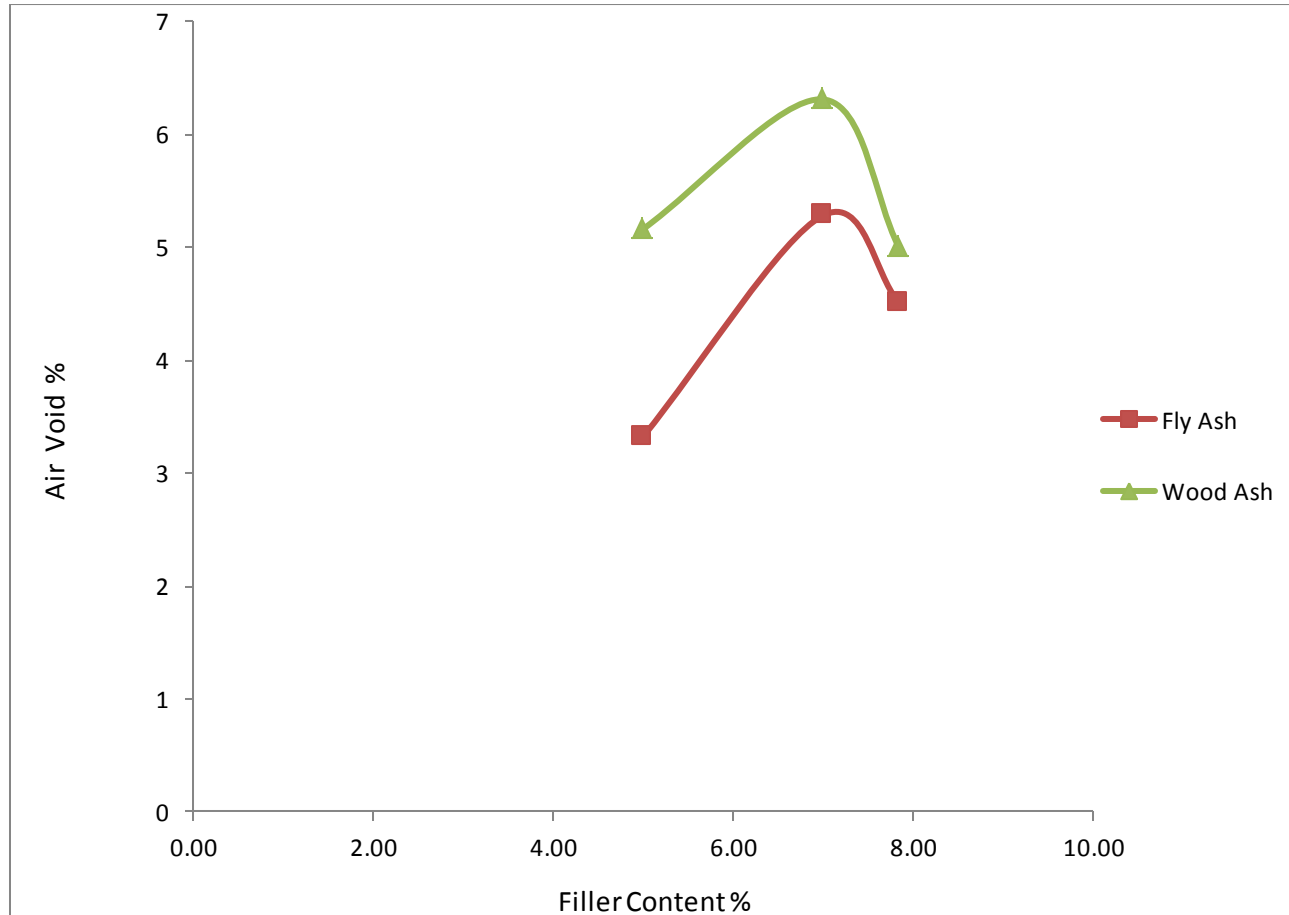


Figure 18 Effect of filler type and content on Air Void

4.4.3. EFFECT OF FILLER TYPE AND CONTENT ON VMA

As can be seen from Figure 19 below, mixtures using both Fly Ash and Wood Ash filler types exhibit same manner, in relation with VMA of the mixture. 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. But both filler types show VMA increment when the filler content increases until 7%. This may be due to the Air Void up to filler content of 7% increases as shown on Figure 18 above. But after 7% VMA decreases when filler content of both fillers increases. This is because at higher filler content voids will be more occupied by filler materials. When we compare the two fillers, Fly Ash has higher VMA than Wood Ash. This is due to higher bulk specific gravity of total aggregates of Fly Ash HMA specimen than Wood Ash HMA specimen which directly relate with specific gravity of the mineral fillers.

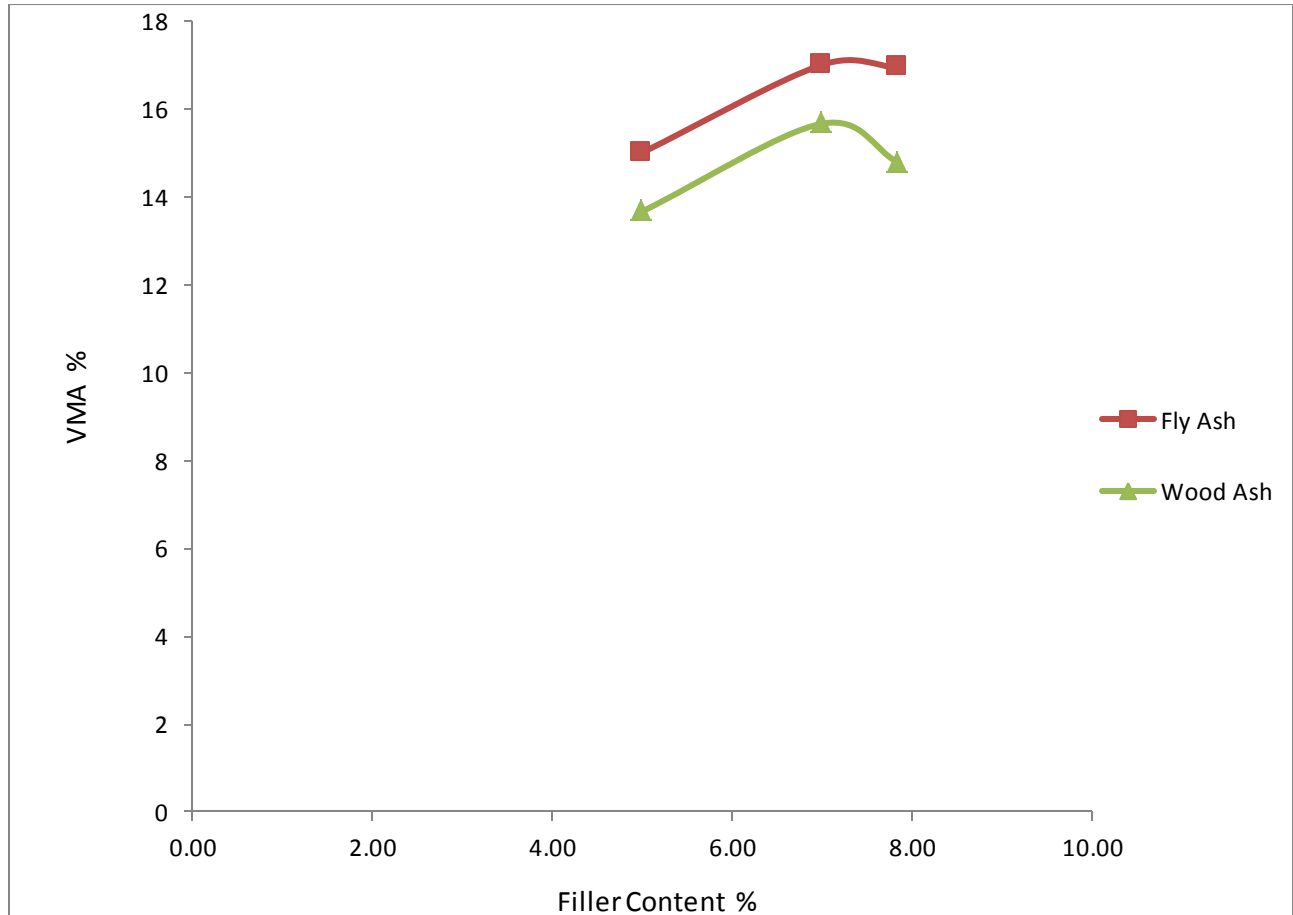


Figure 19 Effect of filler type and content on VMA

When we see the trend of effect of filler content on VMA values, it seems that there would be an optimal filler content that would better improve the bituminous mixture performance. Minimum VMA is necessary in mixtures to accommodate enough asphalt content, so that aggregate particles can be coated with adequate asphalt film thickness. That directly results in composition of durable asphalt paving mixtures.

4.4.4. EFFECT OF FILLER TYPE AND CONTENT ON VFA

Considering Figure 20 shown below, the void filled with asphalt for both filler types decreases till 7% of filler content while after 7% filler content it increases. This is because of the Air Void up to 7% of filler content increases rapidly and the content of filler increases which gradually decreases the void space to be filled by the asphalt. But after 7% the VFA increases which directly related to the Air Void of mixture that decreases gradually. Comparing the two filler types, it's clearly seen

on the figure below that the VFA of Fly Ash is much higher than that of Wood Ash. This is due to the fact that the VMA of Fly Ash is greater than that of that of Wood Ash. Also the air void of Wood Ash is much greater than that of Fly Ash makes huge difference in VFA value.

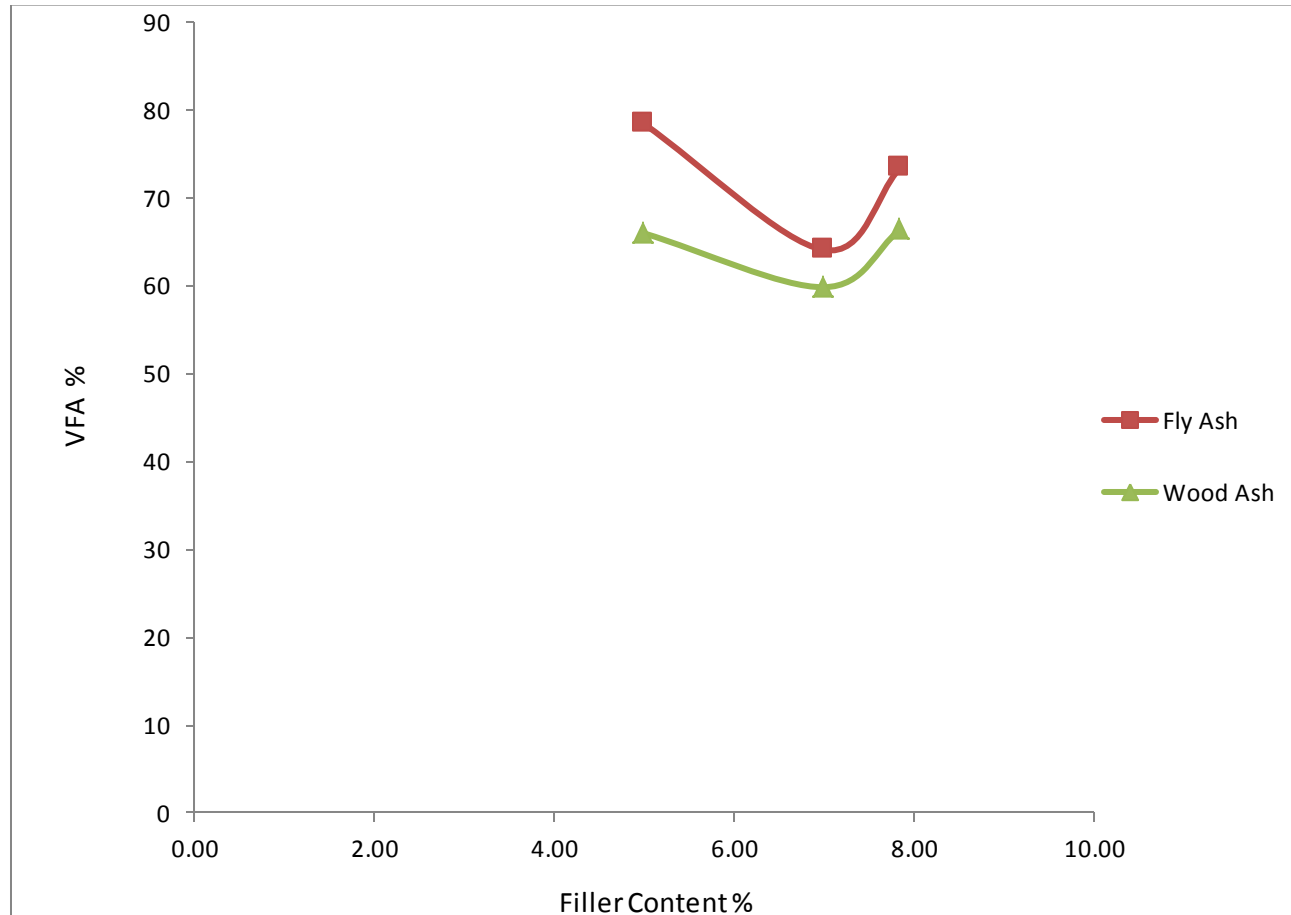


Figure 20 Effect of filler type and content on VFA

Generally if the percentage of voids filled with asphalt is lower than the limit indicated; there will be less asphalt film around the aggregate particles. Lower asphalt films are more subjected to moisture and weather effects where they can be detached from the aggregate particles and subsequently lower performance. On the other hand, if the limit is exceeded, more voids are filled with asphalt than required for durability. This can be explained as the asphalt film around aggregate particles is thicker and lower voids than required are left. This increased amount of effective asphalt results bleeding and lower stiffness of the mix. But both fillers fulfill the Marshall Design property of VFA which is 60% - 80%.

4.4.5. EFFECT OF FILLER TYPE AND CONTENT ON BULK DENSITY

The effect of filler content on Bulk Density for both filler types is completely similar of each other as you have seen on Figure 21 below. For both Fly Ash and Wood Ash, when the content reaches up to 7%, the Bulk Density decreases linearly while the reverse is true beyond 7% of filler content. The main reason is when the filler content increases in the mix, it fills the voids hence increase unit weight for a high filler contents. However, at lower content the mix becomes less stiff that needs lower compaction effort then consequently low dense mixtures obtained.

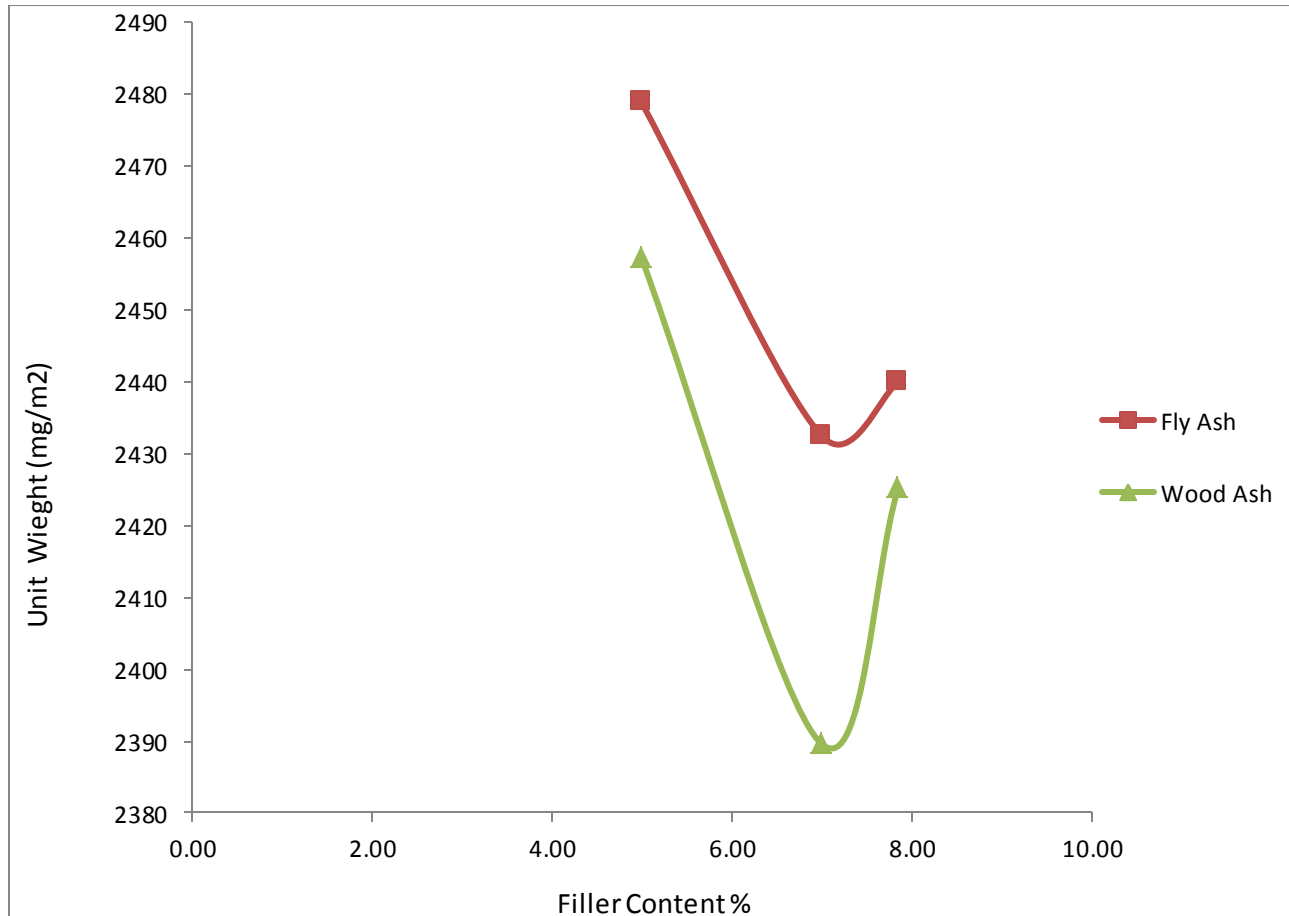


Figure21 Effect of filler type and content on Bulk Density

The unit weight of these mixes simply increases as the filler content in the mix increases from 7% to 7.85%. But it is difficult to explain why the unit weight of the mixtures made decreases in a filler content range of 5% to 7%. This may be due to that effect of filler type at lower content is insignificant on the density of the mixture.

4.4.6. EFFECT OF FILLER TYPE AND CONTENT ON STABILITY

From Figure 22 shown below, the effect of filler type and their contents on Marshal Stability have similar trend for both filler types i.e., as filler content in the mixes increase, Marshal Stability also increases up to maximum then decreases after 7% of filler content. This is due to the fact that voids at lower filler content is too high and the aggregate tend to be finer as filler content increases, hence both effect tend to reduce the stability values. But generally when the filler content increases, it increases the viscosity of the asphalt cement also the Marshal stability. Thus, a small addition of fine material (filler) in the mixture may have the effect of making the asphalt cement/filler mixture act as a more viscous binder thus increasing the Marshal stability.

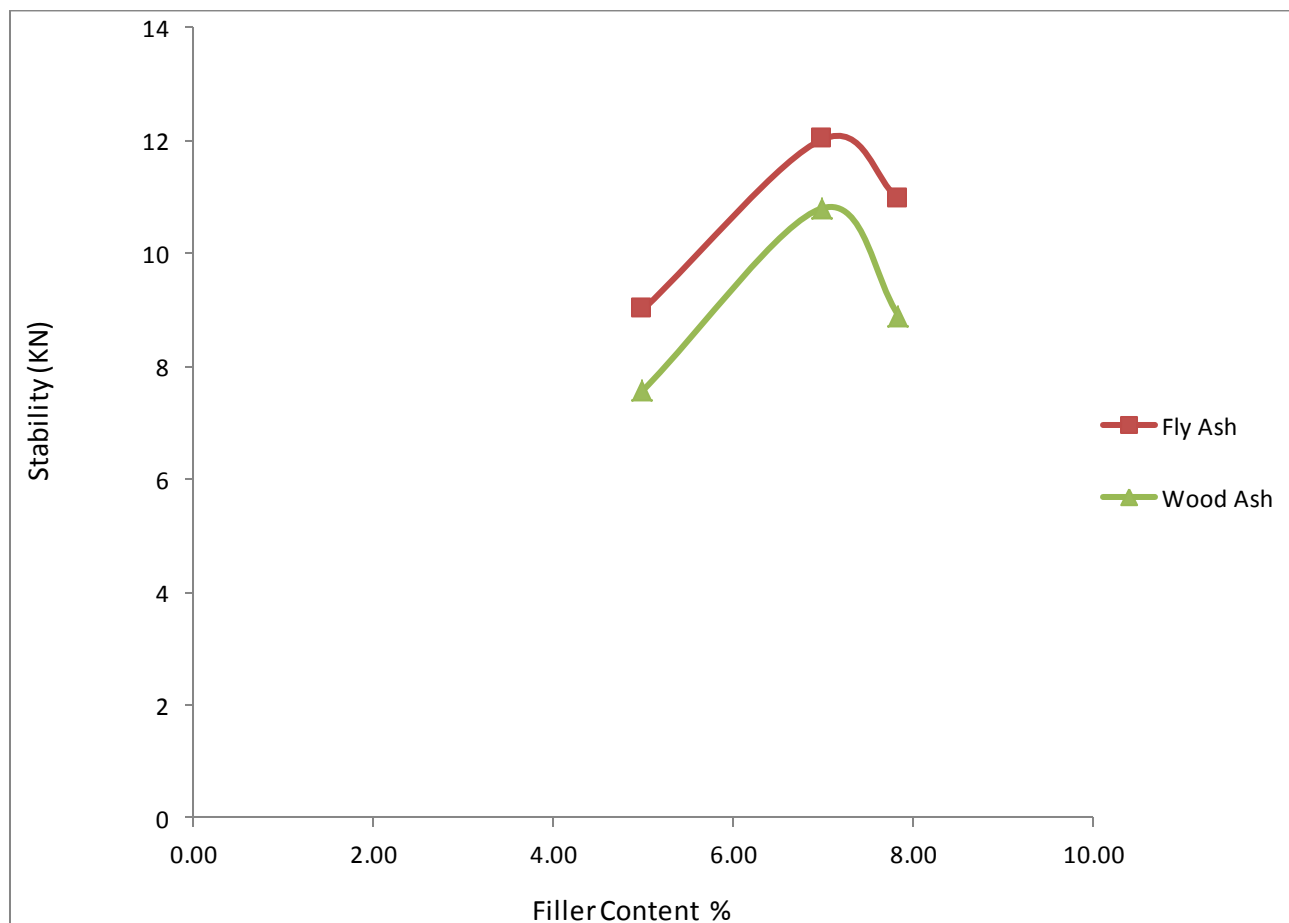


Figure 22 Effect of filler type and content on Stability

Comparing the two types of fillers, Fly Ash mixture has higher stability than wood Ash mixture. The main reason behind is Wood Ash filler is extremely fine than Fly Ash filler, which may extend the asphalt cement, making act like higher asphalt content, and lower the stability.

4.4.7. EFFECT OF FILLER TYPE AND CONTENT ON FLOW

From figure 23 below is shown that the flow value for both types of fillers decreases when the filler content of the asphalt mixture increases. This is because of the addition of filler materials stiffen the mixture. But for both types of fillers the flow value is within the specification limit that fulfills the Marshall criteria.

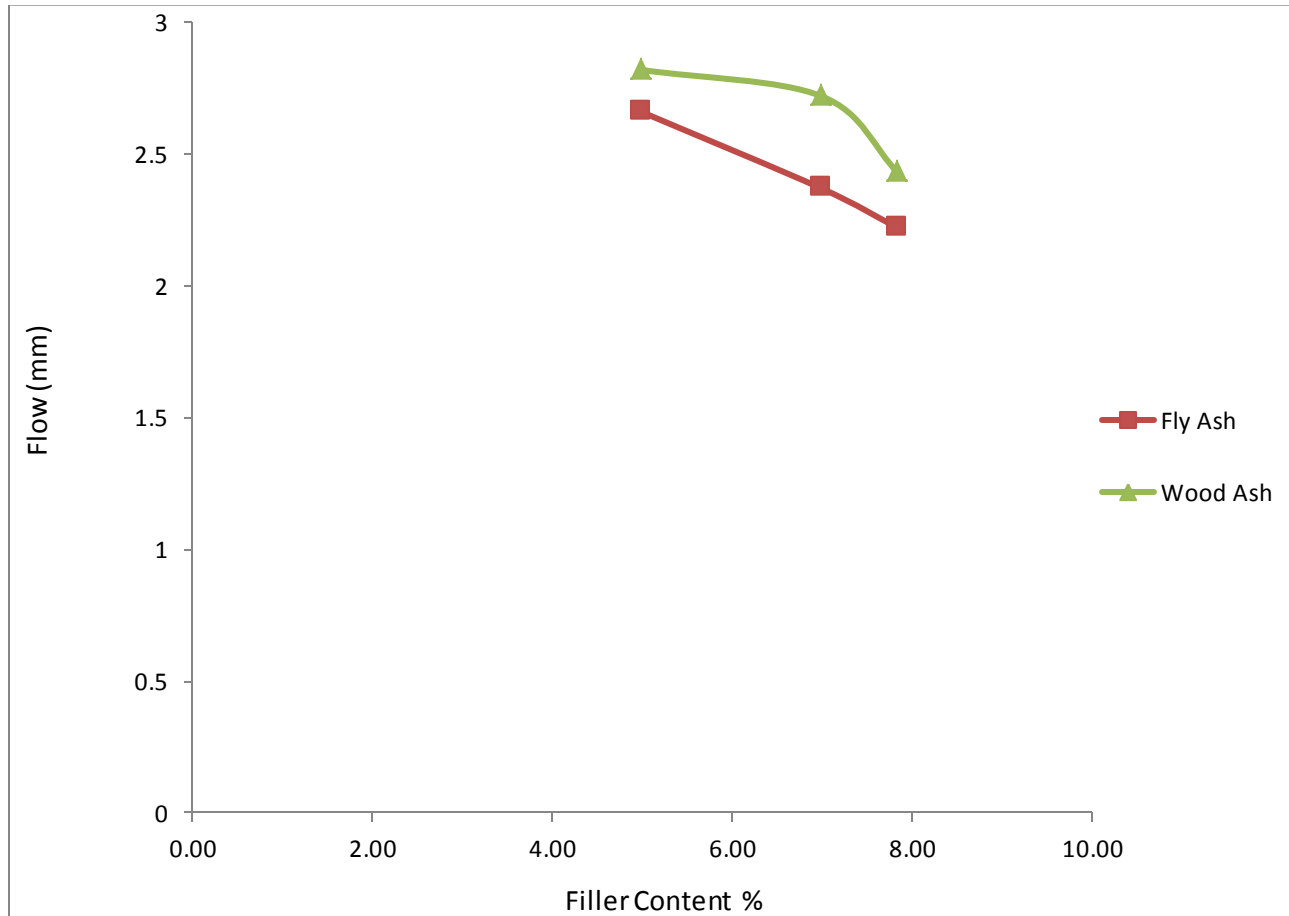


Figure 23 Effect of filler type and content on Flow

Overall looking of the Marshall properties of the two fillers, Wood Ash have inconsistent and lesser value when it's compared with Fly Ash. This may be caused by the existence of carbonate inside Wood Ash. Therefore through chemical process of called decarbonation removal of carbon from the calcium oxide will be crucial to improve the performance of Wood Ash filler in the mixture. Since calcium oxide plays a key role in the performance of filler materials like Fly Ash, Cement, Lime and soon.

4.4.8 ECONOMIC EVALUATION

For every hot mix asphalt design, economy of the project is one factor that shall be considered by a mix designer for the implementation of the design. Especially in our country cost efficient durable roads are acceptable by the government sectors responsible for the construction of roads. Based on that at 7% and 7.85% filler content economic evaluation is calculated as shown below.

Option 1 (7.85% of filler content)

At 7.85% filler content weight of filler needed to mould a single specimen = 94.2gm

For Basaltic rock filler the OBC at 7.85% filler content = 5.1 %

$$= 5.1 \times 1200\text{gm} / 100 = 61.2\text{gm}$$

For Fly Ash filler the OBC at 7.85% filler content = 5.0 %

$$= 5.0 \times 1200\text{gm} / 100 = 60.0\text{gm}$$

For Wood Ash filler the OBC at 7.85% filler content = 5.2 %

$$= 5.2 \times 1200\text{gm} / 100 = 62.4\text{gm}$$

Bitumen cost=6,517.38 Birr/Gallon (Source: Private Bitumen supplier company in Addis Ababa)

Crusher Hourly Cost = 11,000 Birr/ Hour (Source: From ERCC standard)

Let's take a single crusher plant owned by Private Contractor who is working in Harer Asphalt Concrete Road Project. The output of the crusher based on material size is

Coarse aggregate = 20 m³/day = 2.0 m³/Hr since there are 10 working hours per day.

Intermediate aggregate = 14 m³/day = 1.4 m³/Hr

Fine aggregate = 12 m³/day = 1.2 m³/Hr

Consider 1 Km of 10 cm thickness AC road

Per 1m width of the road a total of = 1000m x 1m x 0.1m = 100 m³ of AC exists.

Basaltic Rock Filler

Average density of basaltic rock filler = 1954 Kg/m³

Total volume of filler in single specimen = 0.00942Kg / 1954 Kg/m³ =48 Cm³

Bulk volume of specimen at 5.1% of OBC = 509.66 Cm³

Percentage in volume of filler = 48/509.66 =9.42 %

Total Volume of Basaltic Rock Filler/Km/m = 0.0942 x 1000 = 94.2 m³

Total volume of bitumen in single specimen = 0.0612Kg / 1011 Kg/m³ =61.2 Cm³

Percentage in volume of filler = 61.2/509.66 = 11.97 %

$$\text{Production cost of filler/Km/m} = \frac{94.2 \text{ m}^3}{1.2 \text{ m}^3/\text{Hr}} \times 11,000 \text{ Birr/Hr} = 863,500.00 \text{ Birr}$$

$$\text{Total Volume of bitumen/Km/m} = 0.1197 \times 1000 = 119.7 \text{ m}^3$$

$$\text{Material cost of Bitumen/Km/m} = 119.7 \text{ m}^3 \times 6,517.38 \text{ Birr}/0.02 \text{ m}^3 = 39,006,519.30 \text{ Birr}$$

$$\text{Total cost} = 39,870,019.30 \text{ Birr/Km/m}$$

Fly Ash

$$\text{Total weight of filler for single specimen} = 94.2 \text{ gm}$$

$$\text{Bulk volume of specimen at 5.0\% of OBC} = 510.67 \text{ Cm}^3$$

$$\begin{aligned} \text{Total weight of Fly Ash Filler/Km/m} &= 92.4 \times 10^{-3} \text{ kg} \times 1000 \text{ m}^3 / 510.67 \times 10^{-6} \text{ m}^3 \\ &= 184,463.55 \text{ Kg} \end{aligned}$$

$$\text{Total volume of bitumen in single specimen} = 0.06 \text{ Kg} / 1011 \text{ Kg/m}^3 = 60.66 \text{ Cm}^3$$

$$\text{Percentage in volume of filler} = 60.66/510.67 = 11.87 \%$$

$$\text{Total Volume of bitumen/Km/m} = 0.1187 \times 1000 = 118.7 \text{ m}^3$$

Cost of Fly Ash= 15\$ - 40\$ per ton. On average its 27.5\$ per ton (source: [www.concrete construction.com](http://www.concreteconstruction.com)) and cost include processing of the material.

Current money exchange in Ethiopia for 1\$ = 20.80 Birr (Source: Commercial Bank of Ethiopia)

$$\text{Material cost for Fly Ash per Kg} = 27.5 \times 20.80/907.185 \text{ Kg} = 0.63 \text{ Birr/Kg}$$

$$\text{Material cost for filler/Km/m} = 184,463.55 \text{ Kg} \times 0.63 \text{ Birr/Kg} = 116,212.04 \text{ Birr}$$

$$\text{Material cost of Bitumen/Km/m} = 118.7 \text{ m}^3 \times 6,517.38 \text{ Birr}/0.02 \text{ m}^3 = 38,680,650.30 \text{ Birr}$$

$$\text{Total cost} = 38,796,862.34 \text{ Birr/Km/m}$$

Wood Ash

$$\text{Total weight of filler for single specimen} = 94.2 \text{ gm}$$

$$\text{Bulk volume of specimen at 5.2\% of OBC} = 513.9 \text{ Cm}^3$$

$$\begin{aligned} \text{Total weight of Wood Ash Filler/Km/m} &= 92.4 \times 10^{-3} \text{ kg} \times 1000 \text{ m}^3 / 513.9 \times 10^{-6} \text{ m}^3 \\ &= 179,801.52 \text{ Kg} \end{aligned}$$

$$\text{Total volume of bitumen in single specimen} = 0.0625 \text{ Kg} / 1011 \text{ Kg/m}^3 = 61.82 \text{ Cm}^3$$

$$\text{Percentage in volume of filler} = 61.82/513.9 = 12.03 \%$$

$$\text{Total Volume of bitumen/Km/m} = 0.1203 \times 1000 = 120.3 \text{ m}^3$$

Cost of Wood Ash= 24\$ - 30\$ per ton. On average its 26\$ per ton (source: The stockman grass farmer magazine, United States of America, Madison, Wisconsin)cost include processing of the material.

Current money exchange in Ethiopia for 1\$ = 20.80 Birr (Source: Commercial Bank of Ethiopia)

$$\begin{aligned} \text{Material cost for Wood Ash} &= 26 \times 20.80/907.185 \text{ Kg} \\ &= 0.596 \text{ Birr/Kg} \end{aligned}$$

$$\text{Material cost for filler/Km/m} = 179,801.52 \text{ Kg} \times 0.596 \text{ Birr/Kg} = 107,161.71 \text{ Birr}$$

$$\text{Material cost of Bitumen/Km/m} = 120.3 \text{ m}^3 \times 6,517.38 \text{ Birr}/0.02 \text{ m}^3 = 39,202,040.70 \text{ Birr}$$

$$\text{Total cost} = 39,309,202.41 \text{ Birr/Km/m}$$

- Note that for all filler types, transportation cost of fillers is not considered since it differs with project location from filler source.

Considering all the costs on the AC for each kind of filler, it's possible to say that:

$$\text{Material cost}_{\text{Basaltic Rock Filler}} > \text{Material cost}_{\text{Wood Ash}} > \text{Material cost}_{\text{Fly Ash}}$$

Option 2 (7.0% of filler content)

For Fly Ash filler the OBC at 7.0% filler content = 5.1%

$$= 5.1 \times 1200 \text{ gm} / 100 = 61.2 \text{ gm}$$

For Wood Ash filler the OBC at 7.0% filler content = 5.3%

$$= 5.3 \times 1200 \text{ gm} / 100 = 63.6 \text{ gm}$$

Fly Ash

Total weight of filler for single specimen = 84gm

Bulk volume of specimen at 5.1% of OBC = 512.56 Cm³

$$\begin{aligned} \text{Total weight of Fly Ash Filler/Km/m} &= 84 \times 10^{-3} \text{ kg} \times 1000 \text{ m}^3 / 512.56 \times 10^{-6} \text{ m}^3 \\ &= 163,883.25 \text{ Kg} \end{aligned}$$

Total volume of bitumen in single specimen = 0.0612Kg / 1011 Kg/m³ = 60.53 Cm³

Percentage in volume of filler = 60.53/512.56 = 11.81 %

Total Volume of bitumen/Km/m = 0.1187 x 1000 = 118.1 m³

Material cost for filler/Km/m = 163,883.25 Kg x 0.63Birr/Kg = 103,246.45 Birr

Material cost of Bitumen/Km/m = 118.1m³ x 6,517.38Birr/0.02 m³ = 38,485,128.90 Birr

Total cost = 38,588,375.35 Birr/Km/m

Wood Ash

Total weight of filler for single specimen = 84gm

Bulk volume of specimen at 5.2% of OBC = 517.05 Cm³

Total weight of Wood Ash Filler/Km/m = $84 \times 10^{-3} \text{ kg} \times 1000 \text{ m}^3 / 517.05 \times 10^{-6} \text{ m}^3 = 162,460.11 \text{ Kg}$

Total volume of bitumen in single specimen = $0.0636 \text{ Kg} / 1011 \text{ Kg/m}^3 = 62.91 \text{ Cm}^3$

Percentage in volume of filler = $62.91/517.05 = 12.17 \%$

Total Volume of bitumen/Km/m = $0.1217 \times 1000 = 121.7 \text{ m}^3$

Material cost for filler/Km/m = $162,460.11 \text{ Kg} \times 0.596 \text{ Birr/Kg} = 96,826.22 \text{ Birr}$

Material cost of Bitumen/Km/m = $121.7 \text{ m}^3 \times 6,517.38 \text{ Birr}/0.02 \text{ m}^3 = 39,658,257.30 \text{ Birr}$

Total cost = $39,755,083.52 \text{ Birr/Km/m}$

Considering all the costs on the AC for each kind of filler, it's possible to say that:

Material cost_{Wood Ash} > Material cost_{Fly Ash}

- Comparing the two options, Option 1 has less cost than Option 2 for Wood Ash while the reverse is true for Fly Ash. But in all cases the new filler material has less cost than the traditional one.

The other main idea that shall be discussed here is the availability of the material. From different studies, Woody biomass energy consumption 94% is in rural and urban households and the other 6% is consumed by commercial services and cottage industries. Annually there are about 45.7 million tons of fuel wood and 0.25 million tons of charcoal consumption in households. Out of 484 Woredas surveyed, 336 Woredas are consuming more than their woody biomass annual increment. Therefore the availability of wood ash is vast in the context of our country (source: Latin America Thematic Network on Bio energy). On the other hand (Geological survey of Ethiopia with Ministry of Mines and Energy, 2009) state by their paper called "Investment opportunities in coals of Ethiopia", coal resources appear to be quite widespread in Ethiopia with occurrences in at least on half of the country's administrative regions. A recent discovery at Dilbi in south-west region of the country found to be lignite category with high ash content. The geological survey of Ethiopia and Addis Ababa University carried out some exploration and the deposit of coal found to be 14,016,730 tons at Dilbi area, 27,545,298 tons in Moye Area, 111,753,300 tons Dilbi (Ibid) area, 121,457,030 tons Achibo Sombo and soon. Generally the availability of these filler materials is assured through the deposits of their sources across the country.

5. CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

The main objective of this study was to imply the replacement of the traditional filler material with new filler types which are byproducts of household and industry. The two experimental fillers possessed different particle sizes and were expected to improve the engineering properties of paving mixtures, thereby enhancing pavement performance. The reported improvement in the engineering properties of the paving mixtures containing Fly Ash and Wood Ash can be attributed to the bonding and cementation properties of the fillers. From the investigations conducted in this study using the two different types of fillers with the same content, it can be concluded that:

- At 7.85% and 7% optimum binder content both Fly Ash and wood Ash can fulfill the Marshall design criteria for bituminous mixture. But at 5% of filler content only Fly Ash mixture shows optimum Marshall design criteria values.
- Considering the stability of the traditional filler type (Basaltic Rock Filler), Fly Ash had almost relative value but the Wood Ash shows lower stability.
- Even if the VMA value for the Wood Ash mixture is lesser than 14% at 5% filler content, all other Marshall Properties fulfills the design requirements. Which implies future amendment on the gradation of aggregate can improve the result.
- Wood Ash mixture uses higher amount of asphalt content than that of Fly Ash and Basaltic rock filler. And its implication is higher cost in construction of Asphalt pavements.
- The tradition filler type posses' higher air voids at optimum binder content than that of the new filler materials. Therefore the durability of the pavement compared with the Fly Ash mixture is lesser due to exposure for moisture and weather defects where they can be detached from the aggregate particles and subsequently lower performance.
- Comparing the two filler materials with the new ones, from their results it's possible to say that the traditional filler much more close but a little lower than that of Fly Ash mixture. While it is better than that of Wood Ash mixture except the air void at optimum binder content.
- From the two new filler types Fly Ash mixture is much better than Wood Ash mixture considering Marshall Property results and material cost.

5.2. RECOMMENDATION

The test results obtained during this study revealed that new filler materials can be used for the production of hot mix asphalt. The mixes for this study were made using three types of mineral fillers with different content. Mixtures prepared with Fly Ash fillers show relatively similar trend as Basaltic stone filler (Traditional filler) when compared to the Wood Ash filler. Whereas, inconsistent mixture properties were observed for mixes made with Wood Ash. However, this study indicates that further investigation on the characterization tests for Wood Ash filler can improve its Marshall Properties in relation with the Marshall properties of asphalt concrete that would better simulate the actual field condition is important. The investigation also seeks for its suitability in the asphalt mixtures as alternative mineral filler to the Basaltic Stone Filler.

From the test results obtained, there exists a range of filler content that would result better mixture properties using Fly Ash and Wood Ash fillers, where better results were found at 7 percent filler content for Wood Ash filler while 7 and 7.85 percent for the Fly Ash. And Fly Ash has less cost than Wood Ash. It is indicated in this study and supported by literature that mineral fillers have an important role in the performance of asphalt concrete. The properties of asphalt mixtures were found to be different depending on the filler type and amount in the mix. Thus, it is important to conduct further investigation on the effect of different types of mineral fillers on the performance of asphalt mixtures. Also care should be taken in preparation of sample including test conducting with laboratory apparatuses since aggregate sample disturbance and lab technician errors causes the Marshall property results to vary from the normal trend.

Finally the introduction of new filler materials to this country will bring the ambition of accepting new ideas in the road construction sector which in advance for creativity of new scientific investigation to provide strong and durable pavements for the society. Also using Wood Ash as a filler material can create job opportunities for the people found at lower economy through accumulation and supply of wood ash from their household byproduct. In relation with this it will create a logistics path in transportation of filler materials from their source till the end product. Therefore, it shall be recommended to use wastage materials as Mineral filler in hot mix asphalt production.

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APPENDIX A
Test Results from Marshall Mix Design

BALASTIC ROCK FILLER

First Trial

Method of Test - MARSHAL MIX DESIGN

ASTM D1559/AASHTO T-245

% AC by weight of aggregate	% AC by weight of total mix (pb)	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF (mg/m ²)	Stability(KN)		Flow (mm)
				In Air	In Water	Air SSD							Read	Adjusted	
A	B	C	D	E	F	G	H	I	J	K	L	M			
-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/K	I * 1000	-	-	-
4.04	4	2.842	2.656	1237.6	736.9	1250.40	513.5	2.410	9.257	18.588	50.198	2410.12658	13.12	13.12	2.40
4.04	4	2.842	2.656	1233.50	738.5	1250.00	511.5	2.412	9.204	18.541	50.356	2411.5347	13.10	13.10	2.42
4.04	4	2.842	2.656	1242.80	740.6	1255.40	514.8	2.414	9.106	18.453	50.651	2414.14141	13.07	13.07	2.44
Average =								2.41	9.2	18.53	50.40	2412	13.10	13.10	2.42

Sample No	% AC by weight of aggregate	% AC by weight of total mix (pb)	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF (mg/m ²)	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
A	B	C	D	E	F	G	H	I	J	K	L	M				
-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/K	I * 1000	-	-	-	
A	4.71	4.5	2.842	2.622	1242.30	739.20	1249.60	510.40	2.434	7.171	18.211	60.622	2433.973354	12.08	12.08	2.50
B	4.71	4.5	2.842	2.622	1250.50	745.30	1259.90	514.60	2.430	7.321	18.343	60.088	2430.042752	12.05	12.05	2.53
C	4.71	4.5	2.842	2.622	1243.10	740.60	1251.50	510.90	2.433	7.202	18.238	60.511	2433.157174	12.03	12.03	2.51
Average =								2.43	7.2	18.26	60.41	2432	12.05	12.05	2.51	

Sample No	% AC by weight of aggregate	% AC by weight of total mix (pb)	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF (mg/m ²)	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C							D	E	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I)/C))	(K - J)*100/K	I * 1000	-	-	-
A	5.26	5.0	2.842	2.588	1252.00	748.30	1258.70	510.4	2.453	5.217	18.004	71.022	2452.978056	11.01	11.01	2.6
B	5.26	5.0	2.842	2.588	1250.90	747.70	1257.90	510.2	2.452	5.263	18.044	70.830	2451.783614	11.05	11.05	2.6
C	5.26	5.0	2.842	2.588	1249.00	745.00	1254.50	509.5	2.451	5.277	18.056	70.772	2451.422964	11.03	11.03	2.62
Average =									2.45	5.3	18.03	70.87	2452	11.03	11.03	2.61

Sample No	% AC by weight of aggregate	% AC by weight of total mix (pb)	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF (mg/m ²)	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C							D	E	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I)/C))	(K - J)*100/k	I * 1000	-	-	-
A	5.82	5.5	2.842	2.544	1256.80	750.10	1258.50	508.40	2.472	2.827	17.801	84.116	2472.069237	9.64	10.03	2.72
B	5.82	5.5	2.842	2.544	1252.70	746.40	1253.80	507.40	2.469	2.954	17.907	83.506	2468.860859	9.62	10.00	2.70
C	5.82	5.5	2.842	2.544	1259.80	751.90	1261.10	509.20	2.474	2.749	17.734	84.501	2474.076984	10.00	10.00	2.72
Average =									2.47	2.8	17.81	84.04	2472	9.75	10.01	2.71

Sample No	% AC by weight of aggregate	% AC by weight of total mix (pb)	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF (mg/m ²)	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C							D	E	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100 - ((100 - B)*I/C))	(K - J)*100/K	I * 1000	-	-	-
A	6.38	6.0	2.842	2.520	1239.60	742.70	1240.50	497.80	2.490	1.184	17.637	93.285	2490.156689	8.63	8.98	2.83
B	6.38	6.0	2.842	2.520	1254.80	752.40	1255.90	503.50	2.492	1.105	17.571	93.712	2492.154916	8.68	9.03	2.80
C	6.38	6.0	2.842	2.520	1258.20	754.10	1258.60	504.50	2.494	1.034	17.512	94.098	2493.95441	8.62	8.96	2.81
Average =									2.49	1.1	17.57	93.70	2492	8.64	8.99	2.81

FLY ASH

First Trial

Method of Test - MARSHAL MIX DESIGN

ASTM D1559/AASHTO T-245

Sample No	% AC by weight of aggregate	% AC by weight of total mix (pb)	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF (mg/m ²)	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C							D	E	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100 - ((100 - B)*I/C))	(K - J)*100/K	I * 1000	-	-	-
A	4.06	4.0	2.791	2.623	1225.40	729.7	1240.30	510.6	2.400	8.505	17.452	51.267	2399.92166	13.02	13.02	1.81
B	4.06	4.0	2.791	2.623	1223.60	728.7	1239.00	510.3	2.398	8.585	17.524	51.009	2397.80521	12.98	12.98	1.82
C	4.06	4.0	2.791	2.623	1235.70	723.8	1238.20	514.4	2.402	8.417	17.373	51.549	2402.21617	12.95	12.95	1.83
Average =									2.40	8.5	17.45	51.28	2399.98	12.98	12.98	1.82

Sample No	% AC by weight of aggregate	% AC by weight of total mix (pb)	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF (mg/m ²)	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C							D	E	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/K	I * 1000	-	-	-
A	4.57	4.5	2.791	2.589	1238.10	733.30	1244.90	511.60	2.420	6.526	17.193	62.045	2420.05473	11.95	11.95	2.02
B	4.57	4.5	2.791	2.589	1233.40	738.60	1248.70	510.10	2.418	6.607	17.264	61.733	2417.957263	11.97	11.97	2.00
C	4.57	4.5	2.791	2.589	1241.30	744.80	1257.30	512.50	2.422	6.448	17.124	62.343	2422.04878	11.93	11.93	2.04
								Average =	2.42	6.5	17.19	62.04	2420	11.95	11.95	2.02

Sample No	% AC by weight of aggregate	% AC by weight of total mix (pb)	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF (mg/m ²)	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C							D	E	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/K	I * 1000	-	-	-
A	5.12	5.0	2.791	2.555	1248.00	744.20	1255.70	511.5	2.440	4.506	16.951	73.421	2439.882698	10.91	10.91	2.20
B	5.12	5.0	2.791	2.555	1250.90	742.40	1254.90	512.5	2.441	4.470	16.921	73.580	2440.780488	10.97	10.97	2.24
C	5.12	5.0	2.791	2.555	1239.00	743.50	1251.50	508	2.439	4.541	16.982	73.260	2438.976378	10.54	10.96	2.22
								Average =	2.44	4.5	16.95	73.42	2440	10.81	10.95	2.22

Sample No	% AC by weight of aggregate	% AC by weight of total mix (pb)	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF (mg/m ²)	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C							D	E	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/k	I * 1000	-	-	-
A	5.68	5.5	2.791	2.521	1251.70	750.10	1259.30	509.20	2.458	2.5	16.769	85.138	2458.169678	9.89	9.89	2.42
B	5.68	5.5	2.791	2.521	1252.70	746.00	1255.20	509.20	2.460	2.4	16.703	85.545	2460.133543	9.92	9.92	2.40
C	5.68	5.5	2.791	2.521	1259.80	749.90	1261.50	511.60	2.462	2.3	16.624	86.034	2462.47068	9.98	9.98	2.44
Average =									2.46	2.4	16.70	85.57	2460	9.93	9.93	2.42

Sample No	% AC by weight of aggregate	% AC by weight of total mix (pb)	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF (mg/m ²)	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C							D	E	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/K	I * 1000	-	-	-
A	6.24	6.0	2.791	2.487	1239.60	740.50	1240.50	500.00	2.479	0.314	16.501	98.099	2479.2	8.63	8.98	2.62
B	6.24	6.0	2.791	2.487	1254.80	755.10	1260.90	505.80	2.481	0.248	16.447	98.490	2480.822459	8.63	8.98	2.60
C	6.24	6.0	2.791	2.487	1254.20	757.90	1263.60	505.70	2.480	0.276	16.470	98.322	2480.126557	8.57	8.91	2.63
Average =									2.48	0.3	16.47	98.30	2480	8.61	8.95	2.62

WOOD ASH

First Trial

Method of Test - MARSHAL MIX DESIGN

ASTM D1559/AASHTO T-245

Sample No	% AC by weight of aggregate	% AC by weight of total mix (pb)	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF (mg/m ²)	Stability(KN)		Flow (mm)								
					In Air	In Water	Air SSD							Read	Adjusted									
					A	B	C										D	E	F	G	H	I	J	K
					-	-	-							-	-		-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)/C))	(K - J)*100/K	I * 1000
A	4.10	4.0	2.698	2.610	1220.50	722.8	1240.40	517.6	2.358	9.655	16.098	40.022	2357.99845	11.34	11.34	1.94								
B	4.10	4.0	2.698	2.610	1215.36	723.7	1238.50	514.8	2.361	9.546	15.997	40.323	2360.83916	11.42	11.42	1.90								
C	4.10	4.0	2.698	2.610	1215.15	721.1	1235.40	514.3	2.363	9.474	15.930	40.526	2362.72604	11.02	11.02	1.87								
Average =									2.36	9.56	16.01	40.29	2361	11.26	11.26	1.90								

Sample No	% AC by weight of aggregate	% AC by weight of total mix (pb)	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF (mg/m ²)	Stability(KN)		Flow (mm)								
					In Air	In Water	Air SSD							Read	Adjusted									
					A	B	C										D	E	F	G	H	I	J	K
					-	-	-							-	-		-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)/C))	(K - J)*100/K	I * 1000
A	4.53	4.5	2.698	2.576	1232.70	728.60	1242.70	514.10	2.398	6.918	15.127	54.264	2397.782533	10.21	10.21	1.91								
B	4.53	4.5	2.698	2.586	1234.41	730.60	1244.90	514.30	2.400	7.186	15.042	52.228	2400.174995	10.54	10.54	2.12								
C	4.53	4.5	2.698	2.586	1238.98	728.30	1242.70	514.40	2.409	6.860	14.744	53.471	2408.592535	10.33	10.33	2.02								
Average =									2.40	6.99	14.97	53.32	2402	10.36	10.36	2.02								

Sample No	% AC by weight of aggregate	% AC by weight of total mix (pb)	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF (mg/m ²)	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C							D	E	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100 - ((100 - B)*I/C))	(K - J)*100/K	I * 1000	-	-	-
A	5.04	5.0	2.698	2.562	1246.00	743.30	1258.70	515.4	2.418	5.639	14.875	62.095	2417.539775	9.45	9.45	2.04
B	5.04	5.0	2.698	2.562	1242.70	741.70	1256.10	514.4	2.416	5.706	14.936	61.800	2415.824261	9.34	9.34	2.21
C	5.04	5.0	2.698	2.562	1234.20	742.00	1252.00	510	2.420	5.543	14.789	62.522	2420	9.26	9.26	2.52
Average =								2.42	5.63	14.87	62.14	2418	9.35	9.35	2.26	

Sample No	% AC by weight of aggregate	% AC by weight of total mix (pb)	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF (mg/m ²)	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C							D	E	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100 - ((100 - B)*I/C))	(K - J)*100/k	I * 1000	-	-	-
A	5.68	5.5	2.698	2.538	1252.70	743.30	1257.60	514.30	2.436	4.029	14.686	72.564	2435.737896	8.72	8.72	2.45
B	5.68	5.5	2.698	2.538	1252.30	741.00	1255.00	514.00	2.436	4.004	14.663	72.695	2436.381323	8.39	8.39	2.76
C	5.68	5.5	2.698	2.538	1257.40	745.40	1261.40	516.00	2.437	3.987	14.648	72.784	2436.821705	8.29	8.29	2.84
Average =								2.44	4.01	14.67	72.68	2436	8.47	8.47	2.68	

Sample No	% AC by weight of aggregate	% AC by weight of total mix (pb)	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF (mg/m ²)	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C							D	E	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100 - ((100 - B)*I/C))	(K - J)*100/K	I * 1000	-	-	-
A	6.24	6.0	2.698	2.514	1253.16	731.50	1240.50	509.00	2.462	2.068	14.222	85.458	2462.003929	7.89	7.89	2.89
B	6.24	6.0	2.698	2.514	1255.80	751.10	1260.90	509.80	2.463	2.016	14.176	85.780	2463.318949	8.01	8.01	3.10
C	6.24	6.0	2.698	2.514	1255.30	753.90	1263.60	509.70	2.463	2.036	14.194	85.657	2462.821267	8.35	8.35	3.02
Average =									2.46	2.04	14.20	85.63	2463	8.08	8.08	3.00

FLY ASH

Second Trial

Method of Test - MARSHAL MIX DESIGN

ASTM D1559/AASHTO T-245

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
	A	B			C	D	In Air							In Water	Air SSD	
	-	-	-	-	E	F	G	H	I	J	K	L	M	-	-	-
A	4.03	4	2.764	2.634	1228.70	734.6	1240.70	506.1	2.428	7.829	15.678	50.062	2427.7811	9.75	10.14	1.76
B	4.03	4	2.764	2.634	1231.20	729.2	1236.30	507.1	2.428	7.824	15.673	50.081	2427.9235	9.21	9.58	1.87
C	4.03	4	2.764	2.634	1231.50	726.1	1233.50	507.4	2.427	7.856	15.702	49.970	2427.0792	9.33	9.70	1.92
Average =								2.43	7.84	15.68	50.04	2428	9.43	9.81	1.85	

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
	A	B			C	D	In Air							In Water	Air SSD	
	-	-	-	-	E	F	G	H	I	J	K	L	M	-	-	-
A	4.58	4.5	2.764	2.604	1227.20	733.00	1234.30	501.30	2.448	5.989	15.417	61.151	2448.0351	9.32	9.69	2.12
B	4.58	4.5	2.764	2.604	1223.50	739.40	1239.60	500.20	2.446	6.067	15.487	60.826	2446.0216	9.41	9.79	2.15
C	4.58	4.5	2.764	2.604	1236.10	745.70	1250.20	504.50	2.450	5.908	15.344	61.495	2450.1487	9.65	10.04	2.22
Average =								2.45	5.99	15.42	61.16	2448	9.46	9.84	2.16	

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
	A	B			C	D	In Air							In Water	Air SSD	
	-	-	-	-	E	F	G	H	I	J	K	L	M	-	-	-
A	5.23	5.0	2.764	2.574	1246.90	749.60	1254.80	505.2	2.468	4.113	15.169	72.886	2468.1314	9.21	9.58	2.54
B	5.23	5.0	2.764	2.574	1252.40	750.10	1257.10	507	2.470	4.032	15.097	73.294	2470.217	8.45	8.79	2.67
C	5.23	5.0	2.764	2.574	1238.10	746.90	1249.00	502.1	2.466	4.202	15.248	72.443	2465.8435	8.71	9.06	2.42
Average =								2.47	4.12	15.17	72.87	2468	8.79	9.14	2.54	

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C									
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/k	I * 1000	-	-	-
A	5.59	5.5	2.764	2.544	1246.98	753.10	1252.70	499.60	2.496	1.888	14.664	87.122	2495.9568	8.18	8.51	2.84
B	5.59	5.5	2.764	2.544	1254.50	751.90	1255.10	503.20	2.493	2.003	14.764	86.433	2493.0445	8.17	8.50	2.93
C	5.59	5.5	2.764	2.544	1234.71	752.30	1247.00	494.70	2.496	1.892	14.667	87.103	2495.8763	8.01	8.33	2.71
Average =									2.49	1.93	14.70	86.89	2495	8.12	8.44	2.83

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C									
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/K	I * 1000	-	-	-
A	6.15	6.0	2.764	2.514	1245.50	756.10	1252.70	496.60	2.508	0.236	14.704	98.392	2508.0548	7.91	8.23	2.92
B	6.15	6.0	2.764	2.514	1251.00	756.90	1255.10	498.20	2.511	0.118	14.603	99.194	2511.0397	7.98	8.30	3.01
C	6.15	6.0	2.764	2.514	1244.33	751.30	1247.00	495.70	2.510	0.149	14.630	98.980	2510.2481	8.02	8.34	3.05
Average =									2.51	0.17	14.65	98.86	2510	7.97	8.29	2.99

WOOD ASH

Second Trial

Method of Test - MARSHAL MIX DESIGN

ASTM D1559/AASHTO T-245

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
	A	B	C	D	In Air	In Water	Air SSD	H	I	J	K	L	M	Read	Adjusted	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/K	I * 1000	-	-	-
A	4.11	4.0	2.698	2.611	1211.10	716.6	1225.40	508.8	2.380	8.835	15.304	42.268	2380.3066	9.01	9.01	1.90
B	4.11	4.0	2.698	2.611	1212.57	726.3	1236.00	509.7	2.379	8.886	15.351	42.115	2378.9876	9.06	9.06	1.99
C	4.11	4.0	2.698	2.611	1219.00	732.1	1244.60	512.5	2.379	8.903	15.367	42.063	2378.5366	8.81	8.81	1.96
Average =								2.38	8.87	15.34	42.15	2379	8.96	8.96	1.95	

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
	A	B	C	D	In Air	In Water	Air SSD	H	I	J	K	L	M	Read	Adjusted	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/K	I * 1000	-	-	-
A	4.51	4.5	2.698	2.597	1241.30	731.70	1242.30	510.60	2.431	6.390	13.949	54.192	2431.0615	8.01	8.01	2.04
B	4.51	4.5	2.698	2.597	1236.38	729.90	1238.70	508.80	2.430	6.431	13.987	54.022	2429.9921	8.02	8.02	2.24
C	4.51	4.5	2.698	2.597	1240.40	734.90	1245.50	510.60	2.429	6.457	14.011	53.912	2429.2989	8.3	8.30	2.14
Average =								2.43	6.43	13.98	54.04	2430	8.11	8.11	2.14	

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
	A	B	C	D	In Air	In Water	Air SSD	H	I	J	K	L	M	Read	Adjusted	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/K	I * 1000	-	-	-
A	5.22	5.0	2.698	2.583	1248.28	747.10	1256.60	509.5	2.450	5.149	13.732	62.506	2450.0098	7.86	7.86	2.57
B	5.22	5.0	2.698	2.583	1251.90	741.90	1253.30	511.4	2.448	5.227	13.803	62.132	2447.9859	7.42	7.42	2.78
C	5.22	5.0	2.698	2.583	1245.30	738.20	1247.10	508.9	2.447	5.264	13.837	61.959	2447.0426	8.03	8.03	2.89
Average =								2.45	5.21	13.79	62.20	2448	7.77	7.77	2.75	

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C							D	E	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/k	I * 1000	-	-	-
A	5.71	5.5	2.698	2.569	1248.40	750.10	1255.70	505.60	2.469	3.887	13.516	71.242	2469.1456	7.20	7.49	2.91
B	5.71	5.5	2.698	2.569	1246.30	749.20	1251.90	502.70	2.479	3.495	13.163	73.448	2479.2123	7.00	7.28	2.98
C	5.71	5.5	2.698	2.569	1249.10	750.70	1258.30	507.60	2.461	4.212	13.808	69.497	2460.7959	7.02	7.30	2.89
Average =									2.47	3.86	13.50	71.40	2470	7.07	7.36	2.93

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C							D	E	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/K	I * 1000	-	-	-
A	6.17	6.0	2.698	2.555	1235.04	745.40	1241.60	496.20	2.489	2.583	13.282	80.550	2488.9964	6.98	7.26	2.98
B	6.17	6.0	2.698	2.555	1236.53	755.70	1252.10	496.40	2.491	2.505	13.212	81.040	2490.9952	7.01	7.29	3.04
C	6.17	6.0	2.698	2.555	1240.00	755.80	1253.80	498.00	2.490	2.546	13.248	80.785	2489.9598	6.89	7.17	3.10
Average =									2.49	2.54	13.25	80.79	2490	6.96	7.24	3.04

FLY ASH

Third Trial

Method of Test - MARSHAL MIX DESIGN

ASTM D1559/AASHTO T-245

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
	A	B	C	D	In Air	In Water	Air SSD	H	I	J	K	L	M	Read	Adjusted	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/K	I * 1000	-	-	-
A	4.45	4.0	2.781	2.634	1223.40	724.7	1237.30	512.6	2.387	9.390	17.613	46.684	2386.6563	13.12	13.12	1.81
B	4.45	4.0	2.781	2.634	1221.60	723.7	1236.00	512.3	2.385	9.471	17.686	46.450	2384.5403	13.03	13.03	1.79
C	4.45	4.0	2.781	2.634	1233.70	718.8	1235.20	516.4	2.389	9.300	17.530	46.950	2389.0395	13.01	13.01	1.8
Average =									2.39	9.4	17.61	46.69	2386.75	13.05	13.05	1.80

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
	A	B	C	D	In Air	In Water	Air SSD	H	I	J	K	L	M	Read	Adjusted	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/K	I * 1000	-	-	-
A	4.58	4.5	2.781	2.604	1239.43	725.40	1239.90	514.50	2.409	7.489	17.275	56.650	2408.999	12.57	12.57	2.11
B	4.58	4.5	2.781	2.604	1235.40	730.70	1243.80	513.10	2.408	7.538	17.319	56.476	2407.7178	12.67	12.67	2.08
C	4.58	4.5	2.781	2.604	1243.30	736.90	1252.40	515.50	2.412	7.380	17.177	57.038	2411.8332	12.43	12.43	2.01
Average =									2.41	7.5	17.26	56.72	2410	12.56	12.56	2.07

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C							D	E	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/K	1 * 1000	-	-	-
A	5.18	5.0	2.781	2.574	1246.00	740.70	1253.70	513	2.429	5.639	17.030	66.887	2428.8499	11.98	11.98	2.30
B	5.18	5.0	2.781	2.574	1246.30	738.90	1252.90	514	2.425	5.800	17.171	66.222	2424.7082	12.11	12.11	2.23
C	5.18	5.0	2.781	2.574	1237.00	740.00	1249.50	509.5	2.428	5.677	17.063	66.728	2427.8705	12.06	12.06	2.37
Average =									2.43	5.7	17.09	66.61	2427	12.05	12.05	2.30

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C							D	E	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/k	1 * 1000	-	-	-
A	5.66	5.5	2.781	2.544	1249.70	745.20	1254.40	509.20	2.454	3.5	16.603	78.750	2454.2419	11.88	11.88	2.45
B	5.66	5.5	2.781	2.544	1250.70	741.10	1251.10	510.00	2.452	3.6	16.668	78.386	2452.3529	11.92	11.92	2.67
C	5.66	5.5	2.781	2.544	1255.44	743.80	1256.40	512.60	2.449	3.7	16.776	77.778	2449.1611	11.86	11.86	2.88
Average =									2.45	3.6	16.68	78.30	2452	11.89	11.89	2.67

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
					In Air	In Water	Air SSD							Read	Adjusted	
					A	B	C							D	E	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100-((100-B)*I/C))	(K - J)*100/K	1 * 1000	-	-	-
A	6.20	6.0	2.781	2.514	1234.60	734.50	1234.80	500.30	2.468	1.841	16.589	88.903	2467.7194	9.91	10.31	3.02
B	6.20	6.0	2.781	2.514	1254.80	747.00	1255.90	508.90	2.466	1.921	16.657	88.468	2465.7104	10.32	10.32	3.05
C	6.20	6.0	2.781	2.514	1254.20	749.80	1258.60	508.80	2.465	1.948	16.681	88.319	2465.0157	10.21	10.21	3.10
Average =									2.47	1.9	16.64	88.56	2466	10.15	10.28	3.06

WOOD ASH

Third Trial

Method of Test - MARSHAL MIX DESIGN

ASTM D1559/AASHTO T-245

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
	A	B	C	D	In Air	In Water	Air SSD	H	I	J	K	L	M	Read	Adjusted	
					E	F	G			(D-I)*100/D	(100-((100-B)*I/C))	(K-J)*100/K	I*1000			
	-	-	-	-	-	-	-	G - F	E / H					-	-	-
A	4.08	4.0	2.687	2.632	1220.50	712.7	1234.50	521.8	2.339	11.132	16.433	32.259	2339.0188	11.98	11.98	1.83
B	4.08	4.0	2.687	2.632	1215.36	713.6	1233.60	520	2.337	11.199	16.496	32.110	2337.2308	12.03	12.03	1.89
C	4.08	4.0	2.687	2.632	1215.15	711.0	1230.50	519.5	2.339	11.129	16.430	32.264	2339.076	12.00	12.00	1.88
Average =									2.34	11.15	16.45	32.21	2338	12.00	12.00	1.87

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
	A	B	C	D	In Air	In Water	Air SSD	H	I	J	K	L	M	Read	Adjusted	
					E	F	G			(D-I)*100/D	(100-((100-B)*I/C))	(K-J)*100/K	I*1000			
	-	-	-	-	-	-	-	G - F	E / H					-	-	-
A	4.50	4.5	2.687	2.602	1222.60	723.50	1242.70	519.20	2.355	9.501	16.308	41.737	2354.7766	11.56	11.56	1.93
B	4.50	4.5	2.687	2.602	1224.31	725.70	1244.90	519.20	2.358	9.375	16.191	42.098	2358.0701	11.64	11.64	1.97
C	4.50	4.5	2.687	2.602	1228.88	721.40	1242.70	521.30	2.357	9.403	16.217	42.017	2357.3374	11.43	11.43	2.09
Average =									2.36	9.43	16.24	41.95	2357	11.54	11.54	2.00

Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
	A	B	C	D	In Air	In Water	Air SSD	H	I	J	K	L	M	Read	Adjusted	
					E	F	G			(D-I)*100/D	(100-((100-B)*I/C))	(K-J)*100/K	I*1000			
	-	-	-	-	-	-	-	G - F	E / H					-	-	-
A	5.01	5.0	2.687	2.572	1236.10	738.40	1258.70	520.3	2.376	7.630	16.005	52.323	2375.7448	11.02	11.02	2.11
B	5.01	5.0	2.687	2.572	1232.60	736.90	1256.10	519.2	2.374	7.697	16.065	52.089	2374.037	10.99	10.99	2.32
C	5.01	5.0	2.687	2.572	1224.10	737.00	1252.00	515	2.377	7.586	15.964	52.482	2376.8932	11.06	11.06	2.24
Average =									2.38	7.64	16.01	52.30	2376	11.02	11.02	2.22

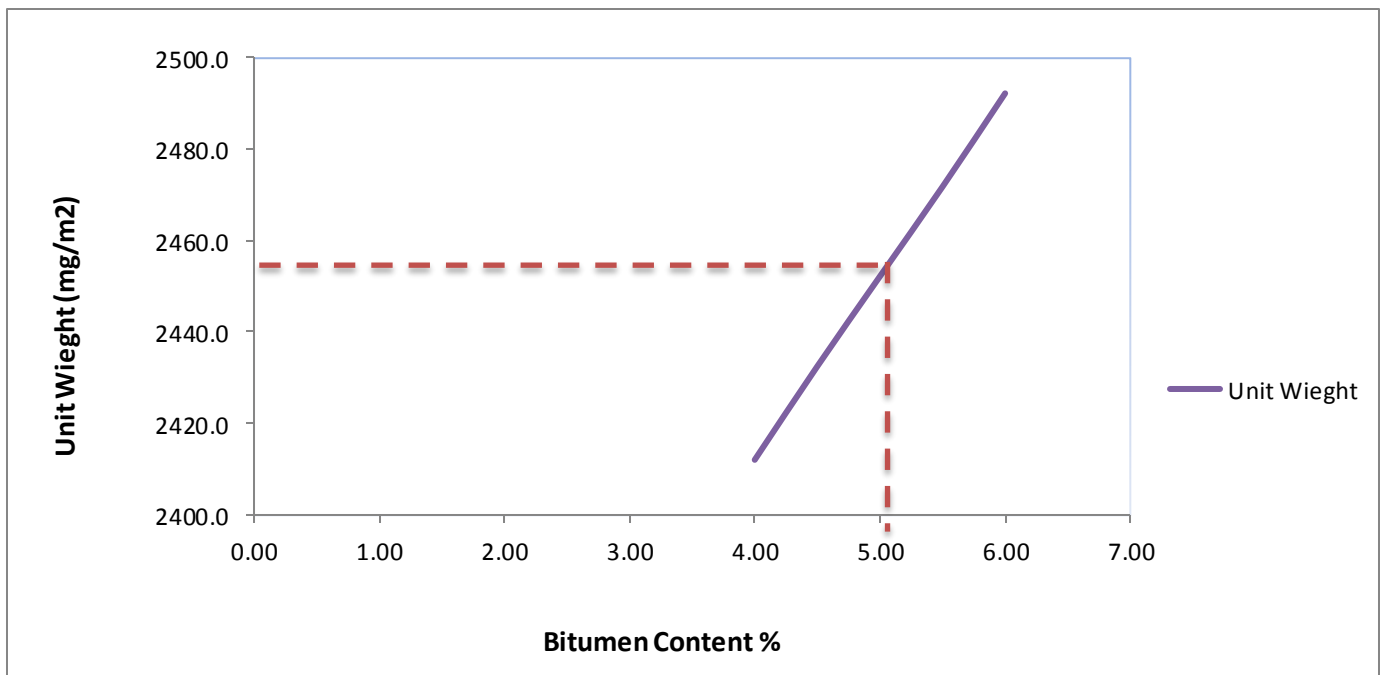
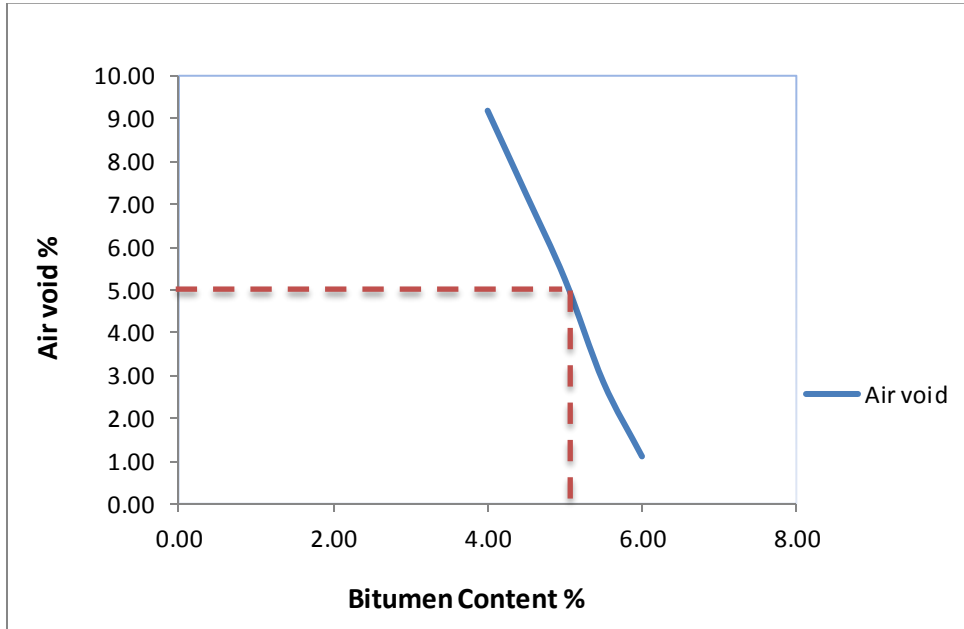
Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
	A	B	C	D	In Air	In Water	Air SSD	H	I	J	K	L	M	Read	Adjusted	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100 - ((100 - B)*I/C))	(K - J)*100/k	1 * 1000	-	-	-
A	5.65	5.5	2.687	2.542	1235.98	738.40	1252.50	514.10	2.404	5.422	15.447	64.897	2404.1626	10.76	10.76	2.45
B	5.65	5.5	2.687	2.542	1240.20	737.10	1252.90	515.80	2.404	5.412	15.438	64.942	2404.4203	10.57	10.57	2.76
C	5.65	5.5	2.687	2.542	1247.30	740.30	1259.30	519.00	2.403	5.457	15.478	64.743	2403.2755	10.42	10.42	2.84
Average =									2.40	5.43	15.45	64.86	2404	10.58	10.58	2.68

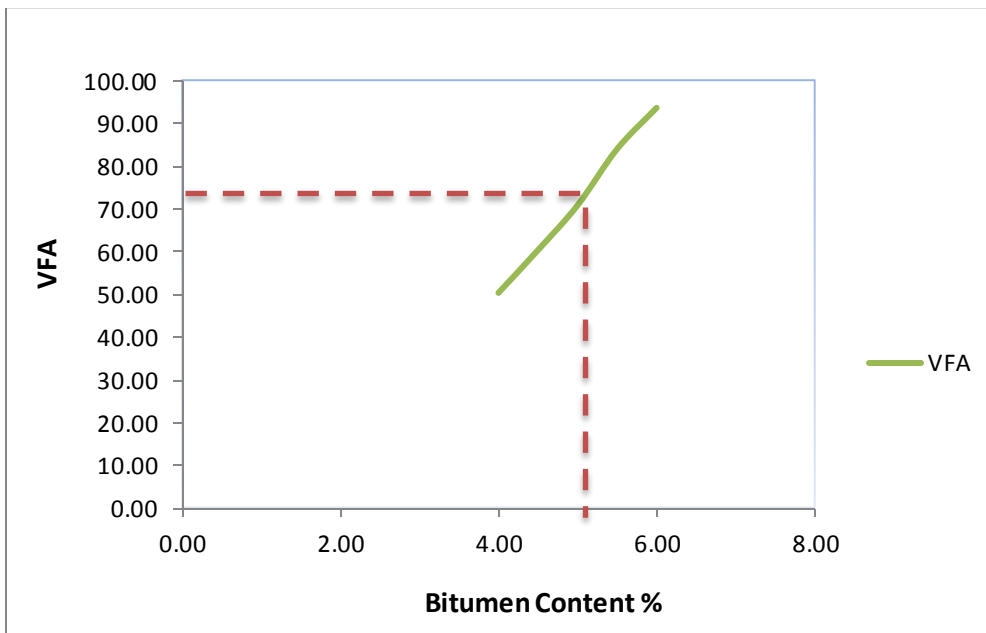
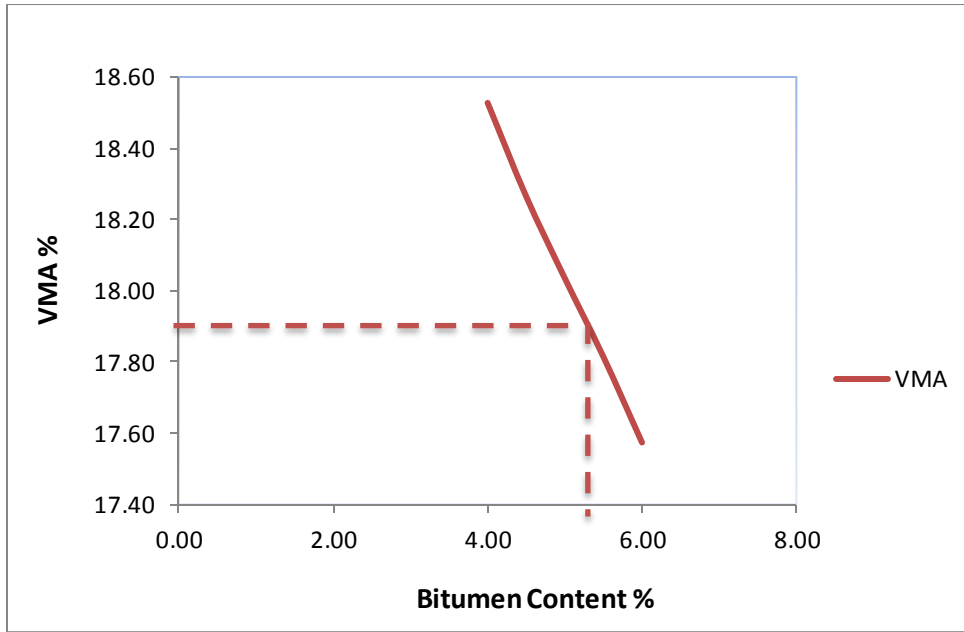
Sample No	% AC by weight of	% AC by weight of	Bulk SG of agg combined	Bulk SG of paving mix (G _{mm})	Weight grams			Bulk Volume CC	Bulk SG Comp. Mix (gm/CC)	Air Void	% V.M.A	% V.F.A	Unit Weight PCF	Stability(KN)		Flow (mm)
	A	B	C	D	In Air	In Water	Air SSD	H	I	J	K	L	M	Read	Adjusted	
	-	-	-	-	-	-	-	G - F	E / H	(D - I)*100/D	(100 - ((100 - B)*I/C))	(K - J)*100/K	1 * 1000	-	-	-
A	6.21	6.0	2.687	2.512	1243.06	722.60	1235.70	513.10	2.423	3.557	15.248	76.672	2422.6467	9.57	9.57	2.78
B	6.21	6.0	2.687	2.512	1245.70	742.00	1255.80	513.80	2.424	3.484	15.184	77.055	2424.4842	9.78	9.78	2.89
C	6.21	6.0	2.687	2.512	1245.40	744.70	1258.40	513.70	2.424	3.488	15.188	77.031	2424.3722	9.44	9.44	2.99
Average =									2.42	3.51	15.21	76.92	2424	9.60	9.60	2.89

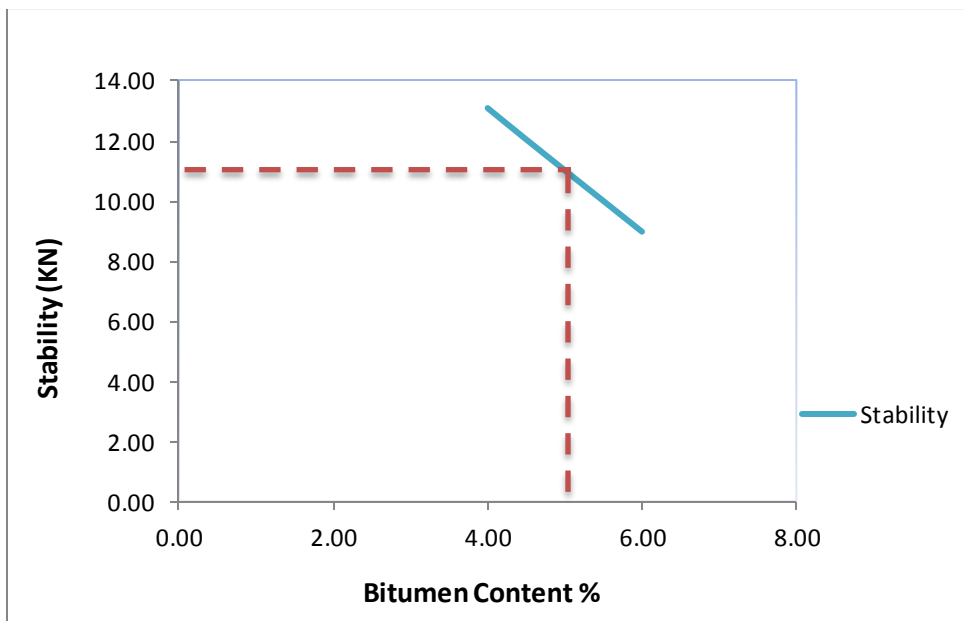
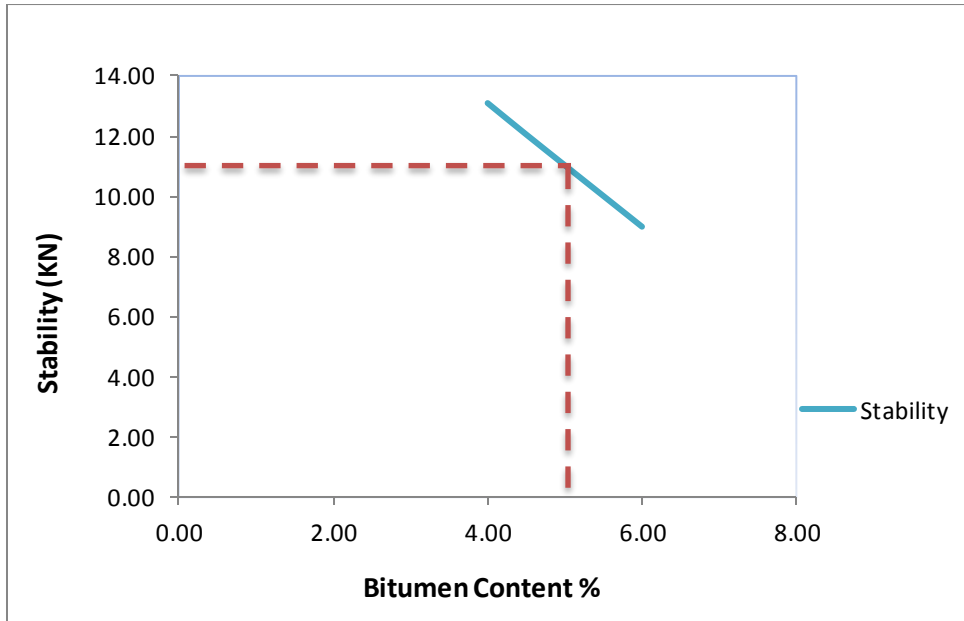
APPENDIX B

Graphs of Marshall Properties at Optimum Bitumen Content

First Trial
Basaltic Rock Filler

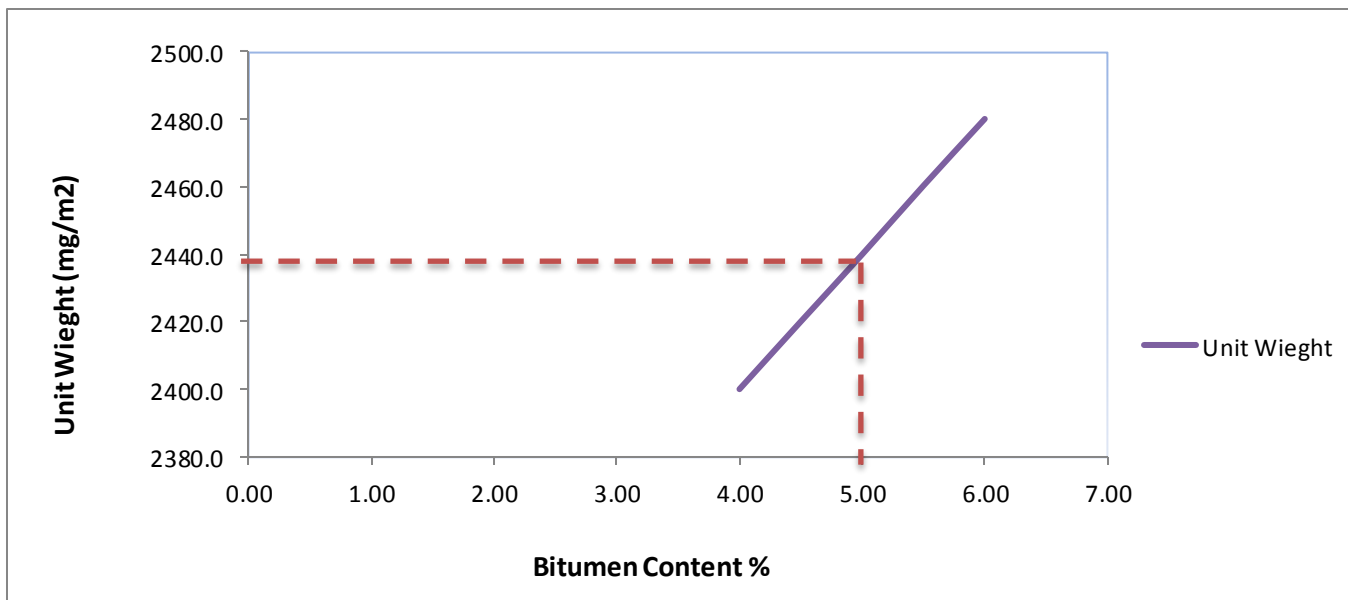
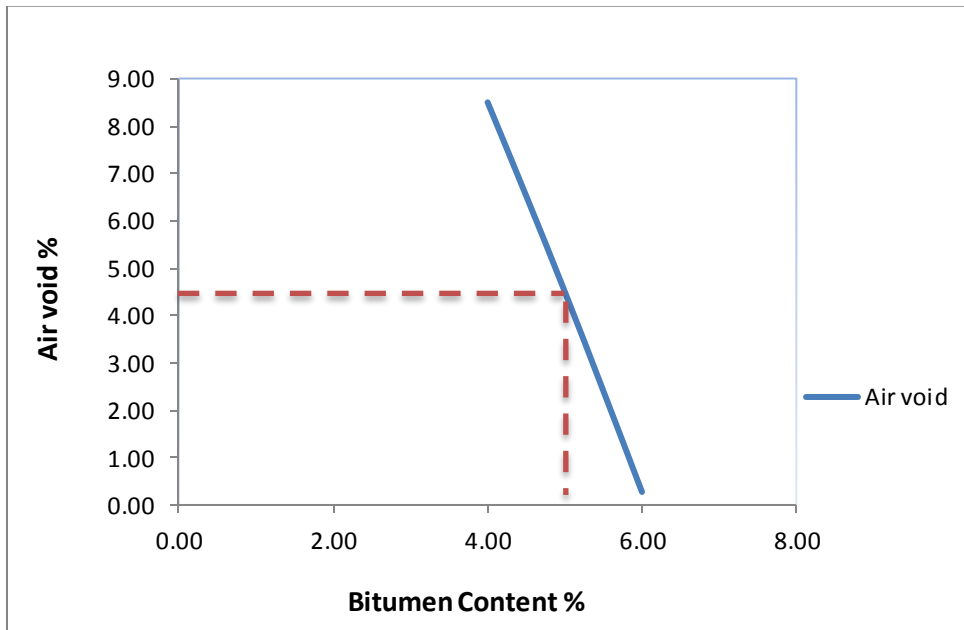


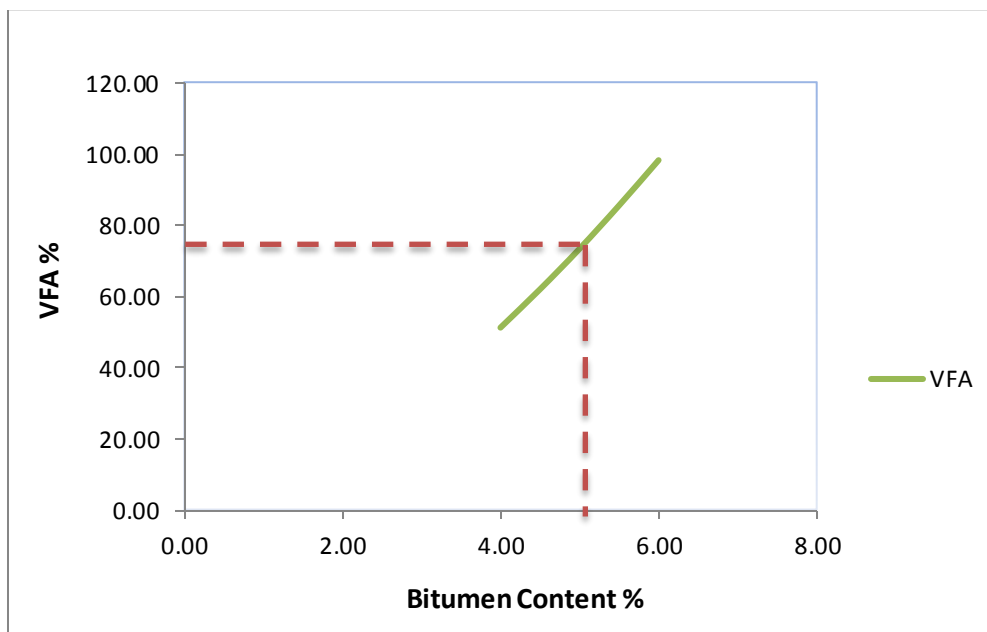
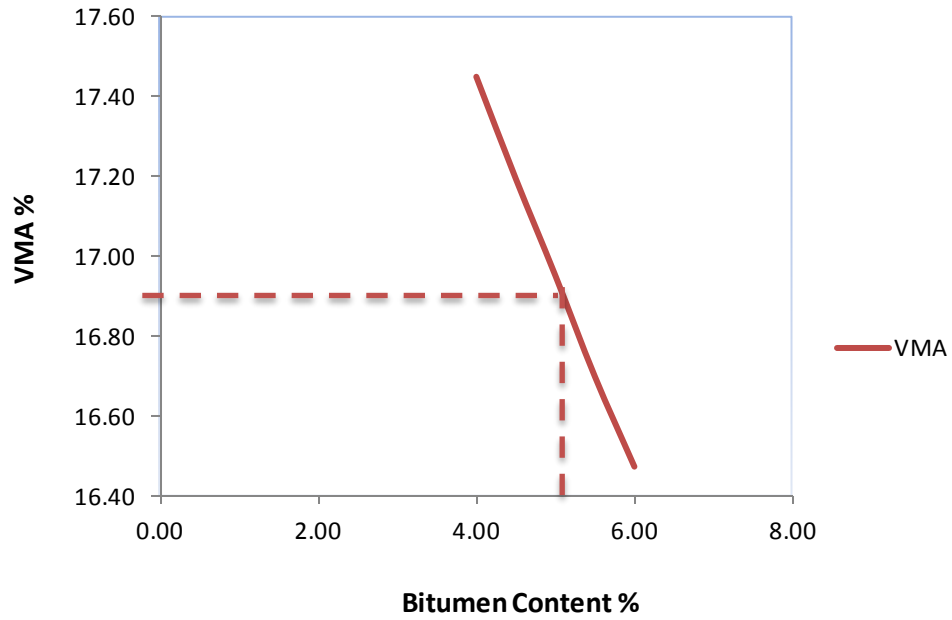


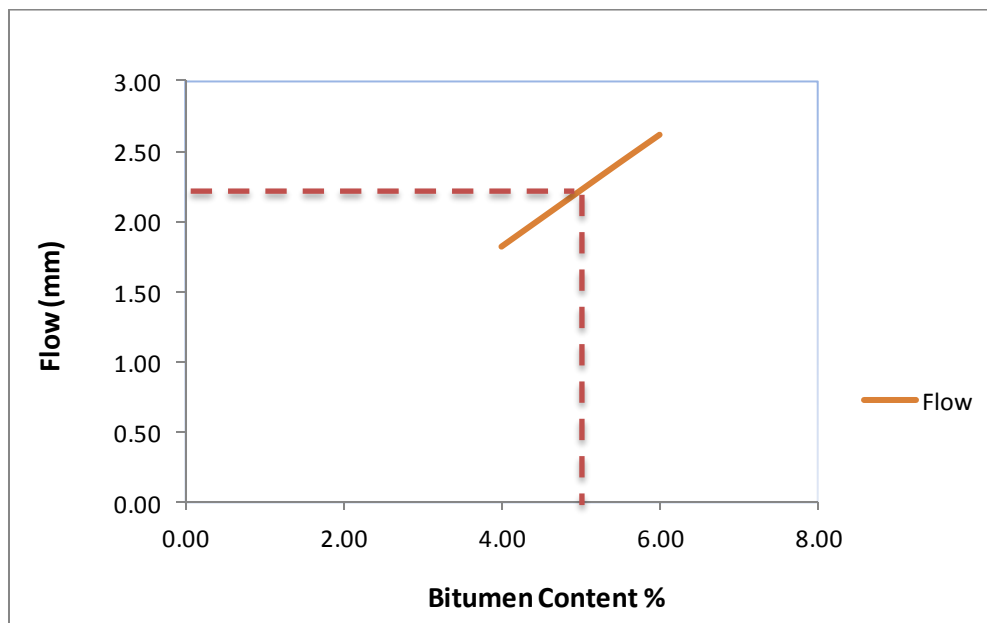
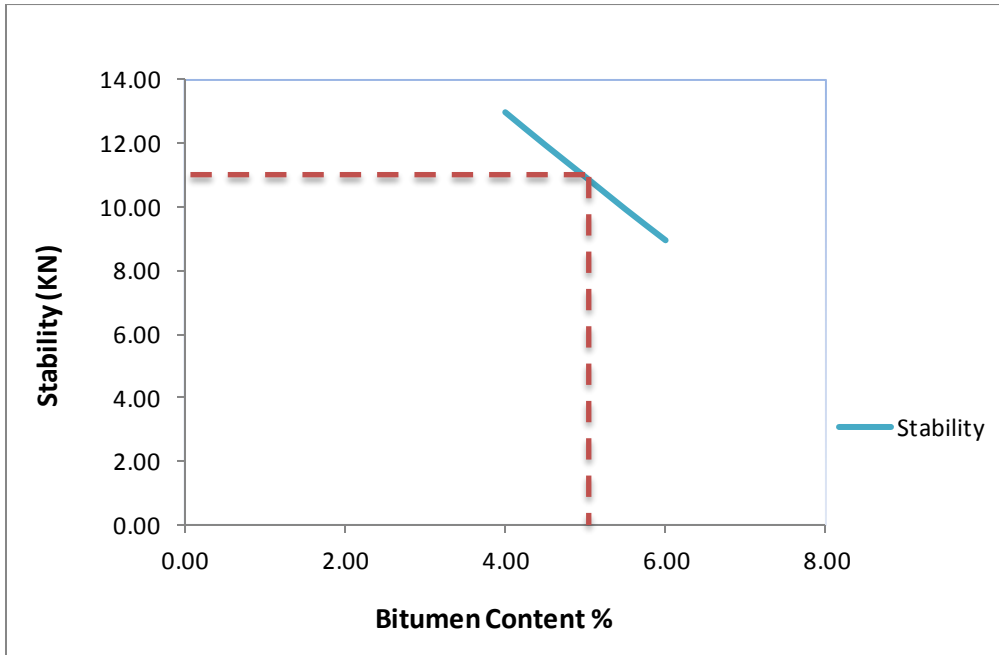


First Trial

Fly Ash

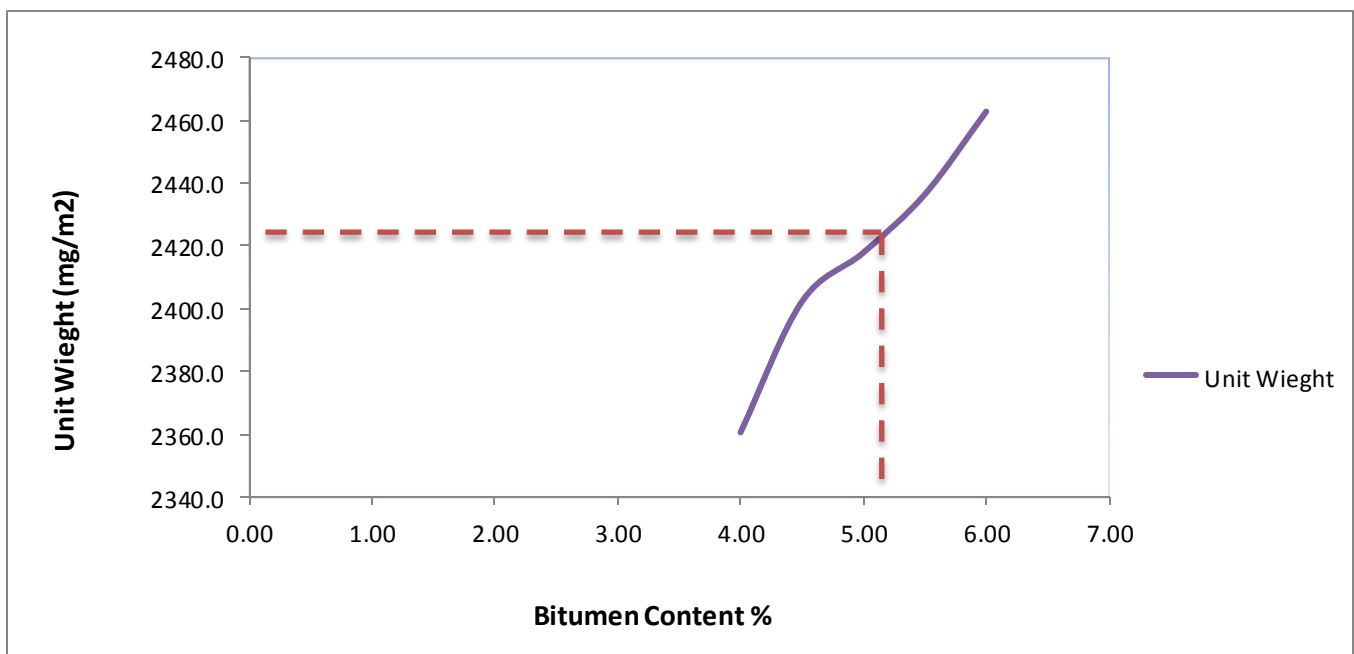
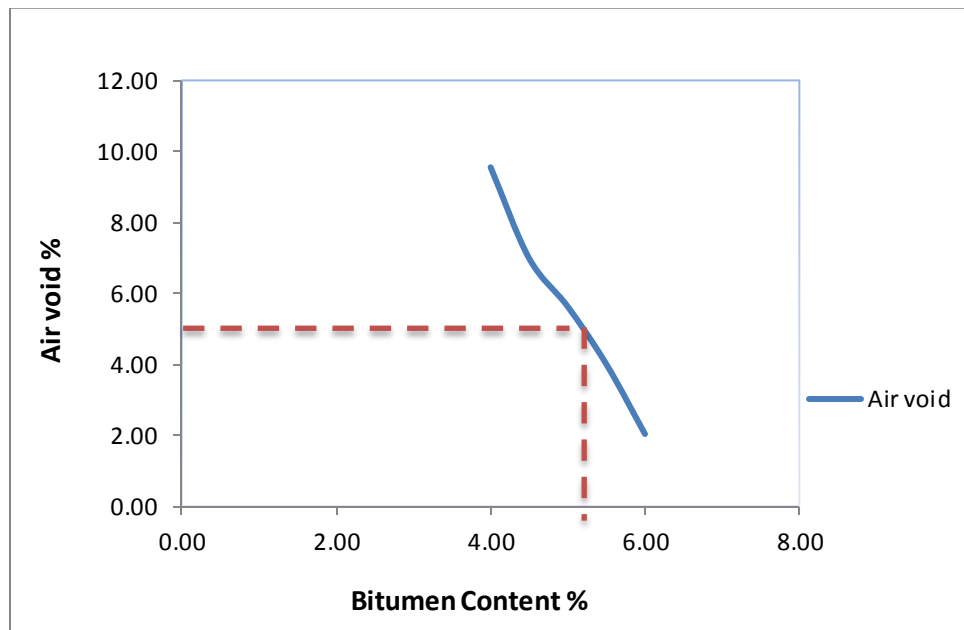


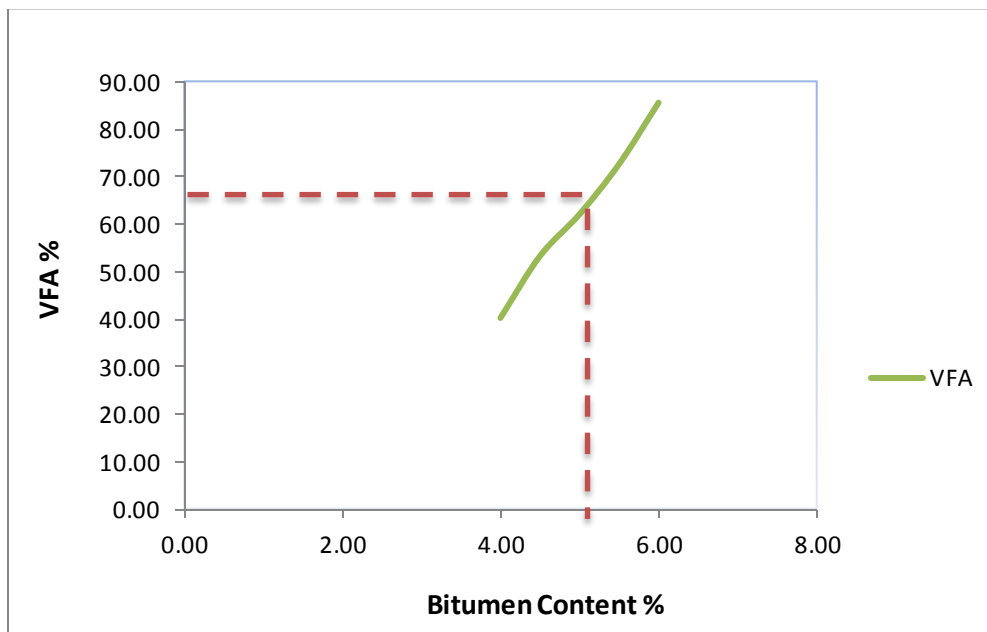
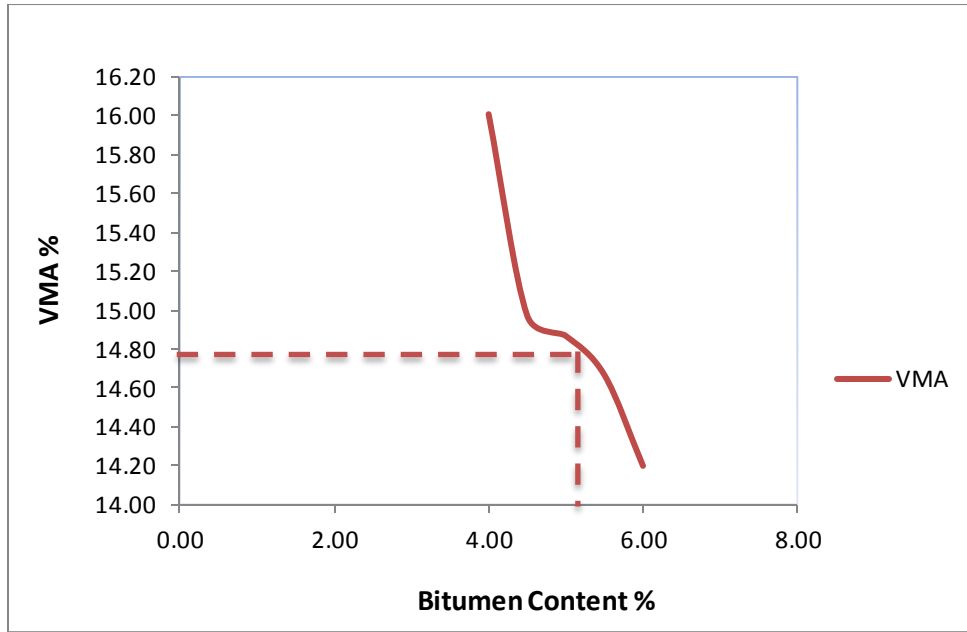


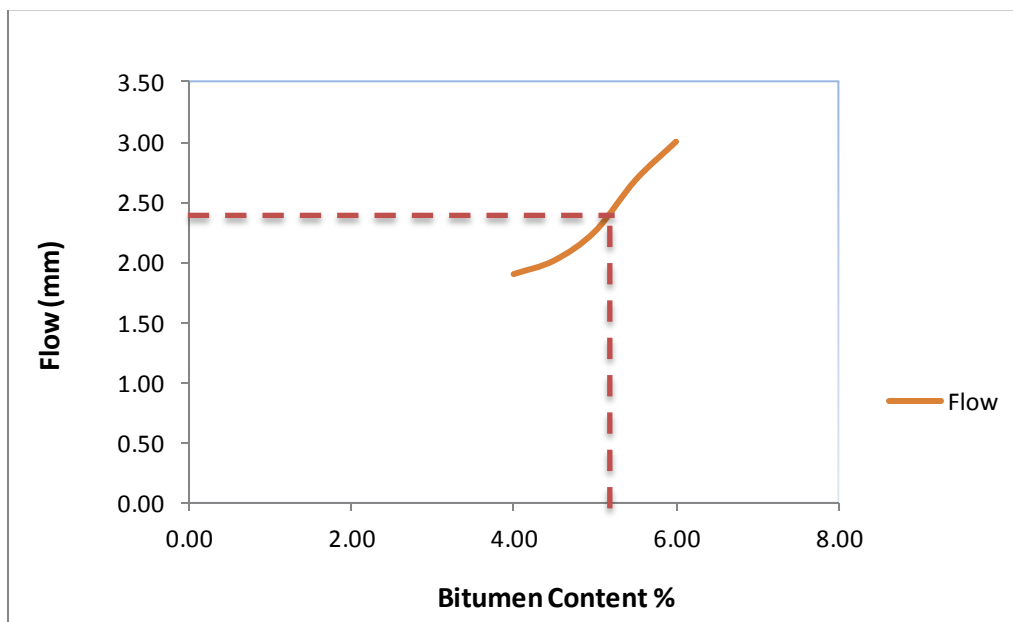
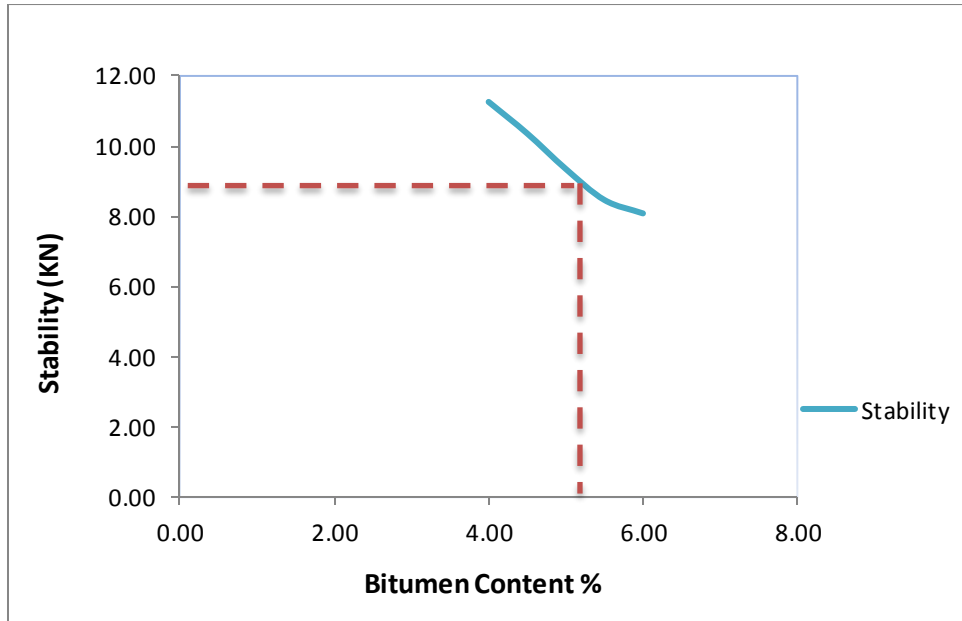


First Trial

Wood Ash

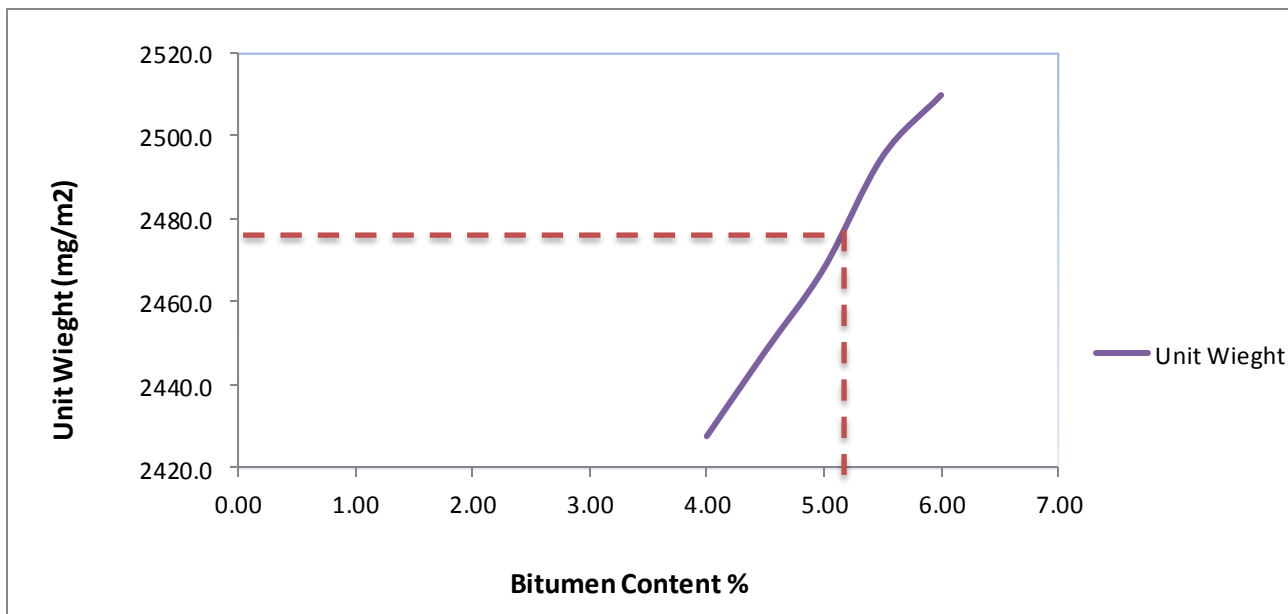
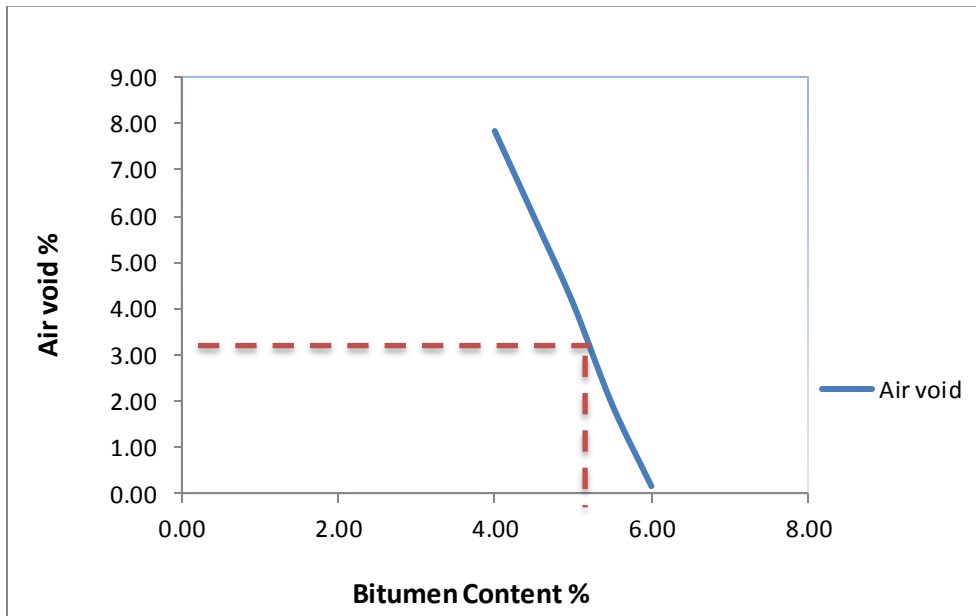


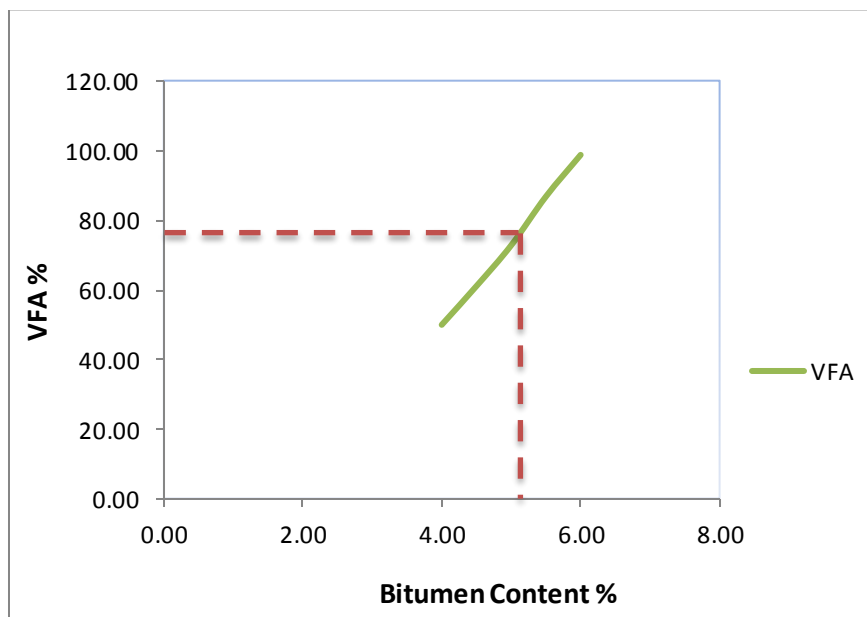
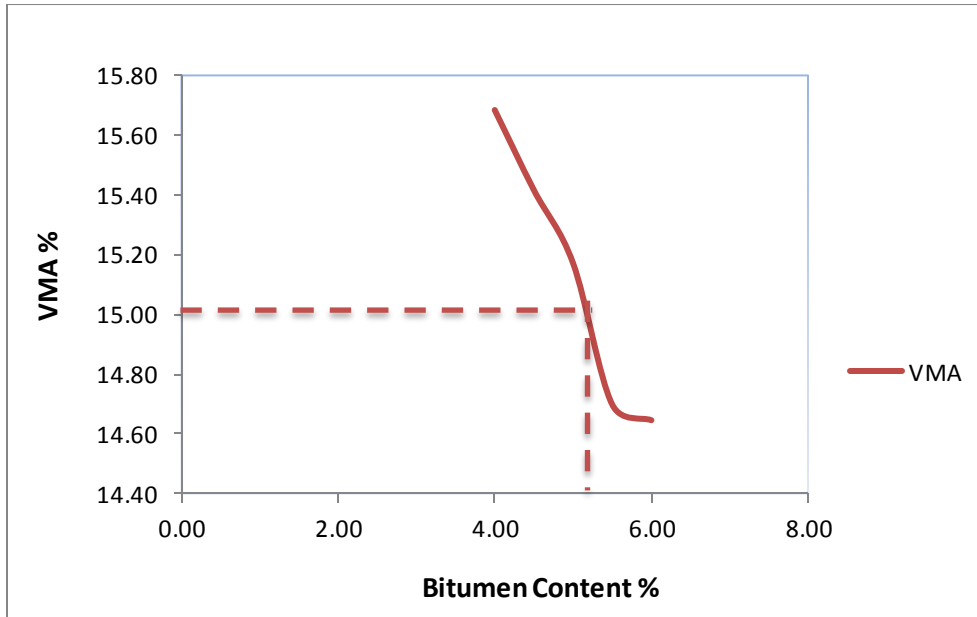


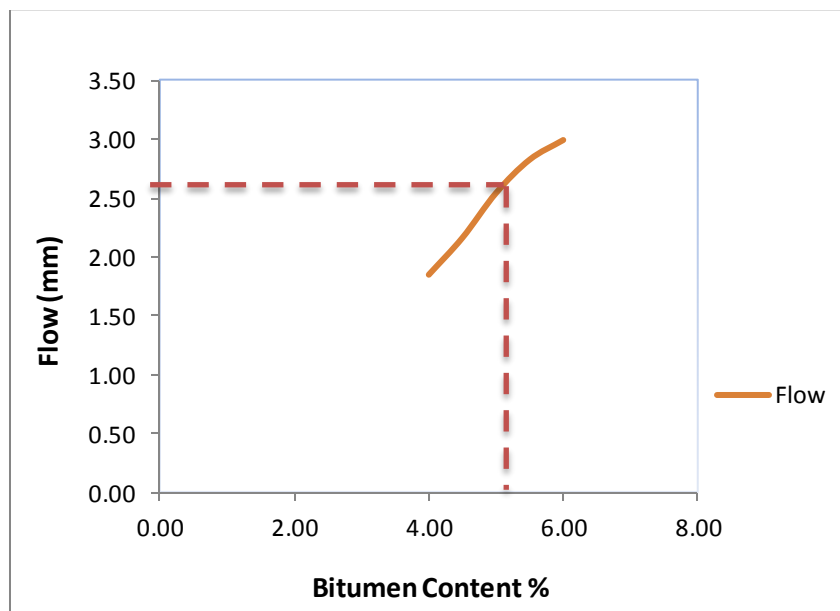
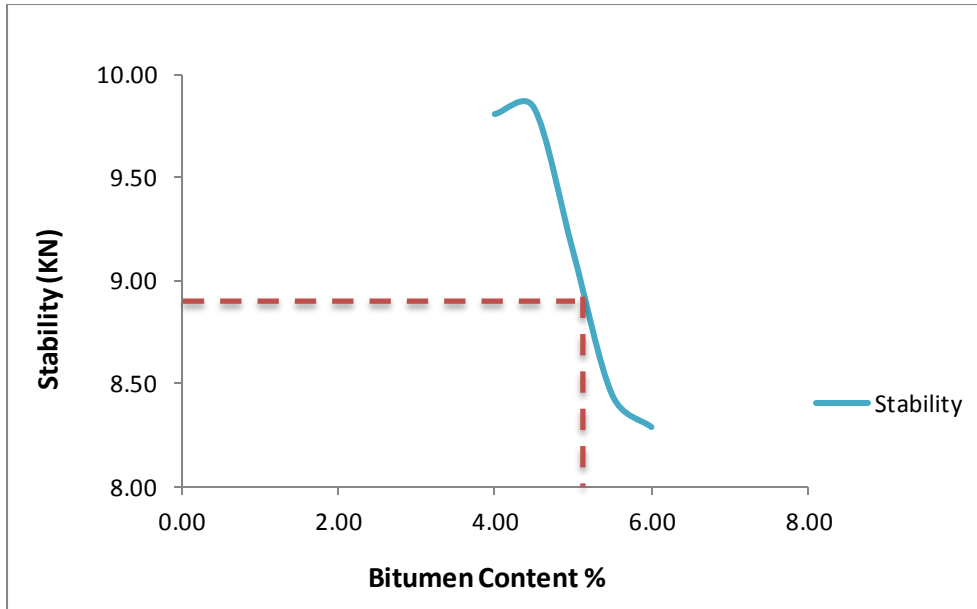


Second Trial

Fly Ash

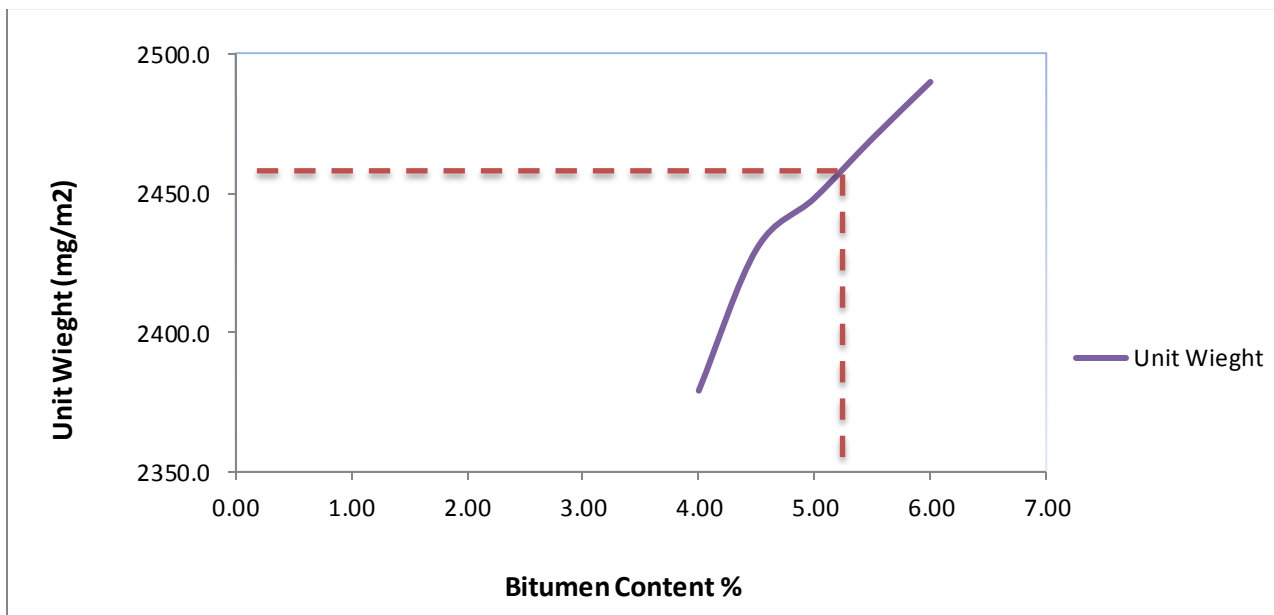
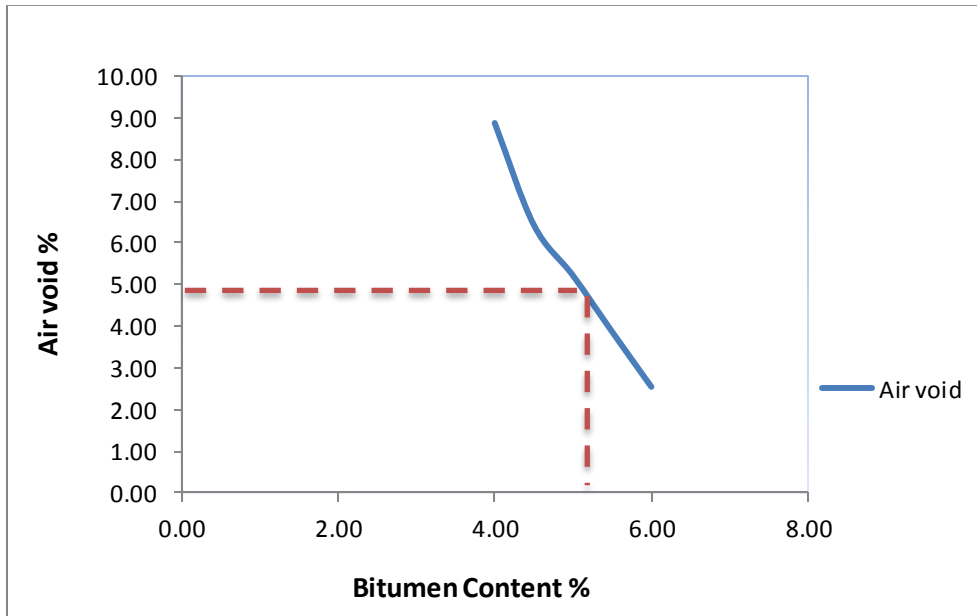


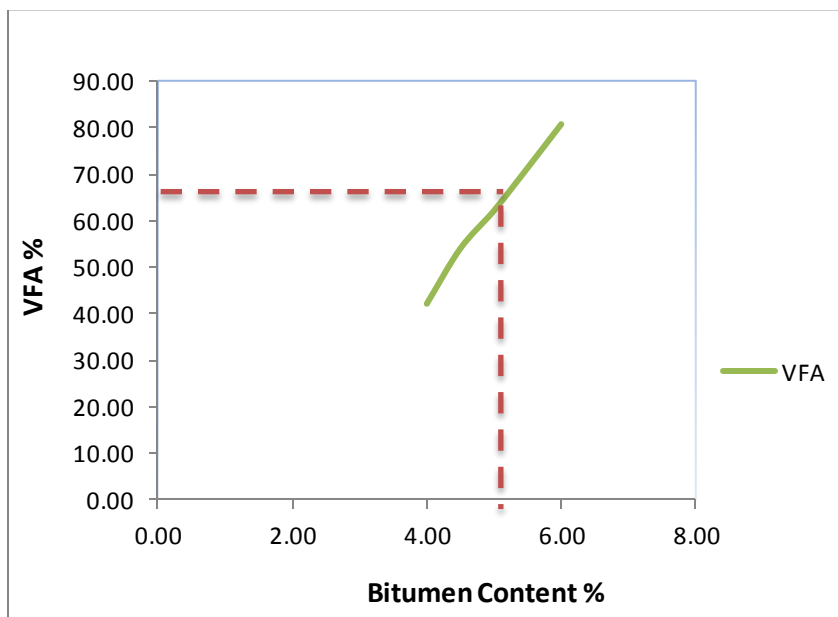
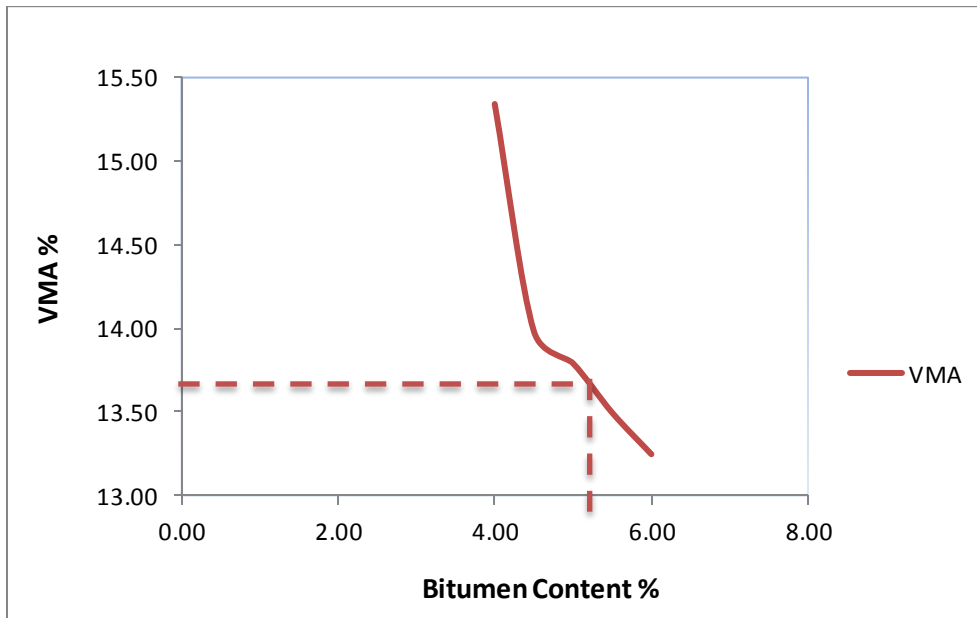


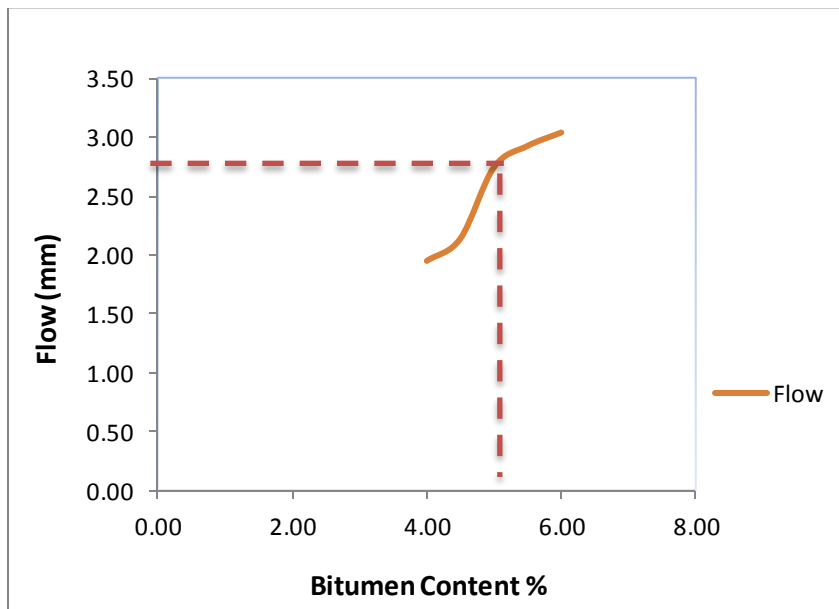
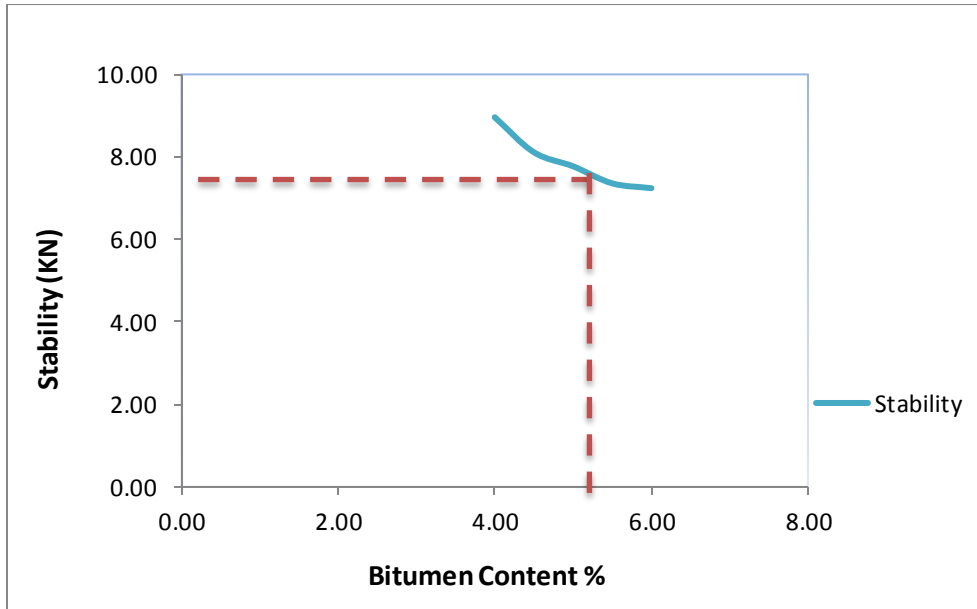


Second Trial

Wood Ash

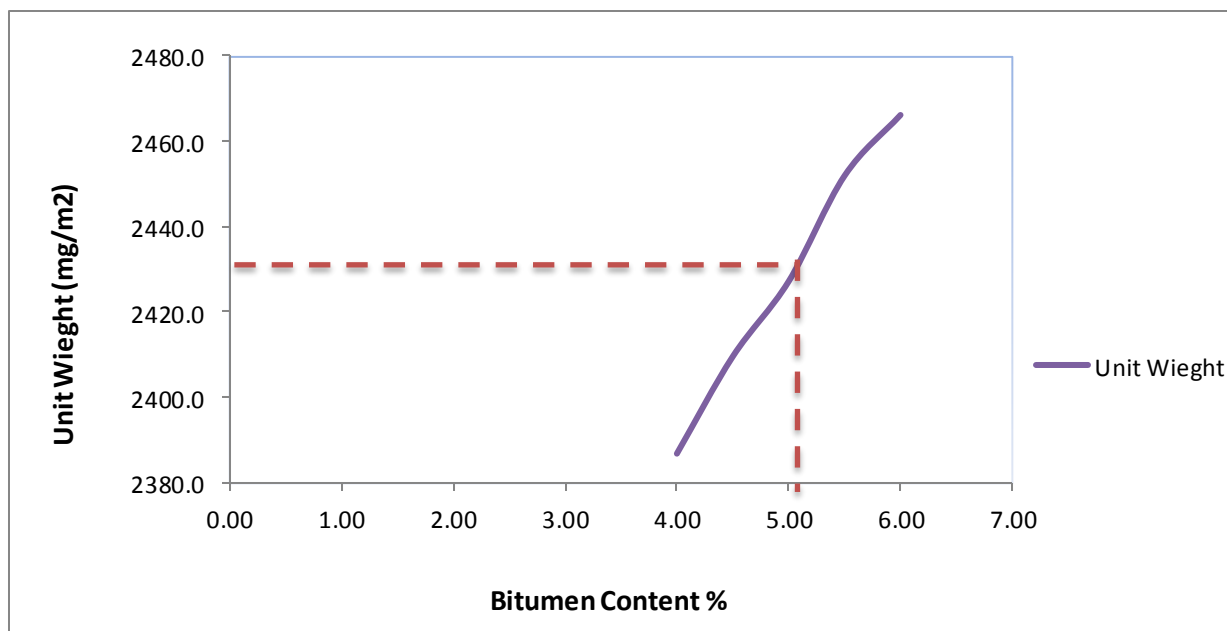
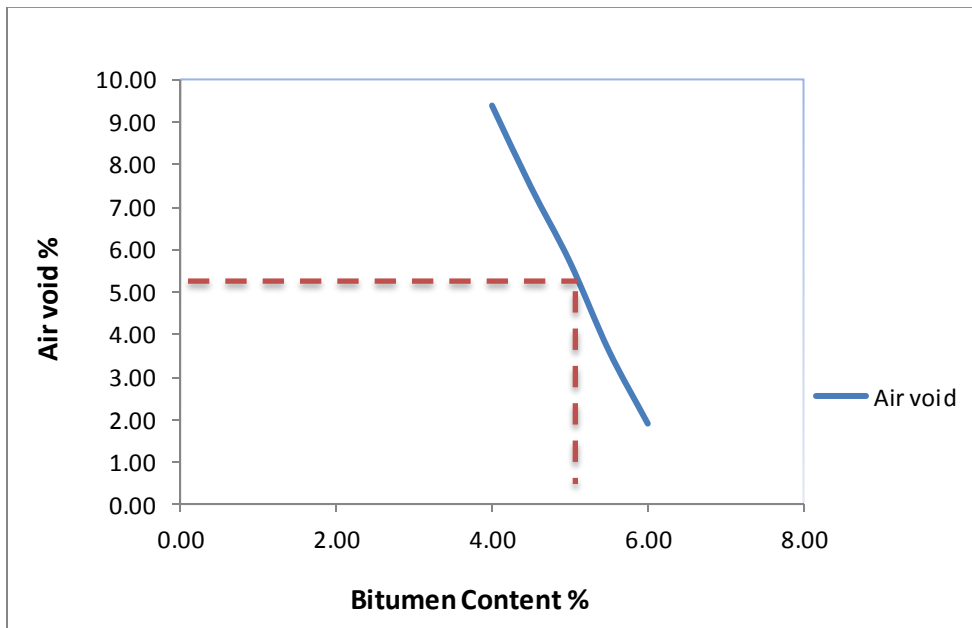


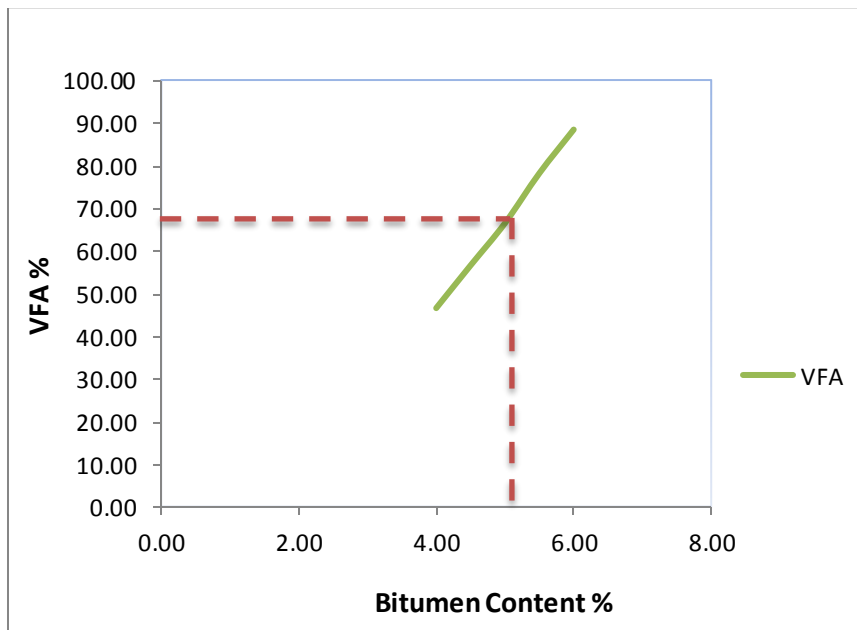
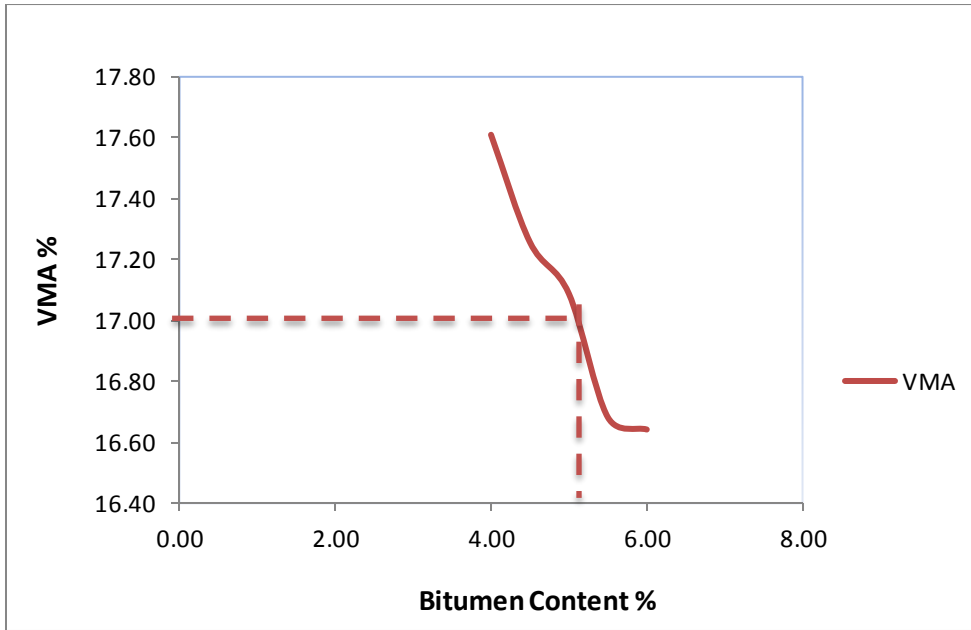


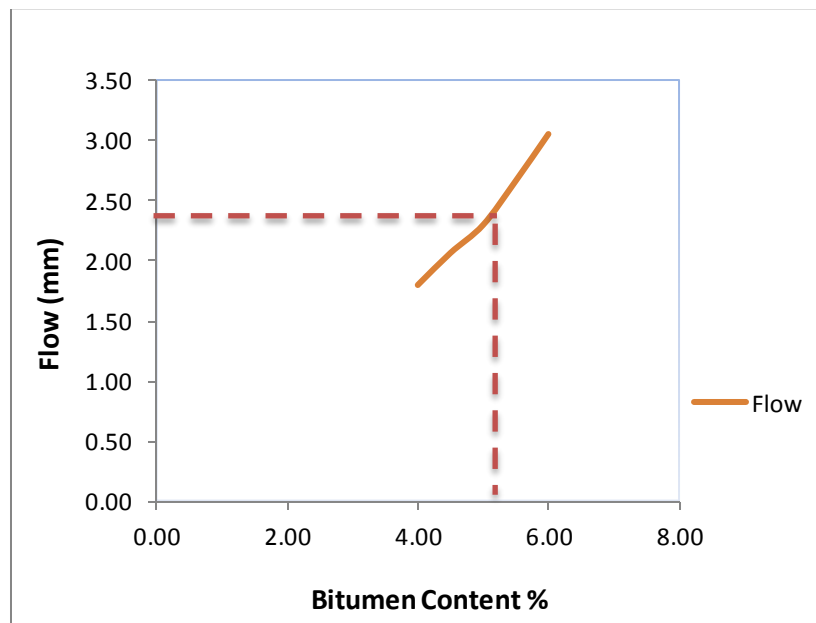
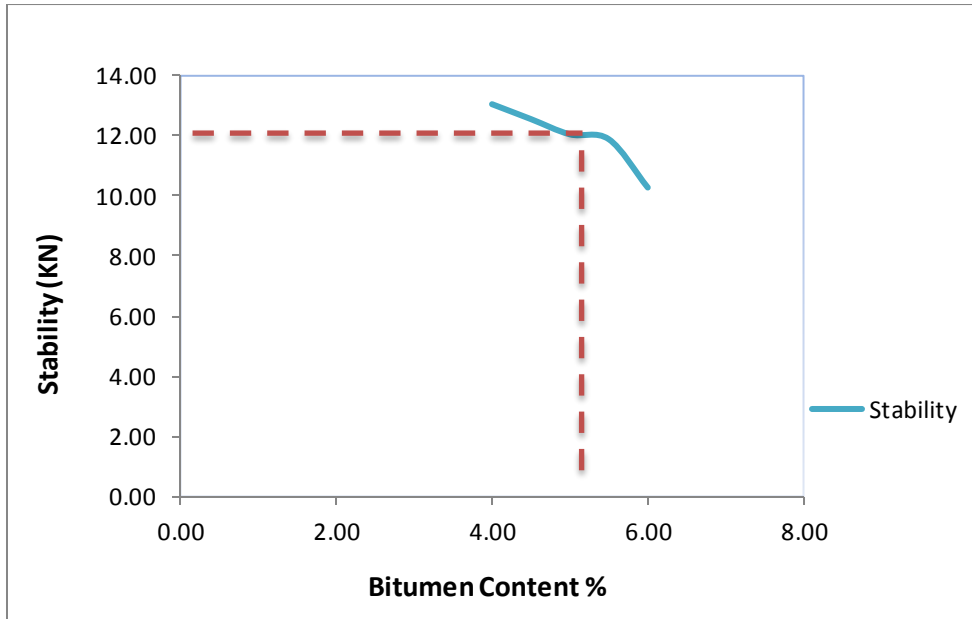


Third Trial

Fly Ash







Third Trial
Wood Ash

