JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

PERFORMANCE EVALUATION OF HOT-MIX ASPHALT MIXTURE USING BELESSA KAOLIN AS A FILLER WITH SUPERPAVE AGGREGATE GRADATION.

A Final Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Highway Engineering Stream).

By:

Amanuel Tamiru

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APPROVED BY BOARD EXAMINER

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Co-Advisor Signature Date

DECLARATION

I, the undersigned, declare that this research entitled by "Performance Evaluation of Hot-Mix Asphalt Mixture using Belessa Kaolin as a Filler with Superpave Aggregate Gradation**"** is my original work and has not been presented by any other person on an award of degree in this or other university and all sources of materials used for this thesis have been duly acknowledge.

Candidate: Amanuel Tamiru ______________ _____/______/____

Signature Date

As masters research advisors, we hear by certify that we have read and evaluated this MSc research prepare under our guidance, by Amanuel Tamiru entitled by *''Performance Evaluation of Hot-Mix Asphalt Mixture using Belessa Kaolin as a Filler with Superpave Aggregate Gradation***".**

We recommend that it can be submitted as fulfilling the MSc research requirement.

1. Anteneh Geremew (Assi.Prof.) _______________ ____/_______/____

   Principal advisor Signature Date

2. Mr. Abubekir Jemal (MS.c) ______________ ____/_______/____

   Co-advisor Signature Date

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ABSTRACT

Filler, as one of the components in asphalt mixtures, plays an effective role in their properties and behavior, especially regarding binding and aggregate interlocking effects. Mineral fillers and different aggregate gradation have a great effect on the mechanical property of asphalt concrete pavements. One of the main problems in the construction of asphalt paving mixture is obtaining a sufficient amount of qualified filler material. To overcome this problem it is important to come across alternative filler material that can address this gap which is easily available. The effects of different minerals are introduced on the performance of hot mix asphalt. However, the influence of Belessa Kaolin on the performance of HMA mixture with Superpave aggregate gradation are not properly established. This research is conducted by using laboratory experimental research design and Non-Probability sampling techniques adopted. In this research, the effect of non-conventional material so called Belessa kaolin and superpave gradation on marshal Properties, moisture susceptibilities and permanent deformation in asphalt mixtures was investigated. The chemical composition of Belessa kaolin shows that the total content of Silicon Dioxide (SiO_2), Iron Oxide (Fe_2O_3) and Aluminum Oxide (Al_2O_3) was 65%, 24.1% and 1.84% respectively. The physical properties of Belessa kaolin was conducted on specific gravity and Plastic Index were 2.62 and 3.24 respectively. Both the physical and chemical properties were address the requirements according to ASTM C-618. Based on the study area characteristics bitumen grade of 60/70 penetration is selected. HMA specimens were prepared from three different Superpave gradation with conventional filler Crushed Stone Dust (CSD) of different proportion (5.0%, 6.0%, and 7.0%) and five different bitumen content (4%, 4.5%, 5% 5.5% and 6%). A hot mix asphalt with 5.0% of CSD were selected as control mix based ERA specifications. The conventional filler was replaced by Belessa kaolin at different replacement rate (0%, 10%, 20%, 30%, 40% and 50%) on the basis of control mix with 5% CSD and 5.1% OBC. Marshal properties and moisture susceptibility were performed to determine the optimum replacement rate of Belessa kaolin. The replacement rate of 30% of Belessa kaolin provide better marshal properties and resistance to moisture susceptibility. This study also investigated the rutting resistance characteristics of HMA with optimum Belessa kaolin and control mix. The results of the experiments indicated that the use Belessa kaolin on HMA has fulfilled the criteria specified on the specification.

Keywords: *Hot Mix Asphalt, Belessa kaolin, Performance, Superpave Aggregate Gradation, Marshall Test, Rut Depth, Tensile Strength Ratio.*

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ACRONYMS

AASHTO	American Association of State Highway and Transport Officials
AC	Asphalt Concrete
ASTM	American Society for Testing and Materials
ARZ	above Restricted Zone
BS	British Standard
BRZ	Below Restricted Zone
CSD	Crushed Stone Dust
ERA	Ethiopian Road Authority
ERCC	Ethiopian Road Construction Corporation
ESA	Equivalent Single Axle load
ETG	Expert Task Group
FHWA	Federal Highway Administration
Gmb	Bulk Specific Gravity
Gmm	The Theoretical Maximum Specific Gravity
HMA	Hot Mix Asphalt
JMF	Job Mix Formula
LOI	Loss of Ignition
MS-2	Manual Series Number 2 of Asphalt Institute
NAPA	National Asphalt Pavement Association
NMAS	Nominal Maximum Aggregate Size
NP	Non-Plastic
OBC	Optimum Bitumen Content
OFC	Optimum Filler Content
PI	Plastic Index
PRD	Proportional Rut Depth
RD	Rut Depth
RT	Rut Test
RZ	Restricted Zone
SHRP	Strategic Highway Research Program

St	Tensile Strength
SUPERPAVE	Superior Performing Asphalt Pavement
TRZ	Through Restricted Zone
TSR	Tensile Strength Ratio
UTM	Universal Transverse Mercator
VIM	Air Void
VFB	Void Filled with Bitumen
VMA	Void in Mineral Aggregate
WTS	Wheel Truck Slope
XRD	X-Ray Diffractometer

CHAPTER ONE

INTRODUCTION

1.1 Background

Construction and maintenance of highway pavement requires a large amount of good quality materials. In order to preserve natural resources, a number of studies have been carried out to prove the usability of different natural and alternative materials in concrete and asphalt pavements such as lime, cement, steel slag, waste rubber, waste polyethylene, recycled concrete, and asphalt aggregate, as well as construction and demolition waste (Lee, S., et al., 2011) (Guha & Assaf, 2019) (Brown & Mallick, 2012) (Kim, K., et al., 2018).

The performance of hot mix asphalt (HMA) is mainly function of the characteristics of its constituents: Fillers, asphalt binder and aggregate. Fillers are powdery materials of various types, most of them pass the 0.075mm sieve and their inclusion in bituminous and non-bituminous binders and in aggregate mixtures confers special characteristics to these mixtures (Asmael, 2010).

The function of mineral filler is essential to stiffen the binder. Mineral fillers serve a dual purpose when it is added to asphalt mixes, the portion of the mineral filler that is finer than the thickness of the asphalt film blends with asphalt cement binder to form a mortar or mastic that contributes to improved stiffening of the mix. Particles larger than the thickness of the asphalt film behave as mineral aggregate and hence contribute to the contact points between individual aggregate particles. In addition, fillers affect the workability, moisture sensitivity, stiffness, and aging characteristics of hot mix asphalt (Eltaher, 2016).

The use of locally available materials in road construction is a key part in road construction (Y.-R. Kim, et al., 2016). One of the most promising filler material in HMA from the point of view of locally availability and to introduce non-conventional filler is Kaolin. Kaolin is a subgroup of clay minerals having polytypes namely kaolinite, dickite and nacrite and a polymorph called halloysite (Dill, 2016). Kaolin is suitable to be used as a natural pozzolan. Pozzolanic materials, of natural or artificial origin, contain a high percentage of amorphous silica and a high specific surface in order to generate a pozzolanic reaction (Velosa AL, 2014).

Kaolin occurrences are generally common and reported on all the continents in the world except Antarctica (Ekosse, G.-I. E., 2010). United States of America is the most ranked country with deposit of kaolin. Japan, Germany, Belgium-Luxembourg, Finland, China and Italy are the biggest producers of kaolin respectively. The biggest producers in other regions of the world are Canada for North America, Egypt for Africa, Argentina for South America and Australia for Oceania. (Yahya , et al., 2020).

There are plenty of deposits and occurrences of kaolin in different African countries. Most kaolin deposits and occurrences were located in Southern and West Africa; and the least number being North Africa (Ekosse, G.-I. E., 2010). Geological works in the past indicated the presence of kaolin in many localities within Ethiopia. Some of which namely, Kombolcha, near Harar, Debre Tabor, kerker, Belesa and many occurrences in Tigray are worth mentioning. Of these the best studied and presently under mining is Bambowha deposit, in Sidamo. (Bedassa.G, et al., 2018)

In HMA mixture gradation is considered as the cornerstone property of aggregate which needs careful attention due to its effect on mix properties and performance of HMA mixtures, including air void, stability, stiffness, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage (Afaf, 2014).

Superpave mix design is one of the newest mix design applicable in different countries. This method introduces Superpave aggregate gradation which is known with it is introducing the restrict zone to aggregate gradation. The restricted zone is through which aggregate gradations are not permitted to pass through and control points through which the blended mixture gradation must pass. The Superpave specified gradation could be used as a guided to select aggregate gradation for wearing course in Marshall Mix design without significant effect. (Mampearachich & Fernando, 2012).

This study was investigate and evaluate the effect of Belessa Kaolin as a substitute for conventional filler material on the performance of HMA. The evaluation is made by preparing laboratory samples with different percentages of the traditional filler would be replaced with the Belessa Kaolin and the Marshal Stability, flow, volumetric properties and performance parameters such as moisture susceptibility, rutting evaluated by the Marshall method of mixture design with conventional engineering properties.

1.2 Statement of the Problem

One of the failures of pavements before its service life is due to the quality of construction materials and defects in the mix design. Among them, the quality of Filler material has a great effect on the failures of pavements. The one reason behind this problem is selection of poor filler materials type and content for hot mix asphalt concrete mixture. 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. Also, filler plays a great role in the failures of HMA due to its insufficient amount and its quality in the mix design (Mohd, et al., 2017).

Therefore, application of new filler materials shall be studied to alleviate the existence of poor Marshall Properties and performance 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 naturally found material such as Kaolin as filler material in hot mix asphalt aggregate mixing gradation.

The particle size distribution, or gradation, of aggregates is most important factor that affects the whole performance of the pavement material. Gradation is one of most influencing factors for Marshall Properties of Asphalt Concrete mix, so it is required to select a best aggregates gradation. When fine particles are properly packed between coarser particles, which reduces the voids space between particles is called as best gradation. Aggregate presents major portion of asphalt concrete. (Mohammad & Mohammad, 2020).

The resource estimation of Belessa kaolin is about 200,000 m^3 (Bedassa.G, et al., 2018). However, currently, the actual usage of Belessa kaolin is very limited and has not been recognized as an alternative filler in local pavement construction. Also, the usage of Belessa Kaolin dust filler in HMA mixture, particularly with different aggregate gradation and percentages are not examined. Therefore, this study was undertaken through laboratory tests to evaluate the properties of the bituminous mixture using Belessa kaolin filler combined with Superpave aggregate gradation.

1.3 Research Question

The researcher formulates the following research questions to conduct the study:

1. What are the physical and chemical compositions of Belessa Kaolin?
2. What are the potential effects of Belessa Kaolin as partial replacement of filler material on marshal properties of hot mix asphalt?
3. What are the characteristics of Belessa Kaolin on the Moisture susceptibility and Permanent Deformation?
4. What are the effect of Superpave aggregate gradations on Marshall Mix properties?

1.4 Objectives

1.4.1 General objective

The general objective of the study is to investigate the performance of Belessa Kaolin as a filler with superpave aggregate gradation during a hot mix asphalt production.

1.4.2 Specific objective

In this research work a number of specific objectives are addressed. Such specific objectives are including:

- To determine the physical and chemical composition of Belessa Kaolin.
- To determine the potential effects of Belessa Kaolin as partial replacement of filler material on marshal properties of hot mix asphalt.
- To determine the characteristics of Belessa Kaolin on the Moisture susceptibility and Permanent Deformation of hot mix asphalt.
- To examine the effect of Superpave aggregate gradations on Marshall mix properties.

1.5 Scope of the Study

The research reported herein was focused on the influence of Belessa kaolin and Superpave aggregate gradation on asphalt concrete characteristics such as the Marshal Properties, moisture susceptibility and deformation. The materials selected for this study were collected from different sources.

All these materials were tested in the laboratory and evaluated. The mixture was designed and evaluated based on Marshall Mix design procedures, and the HMA aggregate was prepared using superpave aggregate gradation. Finally, the mixture containing a different ratio of belessa kaolin filler blended with design gradation was prepared to examine the properties of hot mix asphalt.

1.6 Significance of the Study

In road construction industry, there is much need for the suitable materials for the construction of flexible pavements. Fillers are one of the most crucial components of the hot mix asphalt. These fillers require a lot of time and cost to produce as it involves many re-crushing cycles. The current trend in hot mix asphalt preparation involves the use of fillers from crushed rocks, cement and lime. This study is undertaken to use the locally available material fillers from Belessa Kaolin, which is found abundantly in local areas of Hosaina and using it as a filler for hot mix asphalt. It reduce the time and cost required for the production of fillers. Also the effects of superpave aggregate gradation is not clearly described on marshal mix design in our country.

This research helps for different road agencies as one of non-conventional an alternative filler material to be used in hot mix design preparation in order to improve the performance asphalt properties.

1.7 Limitation of the Study

The results of the study based on a set of limitations and criteria that were taken into account during experimental laboratory activities. These limitations involve:

- The study examines the use of Belessa kaolin as a filler combined with below restricted zone superpave gradation in HMA using Marshall Mix design procedures.
- Gradations of Superpave aggregate used in this study were limited to below-restricted zone gradation and content of filler, as well as the type of bitumen used in the experiment, is limited.
- Due to lack and malfunction of laboratory equipment all performance tests aren't conducted. I.e. moisture susceptibility and rutting test are performed and tests such as creep, fatigue and resilient modulus aren't conducted.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The performance of asphalt mixtures are different due to the complexity of material used in the mixes. The performance of hot mix asphalt mixture is influenced by several features together with type and amount of filler materials and gradation of aggregates. Filler acts as one of the major constituents in asphalt concrete mixture. Fillers not only fill voids in the coarse and fine aggregates but also affect the aging characteristics of the asphalt mix. Scientists and engineers are permanently trying to improve properties of asphalt mixtures, such as their stability and durability by incorporating new additives either in the bitumen or in the asphalt mixture (Golestani, et al., 2015). The main points considered in evaluating and improving the performance of pavements are evaluating and improving pavement materials characteristics. (Eltaher, 2012).

The characteristics of HMA mainly depends on the individual properties of its ingredients and how they counter with each other in the mixture. The behavior of the hot mix asphalt (HMA) in terms of their strength and stability is affected by some characteristics by the properties of the used aggregate in terms of quality, quantity, and grading. Fillers, which are the aggregate materials finer than 75μm in size, have a strong influence on the performance of the asphalt pavement mixtures. Mineral fillers are added to the graded HMA to improve its physical properties. Using fillers improves the density and stability of HMA by reducing the voids in the coarser aggregate. It also plays a role in dropping the temperature susceptibility of the asphalt binder layer (Grawobski, 2011). Mineral filler increase the stiffness of the asphalt mortar matrix, improving the rutting resistance of pavements. (Guha & Assaf, 2020).

Moisture damage and permanent deformation are the primary modes of distresses in hot mix asphalt (HMA) pavements. The performance of HMA pavements is related to cohesive and adhesive bonding within the asphalt–aggregate system. The loss of cohesion (strength) and stiffness of the asphalt film, and the failure of the adhesive bond between aggregate and asphalt in conjunction with the degradation or fracture of the aggregate were identified as the main mechanisms of moisture damage in asphalt pavements (Terrel & Al, 2014). The loss of adhesion is due to water leaking between the asphalt and the aggregate and stripping away the asphalt film. Moisture damaged pavement may be a combined result of these two mechanisms (Epps JA, et al., 2015) (Engoz B. & Agar E., 2017). As moisture damage reduces the internal strength of the HMA mix, the stresses generated by traffic loads increase significantly and lead to premature rutting, raveling and fatigue cracking of the HMA layer (Kandhal, 2013).

Rutting resistance is one of the most important property of well-designed asphalt mixture. Rutting is the longitudinal depression in the wheel path in bituminous pavements, which can be attributed to excessive consolidation, formed by an accumulation of permanent deformations caused by repeated heavy loads, or lateral movement of the material, caused by shear failure of the bituminous concrete layer, or a combination of both mechanisms (Mansour Fakhri & Sayyed Ali Hosseini, 2017). Rutting in pavement is a serious mode of distress beside fatigue in bituminous pavement in high temperature areas and may lead to premature failure in pavements and results in early and costly rehabilitation. In addition, rutting in pavements causes hydroplaning, severe physiological and safety concern for users. Hence, this problems needs to be properly addressed through evaluation and mitigation measures so that the occurrence and resulting impacts are minimized. There are several factors which are connected to rutting resistance: mineral composition, type of used binder and volume relationships of designed asphalt mixture. While it is possible to predict rutting resistance according to asphalt mixture properties and volume relationships, it is not that simple with binder properties. Commonly used binder description seems to be insufficient (Golalipour, et al., 2012).

The aggregate gradation or the particle size distribution is one of the most influential factor affecting on the properties of hot mix asphalt mixtures. To achieve the most important hot mix asphalt properties including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance and resistance to moisture damage are depends on the aggregate gradation or proportions (Elliot R.P., et al., 2011). Gradation with high amount of fines may cause distortion in mixtures as the large amount fine particles tends to push the larger particles apart, and this exposed to the problem of poor deformation resistance of mixtures under traffic loading. In hot mix asphalt mixture excessive small maximum sizes cause for instability and poor workability and segregation may be the result of excessive large maximum sizes (Abedali, A. & Abdulhaq, H., 2014).

2.2 Volumetric Properties of Hot Mix Asphalt

Volumetric properties are the one which shall be determined to create sufficient performance for the pavement in HMA mixture. Different researches has been studied on the effect of mineral fillers on the marshal property of bituminous mixtures. Among them 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. 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 (Guha & Assaf, 2019) (Mistry, R. & Roy, T. K. , 2016) (Modarres, A., et al., 2015). Most of all concluded that mineral fillers have a strong relation with the overall volumetric property of HMA mixture.

2.3 Martial Stability and Flow of Hot Mix Asphalt

The Martial stability value obtained is an indication of the mass viscosity of the aggregate-asphalt cement mixture. In most cases, it is affected significantly by the angle of internal friction of the aggregate and the grade of the asphalt cement. Hence, one of the easiest ways to increase the stability of an aggregate-asphalt mixture is to use a higher viscosity grade of asphalt cement (Jahanian, et al., 2017) (Qasrawi, H. & Asi, I., 2016). It is also possible to increase the stability of the mix by selecting a more crushed angular aggregate than rounded shape aggregates (Mohammad & Mohammad, 2020). Study shows the incorporation of finest fillers which also have higher porosity and specific surface area provided higher stiffening in mastic, which in turn produced mixes with higher Marshall Stability (Islam , et al., 2020)

The flow is measured as the vertical deformation of the specimen in hundreds of inch from start of loading up to the point where the stability begins to decrease. It is obtained at the same time as the Marshal Stability test is conducted. Generally, high flow values indicate a plastic mix that is more prone to permanent deformation problem due to traffic loads, whereas low flow values may indicate a mix with higher than normal voids and insufficient asphalt for durability and could result premature cracking due to mixture brittleness during the life of the pavement (Vivian Silveira dos Santos B., et al., 2013).

2.4 Moisture Susceptibility of HMA

One of the desirable properties of bituminous mixtures is that the resistance to moisture induced damages. The moisture-induced damages (typically called as stripping) can be defined as the weakening or eventual loss of the adhesive bond between the aggregate surface and the asphalt binder in a HMA pavement or mixture, usually under the presence of moisture. The resistance to moisture damage under the presence of moisture in the mixture is a complex matter and the degree mainly depends on the properties of each ingredient materials in the mixture, type and use of mix, Environment, traffic, construction practice, and the use of anti-strip additives. Among these factors, aggregate response to asphalt cement under water is primarily responsible for this phenomenon, although some asphalt cement are more subjected to stripping than others (Ezzat, E. N. & Abed, A. H., 2019).

Moisture damage of asphalt pavement is a serious issue. Measurement of the sensitivity of a specific mix to moisture is a challenge, as are interpreting the results. Treatment options vary with location, and success varies. Recent efforts have concentrated on developing better laboratory test methods to predict moisture damage problems in the field. To fully address the moisture damage problems, it is important to address both the chemical factors and the mechanical factors responsible for moisture damage. The chemical factors affect the interaction of asphalt molecules with the aggregate surface and how the interaction changes in the presence of water. The physical issues are mainly concerned with ways to reduce the access of water to the asphalt aggregate interface. In addition to careful selection and quality control of materials, precautions should be taken in design and construction to keep moisture out of the pavement by providing proper drainage for water and good compaction of the asphalt mixture to minimize air voids and pavement permeability (Asphalt Institute, 2014). Previous studies have suggested that the incorporation of finer filler having higher porosity and surface area due to cellular structure tends to distribute evenly in the mix which increases the asphalt-aggregate adhesion (R , et al., 2019). Also the attendance of higher silica in filler composition, which is widely known to degrade the asphalt-aggregate bonding in the presence of water (Pasandin , 2016).

The most predominant condition causing stripping is when repeated traffic loadings occur on a poorly compacted dense-graded pavement (with >8% air voids) with surface water (rain) present. The hydraulic pressure fluctuations in the interconnected voids can cause a scouring effect, in essence ripping the asphalt binder from the aggregate surface. While adhesion failure between the asphalt and aggregate (referred to as stripping) is the most commonly recognized mechanism of moisture damage, there are others. Other mechanisms include moisture-induced cohesion failures within the asphalt binder, cohesion failures within the aggregate, emulsification of the asphalt and freezing of entrapped water (Asphalt Institute, 2014)

2.5 Permanent Deformation (Rutting) of HMA

Permanent deformation or rutting of asphalt mixtures is a distress that occurs at high pavement temperatures under loaded conditions. As the pavement temperature increases, the asphalt mixture becomes softer and is more susceptible to movement under load. Permanent deformation occurs when the asphalt mixture deforms under load and then does not recover to its original undeformed position. Over time, permanent deformation can lead to channelization or rutting (Asphalt Institute, 2014). A rut, whether consolidated (primary) or instability (secondary) is characterized by longitudinal surface Depression within the wheel path and may have associated transverse displacement, thereby reducing serviceability and safety of a flexible pavement. Rutting can be the result of permanent reduction in volume (consolidation/traffic densification), permanent movement of the material at constant volume (plastic deformation/shear), or a combination of the two. Bituminous concrete is a time, temperature, and stress dependent material, which, when subjected to repeated loading exhibits elastic/ plastic/visco-elastic/ plastic contribute to permanent deformation. There are several factors that influence rutting. Rutting in asphalt mixes is associated with several factors such as higher than optimum asphalt content, high natural sand content, round aggregate shape (e.g., uncrushed gravel) or high binder deformability Vehicle speed/time and contact pressure are represented directly in the creep rate model, while temperature, asphalt/bitumen mixture characteristics and construction quality are represented in the values of the constants. Shear resistance properties of materials, especially bituminous ones, need to be properly addressed for limiting the rutting (Golalipour, et al., 2012). Higher rutting resistance of asphalt mixes might also be due to the fineness of fillers. Finer fillers have a tendency for uniform distribution in asphalt mixes which increased the overall stiffness of asphalt mixes (Pasandin , 2016).

2.6 Crucial materials in Production of HMA

2.6.1 Aggregates

The largest portion of the resistance to permanent deformation of HMA mixture is provided by the aggregate structure, Aggregates are the dominant ingredient of HMA, by making up 80% to 85 % of the mixture by volume and roughly 95 percent of the mixture by weight. The aggregates are generally divided into coarse aggregate, fine aggregates, and filler fractions. The stability of asphalt mixture is affected by several features such as gradation of aggregate, type, and amount of filler materials. Aggregate is expected to provide a strong skeleton to withstand repeated traffic load. Gradation, shape, and surface texture of aggregate have a great effect on the HMA properties.

Aggregates in HMA can be divided into three types according to their size: coarse aggregates, fine aggregates, and mineral filler. Coarse aggregates are generally defined as those retained on the 2.36-mm sieve. Fine aggregates are those that pass through the 2.36- mm sieve and are retained on the 0.075-mm sieve. Mineral filler is defined as that portion of the aggregate passing the 0.075-mm sieve. Mineral filler material also referred to as mineral dust or rock dust - consists of very fine, inert mineral with the consistency of flour, which is added to the hot mix asphalt to improve the density and strength of the mixture (Tran, N. T., & Takahashi, O. , 2017)

2.6.2 Mineral Fillers

Mineral fillers can be screened and grinded rock fines, Portland cement or hydrated lime to assist the adhesion of the bitumen to aggregate and fill up the void. It should be inert material which passes 75-micron sieve. Mineral fillers are by-products of stone crushing procedures, manifesting the feasibility of including them in the design of hot mix asphalt. Mineral filler materials in hot mix asphalt are an important component of the mixture as the design and performance of hot mix asphalt concrete. Some of the studies have been made on the use of different types of fillers in various types of paving mixes. From thus studies the filler exerts a significant effect on the characteristics and performance of asphalt concrete mixture (Ratnasamy, M. E., 2013). Besides, good packing of the coarse aggregates, fine aggregates, and filler provides a strong backbone for the mixture. Another researcher identified that filler as one of the components of asphalt concrete mixture it plays a significant role in the characteristics and performance of the asphalt mixture. In an asphalt mix, the filler acts as an extended to the binder and performs two important functions.

It acts as a voids filling material to enhance density and durability of the mixture and it stiffens the mixture and improves resistance to plastic deformation (Pasandín, A. R & Pérez, I., 2015). Increasing the stiffness of the mixture is dependent on the type of filler, bulk density and the volumetric contribution in the mixture.

2.6.3 Bitumen

Asphalt binder (bitumen) which holds aggregates together in HMA is the thick, heavy residue remaining after refining crude oil. Asphalt binder consists mostly of carbon and hydrogen, with little amounts of oxygen, sulfur, and several metals. The physical properties of the asphalt binder vary considerably with temperature. At high temperature, asphalt binder become fluid with a low consistency similar to that of oil. At room temperature, most asphalt binders should have the consistency of soft rubber. At sub-zero temperatures, asphalt binder can become very brittle. Many asphalt binders contain small percentages of polymer to improve their physical properties; these materials are called polymer modified binders. Most of asphalt binder specification was designed to control changes in consistency with temperature (Qasrawi, H. & Asi, I., 2016). In this study, 60/70, penetration grade bitumen was be used. The main reason for selecting this bitumen grade is because of its common type of asphalt that widely utilized in most of the road projects of case study area and it is recommended for areas having temperature lesser than 24℃.

2.7 Aggregate Gradation

Aggregate grading, also known as gradation, is the most important property that an aggregate can contribute to the performance of asphalt concrete. In hot-mix asphalt, gradation helps to determine almost every important property including stiffness, stability, durability, permeability, workability, fatigue resistance, and resistance to moisture damage (Tran, N. T., & Takahashi, O. , 2017). Aggregate gradation plays a significant role in the asphalt mixture's properties and further significantly influences the performance of HMA.

Aggregate gradation graphs can either be semi-log chart or 0.45 power chart. The 0.45 power chart was developed in 1962 by the United States Bureau of Public Roads that uses an arithmetic scale of the sieve size raised to the 0.45 power. The chart was developed on the assumption that the best aggregate grading for asphalt mixture is the one that gives the densest particle packing. The aggregate gradation is an important difference between the Superpave and Marshall methods for design of HMA.

Researchers have performed the study on the investigation of the effect of variation in gradation of aggregate on the properties of asphalt mixture. According to specific research, five different gradations were tested to investigate the impacts of variation in gradation of aggregate on the HMA properties. The gradation was such as JMF gradation, coarse, fine, fine-coarse, and coarse-fine and their respective effects on the performance of asphalt mixture are concluded as follows: fine-coarse and coarse-fine gradation variation cause higher and lower Marshall Air void, void in mineral aggregates (VMA) respectively. In addition, the aforementioned gradation variation results lowest and highest Marshall Flow, respectively. Generally, the Marshall stability is affected by gradation variation with the fine gradation produced the highest stability, whereas the fine- coarse gradation variation resulted in the lowest stability (I. Haryanto & O. Takahashi, 2017).

2.7.1 Superpave Aggregate Gradation

The aggregate and asphalt–aggregate characteristics of Superpave mixture were developed by the Aggregate Expert Task Group (ETG) of SHRP, and they used a modified Delphi procedure to select the aggregate and mixture characteristics (Khosla, N.P. & Ayyala, D., 2013). To specify the aggregate gradation, Superpave has adopted the 0.45 power curve with gradation control points and a restricted zone. Another important feature of the 0.45 power curve is that it represents the maximum density line. This line represents a gradation, where the aggregate particles fit together to make the densest arrangement. Furthermore, gradation above the maximum density line makes finer gradations, while gradation below the maximum density line makes coarser gradations. The control points function as upper and lower limits of the aggregate gradation, which should be satisfied by the selected aggregate. They are placed at three specific points; nominal maximum sieve, an intermediate sieve (2.36 mm), and the smallest sieve (0.075 mm).

The four upper control points are a result of the definition of nominal maximum and maximum size. The lower control point at 0.075 mm limits the minimum and maximum percentages of 0.075 mm size specified in ASTM D 3515 for dense graded asphalt mixtures. Gradation control points at the 2.36 mm sieve size control the amount of sand size particles in the mixture. The upper control point limits the amount of sand in the mixture to avoid sand - asphalt mixtures and the lower control point ensures that adequate sand is contained to make a dense graded mixture. The restricted zone resides along the maximum density gradation line between the 2.36 mm sieve and the 0.3 mm sieve. The restricted zone encourages development of gap graded mixtures. Figure 2.1 and Table 2.1 below show the control points, restricted zone and gradation limits for a 19.0 mm Superpave mixture, respectively.

Table 2.1: Superpave asphalt mixture gradation requirements for 19mm nominal sixe (Asphalt Institute, 2014)

Sieve, mm	19mm nominal size			
	Control points		Restricted zone boundary	
	Minimum	Maximum	Minimum	Maximum
25		100		
19	90	100		
12.5		90		
9.5				
4.75				
2.36	23	49	34.6	34.6
1.18			22.3	28.3
0.6			16.7	20.7
0.3			13.7	13.7
0.15				
0.075	2	8		

2.7.2 The effects of Superpave aggregate gradation on HMA

Many research has been focused on the effect of restricted zone on the performance of HMA. This indicated that good performance can be achieved with fine graded mixtures and, in most cases, fine Superpave mixtures out - perform coarser Superpave mixtures. Superpave restricted zone does not affect the VMA and particle interlock, if the blend contains only crushed aggregates. Therefore, the restricted zone is not adopted as an essential requirement of local specifications, rather that it is an option for heavily trafficked roads (Kandhal, P.S. & L.A. Cooley, Jr., 2011). Superpave coarse mixtures (gradation passing below the restricted zone) is normally provide the most effective material for roads on heavily trafficked and severe sites.

A broad range of aggregate gradations ranging from restricted zone to stone matrix asphalt could yield good shear resistance in HMA. The gradation of the coarse aggregate fraction is the most critical factor affecting the shear resistance of the HMA and that VMA could not be related to shear resistance of the mixture. Both laboratory and prototype-scale performance tests indicated that adequate rutting performance could be achieved with gradations above, though, and below the restricted zone. They found that above and through restricted zone mixtures might show slightly lesser performance than below mixtures (Jitsangiam, P., et al., 2013). Another study has focused on 128 trial aggregate blends used for mixture design to setup a guideline for the mixture designers; more specially, the blends were examined to find the gradation or gradation characteristics, which can yield the required VMA for the asphalt concrete. He tried to find a correlation between VMA and the distance from maximum density line on the 0.45 power gradation chart or distance from the restricted zone and did not find any statistically significant relationship between VMA in the HMA and the sum of the distances from the Superpave maximum density line or the sum of the distance from the restricted zone (Mampearachchi, W. K. & Fernando, P.R.D. , 2012). The same study, designed and evaluated HMA of four different gradations using only one aggregate source.

2. 8 Effects of mineral fillers on HMA

The mineral filler can greatly affect the properties of a mixture such as strength, plasticity, voids, resistance to the action of water, and the resistance to the forces of weathering. The proper use of Filler can improve the asphalt paving mixture through increased density, stability, durability, and skid resistance. Various research are conducted on the effect of filler in hot mix asphalt from thus: the filler plays a major role in the properties and behavior of bituminous paving mixture. Other research studied that the mineral filler increase stiffens of the asphalt mortar matrix and improving the rutting resistance of pavements (Nathem A.H., A.-S, 2013). The mineral filler also helps to reduce the amount of asphalt consume in the mix during construction, which improves the durability of the mix by maintaining the amount of asphalt initially used in the mix.

Filler in an asphalt-concrete mixture, whether artificial or natural may stiffen the asphalt concrete, extend the asphalt cement, and affect the workability and compaction characteristics of the mix. The workability of mixing during the operation and compaction of the asphalt-concrete mixture is the consequential property of asphalt-filler mastic also affected by filler materials (Ratnasamy, M. E., 2013). The filler provides better resistance to micro cracking so that it can increase the fatigue life of the asphalt-concrete mixture. The use of waste cement dust as filler on the asphalt concrete mixture enhances the mechanical properties of the mix, and the laboratory results indicate that the cement dust can totally replace limestone powder in the asphalt paving mixture. The addition of mineral filler increases the resilient modulus of an asphalt mixture. On the other hand, a disproportionate amount of filler may weaken the mixture by raising the amount of asphalt (R Muniandy, e. a., 2013).

Considering all the studies performed on mineral fillers, it's possible to generalize that the effect of mineral fillers on asphalt pavement performance is enormous. Therefore, Performance of asphalt pavement is directly affected by the quality and amount of mineral filler. In HMA mixture volumetric properties are the one which shall be determined to create sufficient performance for the pavement. Different researchers studied that 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.

2. 9 Kaolin

Kaolin or china clay is a mixture of different minerals. Its main component is kaolinite. Kaolinite, the main constituent of kaolin, is formed by rock weathering.Kaolin is both a rock term and a mineral term. From the rock point of view, kaolin means that the rock is comprised predominantly of kaolinite and or one of the other kaolin minerals.Mineral wise, it represents the group name for the minerals kaolinite, dickite, nacrite, and halloysite (Dill, 2016). Kaolin is also defined as a rock mass containing principally kaolinitic clays that are low in iron, and usually white or nearly white in color comprising naturally occurring kaolin group minerals. It can be contained in a variety of kaolinitic rock types. The primary kaolin explains kaolin which is altered from an igneous or metamorphic rock that was kaolinized in situ by hydrothermal or weathering processes.Secondary kaolin is sedimentary kaolin comprising transported mineral particles.

Kaolin is among the major industrial clays including Smectites, and Palygorskite–Sepiolite. The main Kaolin minerals include kaolinite, dickite, nacrite, and halloysite. These minerals are dioctahedral 1:1 phyllosilicates having a sheet of silicon atoms in tetrahedral coordination with four oxygen atoms and a sheet of aluminum atoms in octahedral coordination with two oxygen atoms and four hydroxide molecules. In general, the basic kaolin mineral structure constitute a layer of a single tetrahedral sheet and a single octahedral sheet. Among the kaolin minerals, Kaolinite ($Al_2Si_2O_5$ (OH) 4) is the most common mineral and has great industrial importance (Qiu, X., et al., 2014).

Primarily, kaolin is used as (1) a pigment to improve the appearance and functionality of paper and paint, (2) a functional filler for rubber and plastic, (3) a ceramic raw material, and (4) a component for refractory, brick, and fiberglass products. Other less significant uses for kaolin include chemical manufacture, civil engineering, agricultural applications, and some pharmaceuticals (Ghadimian A. & Khodami M., 2015)

2.9.1 Belessa Kaolin

Belessa kaolin occurrence is located in the central portion of the study area east of Belessa town and it is known as Belessa Kaolin. The specific location of this deposit is 384352 E and 837967 N. Presently, it is being exploited by local people and sometimes sold for industries. The deposit is found in the mountainous topography and clearly exposed in the mine site. The mine area is comprised of a low land terrain which is slightly undulating and in parts ascribed to a plateau landforms. The geology of the study area dominantly consists of pyroclastic tuff and Miocene rhyolite. The kaolin is altered from and is associated with this rhyolite. The host rock (rhyolite) is characterized by moderate to high degrees of alteration. The kaolin is found overlain by overburden that ranges in thickness from 5 to 10 meters. The overburden consists of silt to sand size and reddish brown eluvium sediments. The kaolinization zone is restricted to a limited vicinity and a fresh unaltered rhyolite is encountered after a short traverse from the kaolinized area. That means, the degree of alteration gradually increases towards the exposed deposit as approaching it from all direction. In the freshest rhyolite exposure there is either no or very thin overburden. Three exposed outcrops of kaolin occurrences show variable thicknesses having a maximum of about 8 meters (Bedassa.G, et al., 2018).

Figure 2.1: Views of Belessa kaolin occurerence.

2.9.2 Resource Estimation of Belessa Kaolin

The exact quantity of Belessa Kaolin in the area aren't stated by mining bureau. But the resource estimation was done by geologist before. They adopted conventional approach by using the geological map of study area, field observation and estimated kaolin deposit thickness. Therefore, Resource of estimation of Belessa Kaolin deposit is 280000 tons or 200,000m^3 (Bedassa.G, et al., 2018).

The above resource estimation considers the approximate quantity of kaolin. Moreover, it should be noted that this tonnage represents only those kaolin resources found in Belessa area. Based on the level of geological knowledge and confidence, this resource is classified under indicated mineral resource. This is because the study lacks drill hole and it is only based on data from field observations and mineralogy test (Bedassa.G, et al., 2018). The new kaolin occurrences found in other parts of near the study area aren't included.

2.9.3 Use of Kaolin in Construction of HMA

Partial replacement of the binder or filler by kaolin in asphaltic concrete mixtures improves mechanical properties, enhances durability, reduces construction costs, and ensures safe disposal of waste materials. Many studies have utilized kaolin clay as a cement replacement in concrete constructions. In addition, using kaolin mineral rather than using conventional purpose and an attempt was made in as partial replacement of fine aggregate in Portland cement concrete and from the test result it is concluded as it increase the strength of Portland cement. Kaolin is an important raw material in various industrial sectors and it is composed of kaolin stone, and it is one of the main minerals in the world and one of the most widely used minerals. Large volumes of kaolinite clays are used for the production of cement, ceramics, bricks, and porcelain. There is an ongoing interest to utilize selected clay minerals including kaolinites in the construction industry. Conventionally, special grade kaolin clay is used for the production of white cement clinker and, subsequently, white cement (EI-Shafie M, I. I. , 2012).

The performance of waste kaolin clay on the hot-mix asphalt was evaluated through a Marshall stability and flow test, including stiffness, density, voids in total mix, and voids in filled with asphalt. Test results showed that kaolin clay can be satisfactorily used as filler replacement material to increase the asphalt mixture properties (Mohd, et al., 2017). Another study carried out based on the replacement of kaolin at 15% increment provides asphaltic concrete with 60% kaolin replacement level exhibits excellent performance with good stability and stiffness (Assefa , 2019) . Another study results showed that the presence of Kaolin filler in an asphalt-concrete mixture affects the mixture's performance in three ways: kaolin filler influences the amount of asphalt content, kaolin affects the workability during mixing and compaction, and the resultant properties of asphalt-filler mastic contribute to the mixture's performance. The results show that the properties of the filler determine its interaction with asphalt and its contribution to the mixture's performance. (Anggraini Zulkati, et al., 2012).

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

The approaches followed in this study is quantitative approach which involves the generation of data in quantitative form which can be subjected to rigorous quantitative analysis. The study focus on the performance of hot mix asphalt mixture using combined effects Belessa Kaolin and Superpave aggregate gradation. Experimental method has been used to accomplish the finding. There are two parts to this experiment. The first part includes preparation of mix design for asphalt binder, aggregate and different quantities of Belessa kaolin. The second part investigates the sensitivity of the mix at optimum asphalt content to different performance measures.

This chapter describes the different procedures and test methods used in the study. Various activities are involved in answering the research questions and in attaining the objectives of the study. These activities are including material selection and characterization, preparation of mix design, evaluation of Marshall Properties of the bituminous mixture. In order to achieve the proposed goal of the study, the experimental research methodology is going to be used.

3.2 Study Area Description

The study area is found in Southern Nations, Nationalities and Peoples Regional Government (SNNPR), Hadiya Zone, near Hosaina town. It is more specifically located in the Hosaina map sheet, 0737 B4 according to the Ethiopian Mapping Agency. Hosaina is about 230 km south west of Addis Ababa. The UTM (Universal Transverse Mercator) coordinates shows that the area is bounded by 380000 to 390000 m E and 830000 to 850000 m N. From Hosaina town the study area is accessed by the main asphalt road that runs to the small town called Belessa situated in the NE of Hosaina. This asphalt road passes through the study area and helps to access the North, North-East and West part using vehicle. The South, East and Central portions of the study area which are far from the asphalt road, can be accessed by all-weather gravel roads.

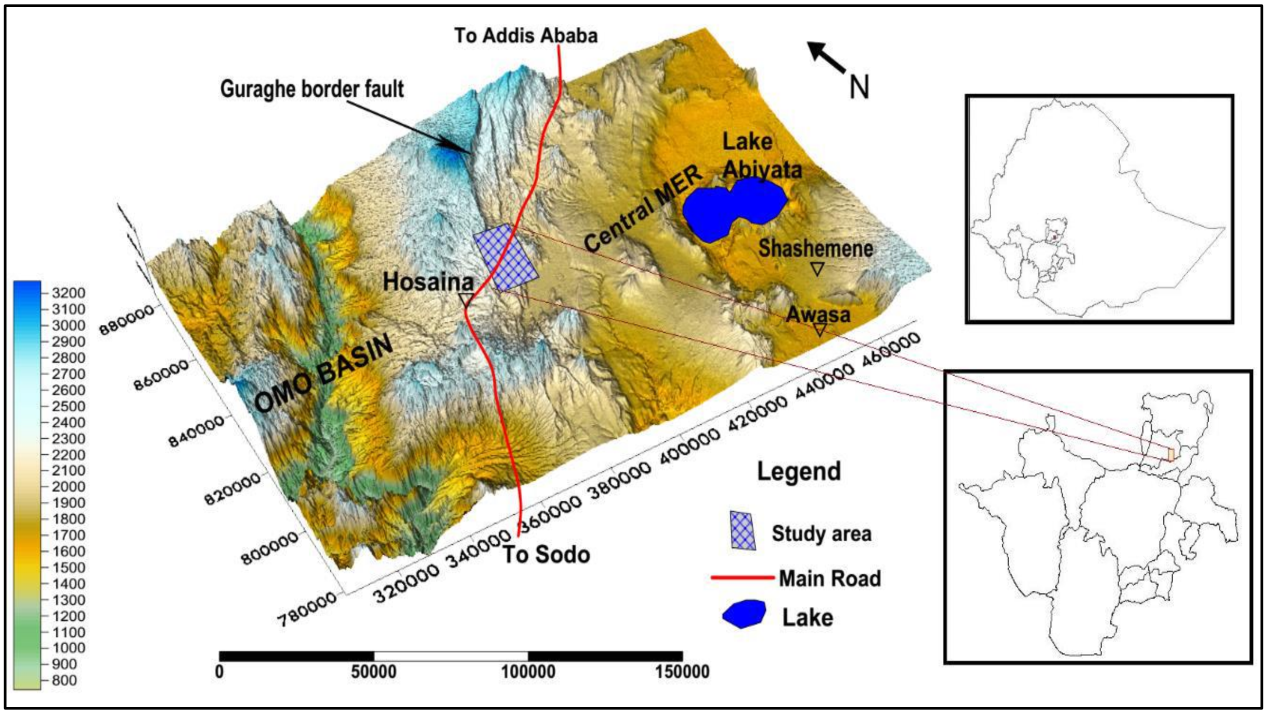

Figure 3.1: Location of the study area (GIS and www.http://.earth google.com/web, 7pm, 2/12/2021).

3.3 Research Design

The research is designed to answer the research questions and meet its objectives based on experimental findings. The research is conducted using a laboratory experimental research design. Subsequent to organizing a literature review of different previously published researches, the study was evaluate the performance of the Kaolin as filler and Superpave gradation for asphalt mix design. In order to evaluate effect of Belessa Kaolin as filler with Superpave aggregate gradation in asphalt mixtures, numerous experimental works has been undertaken. In particular, for all materials (asphalt binder, coarse aggregate, fine aggregate, and fillers, binders) AASHTO, BS, ERA, and ASTM standard procedures were performed.

Different materials collected from different available area for the preparation of hot mix asphalt mixtures. These materials are used in the mixtures includes: coarse aggregate, fine aggregate, crushed stone fillers, bitumen as asphalt binder and non-conventional filler. Aggregate samples for the proposed HMA mix design are obtained from ERCC (Ethiopian road Construction Corporation) quarry. The crushed stone dust is also brought from the same source as of aggregate.

Bitumen 60/70 penetration grade is also obtained from ERCC, the same project site, whereas Belessa Kaolin filler is collected from Belessa, which located 10km from Hadiya Hossaina town.

The aggregates, fillers and other ingredient materials used to prepare the mix were subjected in different laboratory tests in order to identify their physical properties whether they can achieve the specification requirement limits. Also the chemical composition of non-conventional material (Belessa Kaolin) is investigated using x-ray diffractrometer.

The Marshall Mix design and Superpave aggregate gradation method was used to prepare the specimens. The Marshall Design method used to investigate the stability and flow value of the mixtures as well as to determine the volumetric properties of marshal mix deign. These all the marshal properties within ERA2013 flexible pavement specification limit, then the effect of the Belessa kaolin along with different content on the marshal properties analyzed at optimum binder content. The standard Marshall specimens were prepared by applying 75 blows on each face according to ASTMD 6926 with five different bitumen content (4%-6%) at 0.5% increments by weight of total mixes `and different conventional filler content (5.0%, 6%, and 7.0%). From this, Marshall Specimens in each filler content prepared of the 15samples, and each of them was weighed 1,200gm in weight. The prepared Mixes containing 5.0%, 6.0%, and 7.0% crushed stone dust filler were used for determining the OBC and optimum filler content. Belessa Kaolin was used to replace conventionally used crushed stone dust at 0 %, 10%, 20%, 30 %, 40%, and 50% by weight of optimum crushed stone dust filler.

Finally, test results of marshal parameters, moisture susceptibility and rutting were evaluated as per ERA 2013 flexible pavement manual specification and as the method of asphalt institute manual series, MS-2. The final results were presented in tabular and graphical forms and then analyzed, as well as discussions, were made on the research findings, and based on the findings, conclusions and recommendations were forwarded.

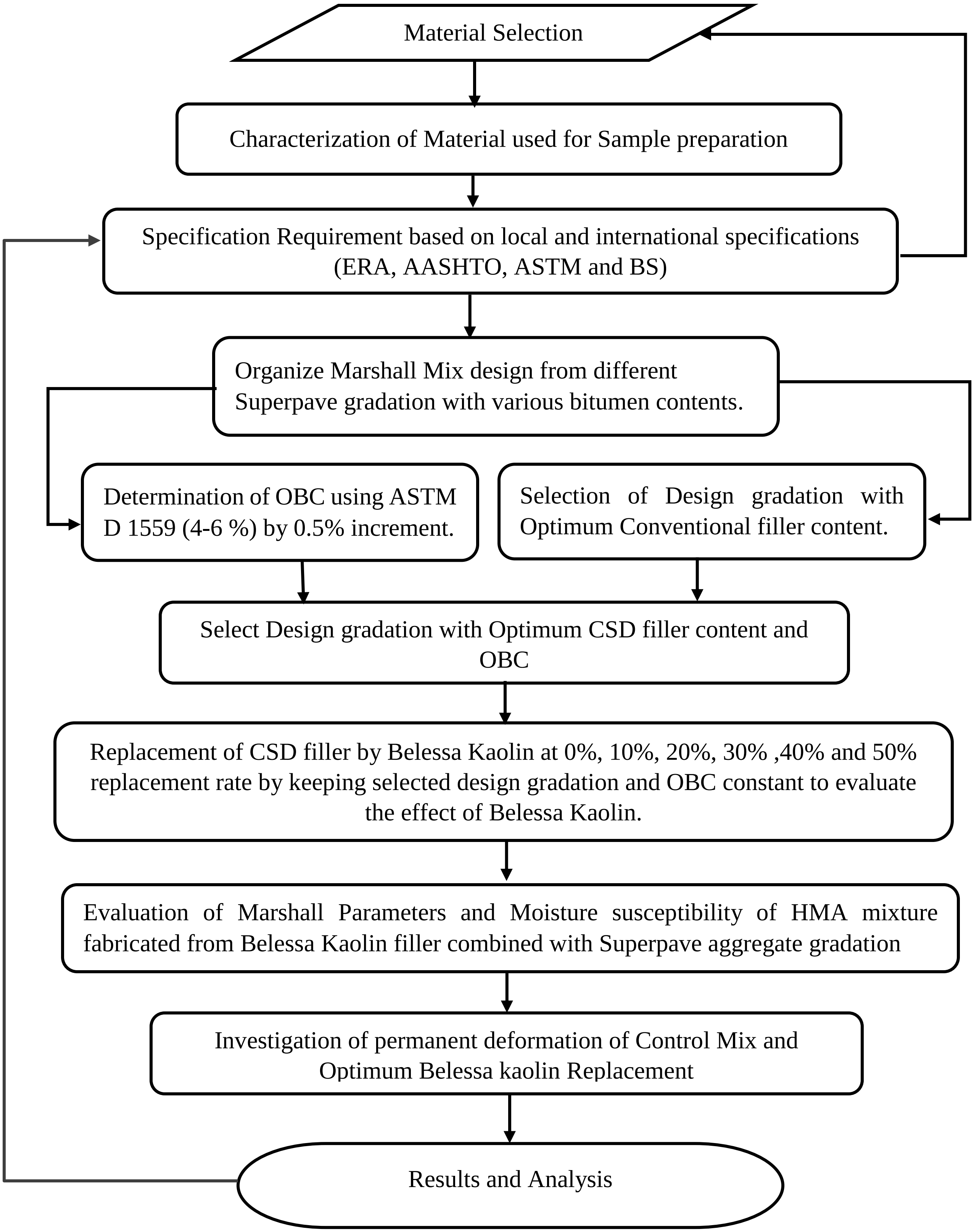

Figure 3.2: Flowchart of research design

3.4 Source of Data

The research data were conducted mainly based on achieving the objective of the research. Various data were collected and processed for the study. Firstly, reviewing previous related literature and different international and local standard specification were assessed, followed by laboratory tests regarding Superpave aggregate gradation and the preparation of hot mix asphalt mixtures. Typically, two various sources of data were obtained in this study. These are primary and secondary data.

3.4.1 Primary Source of Data

Primary data were collected from laboratory tests on crucial material in a mix proportions such as aggregate properties, asphalt binder and filler material.

3.4.2 Secondary Source of Data

The secondary data were collected from various related previous studies, local and international pavement design manuals, and standards.

3.5 Study Variables

There are different variables related to the property of hot mix asphalt in this research. The study variables included for the research study are dependent and independent variables.

3.5.1 Dependent Variables

The dependent variable in this study was the Performance of hot mix asphalt due to the superpave aggregate gradation and replacement of Belessa Kaolin filler.

3.5.2 Independent Variables

The independent variables of the study were the proportion of Aggregate sizes sieved by Superpave aggregate gradation, percent content of Belessa Kaolin, Laboratory tests including aggregate crushing value, aggregate impact value, loss angles abrasion value, specific gravity of aggregate, elongation index, and flakiness index, Marshall stability and flow, as well as HMA mix volumetric properties namely void in mineral aggregate (VMA), void filled with bitumen (VFB), bulk density, air void (VIM), and bitumen properties test values namely penetration, softening point, ductility, fire point, Moisture susceptibility and Rutting Test (RT).

3.6 Data Processing and Analysis

The study is conducted in performing physical properties and characteristics of aggregate, asphalt binder/bitumen, and filler material through laboratory tests. Subsequent to ensuring the quality of material preparation of specimen are performed in order to determine the design gradation, the optimum content of both filler and bitumen through the marshal properties and volumetric properties of each sample were determined. The data are analyzed and processed using graphs and tables, and the test result comparison made with a standard specification of the Binder course on the ERA pavement design manual was be an important aspect of the analysis.

3.7 Laboratory or Experimental works

3.7.1 Materials selection and characterization

Selection and characterization of individual ingredients are extremely significant to provide the required quality and properties of the prepared mix in the HMA mix design and production proportioning. The materials were subjected to various tests in order to assess their physical characteristics and suitability in the road construction. The overall mix design procedure starts with the evaluation and selection of aggregate and bitumen sources. The individual ingredients of the mixture are tested in the laboratory in order to decide if they meet the specified requirement or not. Different material quality tests were performed as per set by AASHTO, ASTM, and BS standards. The quality tests which were carried out on aggregate, including mineral filler, were sieve analysis (gradation), aggregate crushing value, Los Angles abrasion, aggregate impact value, and specific gravity and water absorption test. Besides, bitumen quality tests, namely specific gravity, softening point, ductility, penetration, and flash point, were conducted to determine its quality.

3.7.1.1 Mineral aggregate

Aggregate is the main constituent in HMA, and the quality, physical properties of this material have a great influence on mix performance (ERA manual, 2013). Because of the amount of mineral aggregate in asphalt paving mixture is generally 90 to 95 percent by weight. These imply that mineral aggregate is primarily responsible for the load supporting capacity of pavement. Due to this Aggregate gradation, shape, surface texture, water absorption, soundness, resistance to crushing, and impact loads have a great impact on a shear strength hot mix asphalt properties. AASHTO, ASTM and BS standards are taken for the methods of tests for road construction for dense graded asphalt. The mineral aggregates used in the research were subjected to various tests in order to determine their physical characteristics and suitability due to these various tests were conducted.

3.7.1.2 Mineral filler

The effects of filler on the mechanical properties of the asphalt mixture are remarkable as it is one of the crucial ingredients in the HMA mixture. Fillers, as one of the ingredients in an HMA mixture, plays a vital role in determining the performance and properties of mixes, especially its interlocking and binding effects (Zulkati A. et al., 2010). In this study, crushed dust and Belessa kaolin which pass through No. 200 mesh were used as mineral filler in the preparation HMA mixture. The physical properties, which are expected to be critical in affecting the HMA mix property such as plasticity index and specific gravity were tested in the laboratory. Additionally, the chemical composition of Belesa kaolin is evaluated with different material laboratory tests. In this study, crushed stone dust and Belessa kaolin used as filler material whose apparent specific gravity has been found to be 2.67 and 2.62, respectively, and both fillers passing 100% through sieve No.200. Tests were performed on mineral fillers to evaluate the physical properties of both fillers.

Table 3.1: Physical properties of Crushed stone aggregate (CSD) and Belessa kaolin

	Properties of mineral filler		**Specification ASTM D242**
	Crushed stone dust	Belessa kaolin	
Quarry Site	ERCC, Jimma district, Deneba site	Belessa kaolin deposit	
Sieve Seize No (0.075mm)	100	100	70-100
Plastic Index	Non-plastic	Non-plastic	<4
Apparent specific gravity (SG)	2.668	2.619	

3.7.1.3 Asphalt binder

The physical properties of the asphalt binder vary considerably with temperature. At high temperature, asphalt binder become fluid with a low consistency similar to that of oil. At room temperature, most asphalt binders should have the consistency of soft rubber. At sub-zero temperatures, asphalt binder can become very brittle. Most of asphalt binder specification was designed to control changes in consistency with temperature [48].The asphalt binder used in this study was a penetration grade of 60/70. The main reason for selecting this bitumen grade is because of its common type of asphalt that widely utilized in most of the road projects in the study area. The physical properties of the asphalt binder were determined according to the procedure specified by AASHTO standards. A series of tests including penetration, specific gravity, softening point and ductility were conducted for the basic characterization properties of penetration grade asphalt

3.8 Marshal Mix Design

The Marshall method of design was originally developed by Bruce Marshall, formerly of the Mississippi Highway Department, and improved by the U.S Army Corps of Engineers. The Marshall method is applicable only to hot mix asphalt using penetration, viscosity, or PG graded asphalt binder or cement and containing aggregate with a maximum size of 25.0 mm (1 in.) or less (AASHTO, 1993). Marshal Mix Design method was used to determine the optimum asphalt content and evaluate the stability of the mixtures in the laboratory. And also, it provides information about the properties of the resulting pavement mix, including density and void content, which are used during pavement construction.

3.8.1 Mix Preparation

The Marshall Mix design method used to determine the stability and flow of the asphalt mixture and used to evaluate the optimum binder content in the laboratory. Approximately 1.2kg of the total of coarse aggregate, fine aggregate and filler materials were taken according to the adopted gradation. Belessa kaolin with the content of 10% -50% from the total weight of filler with 10% increment added in to the mix ingredient before heated bitumen adding.

One type of binder (60/70) penetration grade already stated were used in different proportions in the mixes starting from 4% to 6% with increment of 0.5% of the total mix in order to obtain the optimum binder content required in asphalt mixes and also to determine the effect of binder content on the mix properties. Two type of mixes without and with Belessa kaolin were conducted in this study. First, the control mix conducted in the laboratory in order to determine the optimum binder content. Then Belessa kaolin passing sieve No. 200 were added directly to the aggregate sample in five different proportions, 10%, 20%, 30%, 40% and 50% of the total mix respectively. This mixes are using to assess the optimum non-conventional requirement for the best possible mixes and for the use of further indirect tensile strength test and rutting test.

3.8.2 The mix and compacted specific gravity test

The Bulk specific gravity and the theoretical maximum specific gravity of an asphalt concrete are essential in order to determine the volumetric properties of hot mix asphalt mixture. These volumetric properties are one of a good indicator of the asphalt concrete performance.

The compacted sample allowed cooling down at room temperature for 24hours and the bulk specific gravity was done at 25˚c according to ASTM 2726. For each sample mass in the air, mass of sample in water and mass in surface saturated sample were measured. The theoretical maximum specific gravity of an asphalt concrete mixture is the specific gravity of the mixture at zero air void. This maximum specific gravity is determined by measuring the specific gravity after removing all of the air interrupted in the mixture by subjecting the mixture to a partial vacuum saturation. The maximum specific gravity of the mix conducted according to ASTM D 2041 method. The compacted and the mix specific gravity determination expressed in below Equation.

$$Gmb = \frac{A}{B-C}$$

Where: Gmb = bulk specific gravity

A= dry mass of the specimen in air at room temperature

B= saturated surface-dry (SSD) mass of the specimen in air

C= mass of the specimen in water at (25˚c)

$$Gmm = \frac{A}{A+D-E}$$

Where: Gmm= Theoretical maximum specific gravity

A= the mass of mix in air dry at room temperature

D= the mass of container with filled water at 25˚c

E= the mass of container with mix sample and water

3.9 Volumetric properties

Mix design is meant to determine the volume of bitumen binder and aggregate necessary to a mixture with the desired properties. Since weight, measurements are typically much easier; weights are taken and then converted to volume by using specific gravities. The volumetric properties of a compacted paving mixture provide some indication of the mixture's probable pavement service performance. The properties that are to be considered include the theoretical maximum specific gravity Gmm, the bulk specific gravity Gmb, percentage of voids in total mix VIM, percentage volume of bitumen Vb, percentage void in mineral aggregate VMA, percentage voids filled with bitumen VFB, Effective asphalt content. Figure 3.3 show a phase diagram of the bituminous mix.

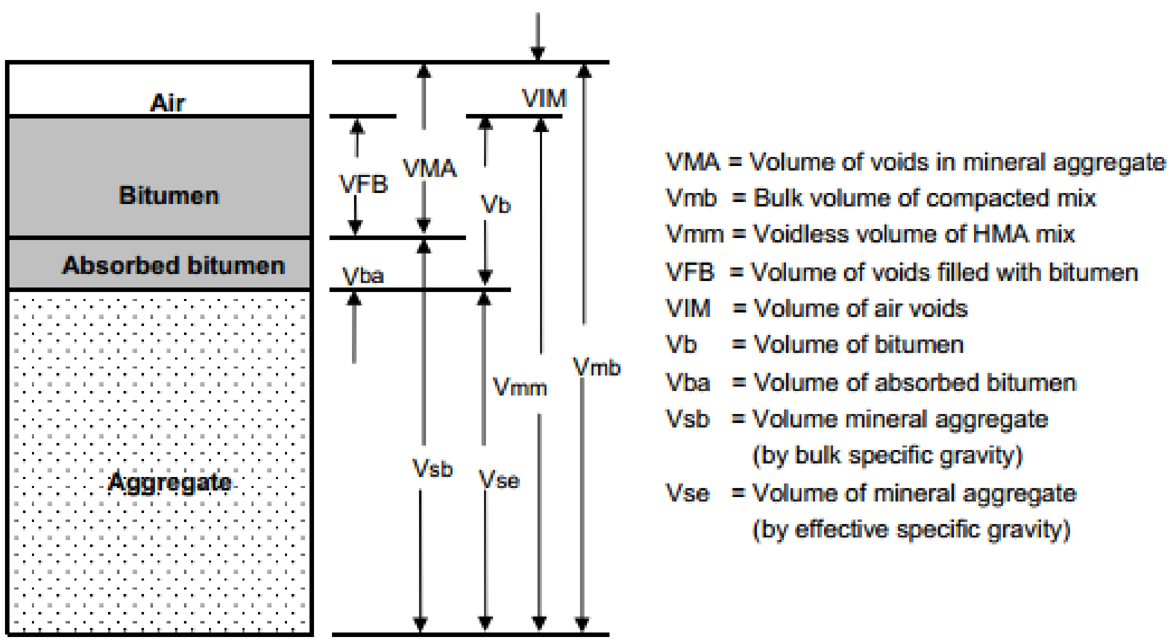

Figure 3.3: Phase diagram of bituminous mix (Asphalt Institute, 2014)

3.9.1 Air voids (VIM)

Air void (VIM) is a void in between the coated aggregate particles in the final compacted mixes. The air void of the compacted specimen depends on the method of the compaction, the compaction temperature, the number of loading on the mixes, the height and the weight of compaction and so on. AC mixes are compacted at least 96 percent density because the mix needs a certain air void to allow additional traffic compaction after construction. The air void in the AC mix recommended 3-5 % as per ERA2013 volume –I specification. The air void analyzed after obtaining the loss and compacted specific gravity of the mixtures. This result expressed as in percentage. The air void is calculated as in equation below as per ERA flexible design method manual.

$$VIM = \frac{Gmm - Gmb}{Gmm}$$

Where: VIM= percent air void in HMA

Gmm = maximum specific gravity of the mix

Gmb = bulk specific gravity

3.9.2 Voids in mineral aggregate

The Voids in Mineral Aggregate (VMA) includes the volume of air between the coated aggregate particles and the volume of effective bitumen as per ERA 2013 flexible pavement design definition. The value of the VMA increases the void space available in the asphalt increases. Dense wearing course mixes with low VMA are not suitable for this type of surfacing, because the design bitumen content is too low for the mix to be workable. The VMA was determined by using the compacted specific gravity of specimen, bulk specific gravity of blending aggregate and by using individual percentage of total aggregates. The specification stated in ERA 2013 flexible pavement design based on their air void and nominal maximum aggregate size. For this value calculation the following mathematical expression is used.

$$VMA = 100\% - \frac{Gmb \times ps}{Gsb}$$

Where: VMA = Voids in mineral aggregate

Ps = aggregate content, percent by total weight of mix

Gsb = bulk specific gravity of blending aggregate

Gmb = bulk specific gravity

3.9.3 Voids filled with Bitumen

The voids filled with bitumen (VFB) expressed as the percentage of volume of the VMA that filled with the effective binder. VFB, like VMA, also tends to increase as the mix becomes finer and gains more total aggregate surface area. The value of VFB determined after to obtain the value of air void and void filled with minerals that expressed as in percentage. For this study, VFB value calculated as per ERA 2013 flexible pavement design manual equation methods shown in the below equation

$$\text{VFB} = \frac{VMA - VIM}{VMA}$$

3.9.3 Percent of the volume of absorbed asphalt

Percent of the volume of absorbed asphalt (Pba) is the volume of bitumen expressed by percentage in the mixture that has been absorbed by the pore space of the aggregate. It is expressed as:

$$Pba = Gb \times \left(\frac{Gse - Gsb}{Gse \times Gsb}\right) \times 100$$

Where: Pba = percentage of absorbed asphalt binder

Gb = specific gravity of asphalt binder

Gse = effective specific gravity of total aggregate

Gsb = bulk specific gravity of total aggregate

3.9.4 Mix design specification

During this study, the result of the mix design achieved the minimum requirement of the standard. The mix design specification stated in according to the ERA 2013 flexible pavement design method. All mixes should designed to the asphalt institute (1994) marshal criteria for wearing courses. The study area of this research experiences Heavy traffic which is a design traffic between 1 to 5 million ESA. Therefore, Heavy traffic criteria is used to analyze different properties of hot mix asphalt throughout this paper. The limit design standard specification of different traffic class is listed in table 3.2.

Table 3.2: Marshal Criteria for asphalt concrete mix design

Category and design traffic (million ESAL)	Compaction Blow	Minimum Stability (KN)	Flow (mm)	VFB (%)	VIM (%)	VMA
Very heavy (>5)	75	9	2 - 3.5	65 - 73	3 - 5	>13
Heavy (1-5)	75	8	2 - 3.5	65 - 75	3 - 5	>13
Medium (0.4-1)	50	5.3	2 - 4	65 - 78	3 - 5	>13
Light (<0.4)	35	5.3	2 - 4.5	65 - 80	3 - 5	>13

3.10 Determination of optimum bitumen content

The air void, stability, flow and bulk density are factor for deciding the optimum binder content of the bituminous mixtures, but the stability, flow and bulk density are not suitability factor for deciding the optimum binder content of the hot mix asphalt mixtures as per ERA 2013 specification. There are two commonly used methods to determine the optimum bitumen content. Those are method 1 NAPA (National Asphalt pavement Association) and method 2 Asphalt Institute method. Determination of optimum bitumen content was proceeded after analyzing different volumetric properties of the mix and preparation of separate graphical plot for the value of stability, flow, VFB, VMA, Air Void, Bulk specific gravity with Asphalt content. The following discussion briefly states the procedure of both methods in order to determine optimum bitumen content.

3.10.1 Method 1: Asphalt institute method

Asphalt institute method (MS-2) says that it isn't right to depend on only one particular parameter for selecting design asphalt content because one single asphalt content cannot address all the issues to the highest extent at the same time. It also says, if one single parameter has the maximum influence on the overall performance of the mix, it is the percentage air void (VIM). An acceptable range of 3 to 5 % air void is used. The design bitumen content of the mix is selected by considering all of the data discussed previously. As an initial starting point it is recommended that the bitumen content giving 4% air voids is chosen as the design bitumen content. All of the calculated and measured mix properties at this bitumen content are determined by interpolation from the each individual graphs. The individual properties are then compared to the mix design criteria as specified in MS-2 (Asphalt Institute, 2014). With this range, 4 % air void is considered to be the best initial estimate to determine the design bitumen content which was balance the mix performance. Fine-tuning of air void is done on the basis of other parameters.

The final selected mix design is usually the most economical one that was satisfy all of the established criteria stated in MS-2. However, the mix should not be designed to optimize one particular property but should be a compromise selected to balance all of the mix properties.

3.10.2 Method 2: NAPA (National Asphalt Pavement Association)

Asphalt content corresponding to specification's median air void content (4 % typically) is the Optimum Asphalt Content. These methods mainly based on the plots were prepared using different volumetric properties with asphalt content. From this method optimum asphalt content is determined by:-

1. The asphalt content which corresponds to the specification's median air void content (4 percent typically) of the specification. This is the optimum asphalt content.
2. The asphalt content is then used to determine the value for Marshall Stability, VMA, flow, bulk density and percent voids filled from each of the plots
3. Compare each of these values against the specification values for that property, and if all are within the specification range, the asphalt content at 4 percent air voids is optimum asphalt content. If any of these properties are outside the specification range, the mixture should be redesigned.

Method 1 (MS-2) was selected for this research in order to determine the optimum asphalt content and for further mix design i.e. for Replacement of filler in a mix. The marshal properties of the asphalt mix, such as stability, flow, bulk density, air void in the total mix, and voids filled with bitumen were must be in the range of suggested marshal criteria for asphalt concrete mix design (ERA manual, 2013).

3.11 Determination optimum Belessa kaolin filler content

Before beginning the replacement procedure, the physical and chemical properties of non-conventional (Belessa Kaolin) are investigated in the laboratory. The purpose of the test to identify if the non-conventional material fulfill the specification to use as a filler material. It was tested for physical properties as per AASHTO and chemical properties as per ASTM C 618.

Next to determination optimum bitumen content and optimum crushed stone dust filler proportion together with design aggregate using a 0.45 power chart, the next step would be replacing the conventional mineral filler crushed stone dust by Belessa kaolin filler. Throughout partial replacement of Belessa kaolin filer, design bitumen content and filler proportion together with design gradation are remain constant for all mixes. Before determination of optimum replacement ratio of non-conventional filler different replacement ratio were used. The replacement ratio used for non-conventional filler (Belessa kaolin) are 0% (control mix), 10%, 20%, 30%, 40% and 50% by weight of optimum crushed stone dust filler. Based on this, totally, 58 samples were prepared for the marshal test, moisture susceptibility and rutting test.

The steps followed to prepare marshal and performance specimen at different percentages of kaolin and constant bitumen content are discussed below. The properties of the specimen were checked with the specified range of design criteria. The optimum replacement ratio was obtained the Belessa kaolin content having maximum stability, maximum bulk density, and air void, indirect tensile strength and less deformation within the allowed range of specification. The steps followed to prepare Belessa Kaolin for filler samples are summarized as follows:

1. Purposive sampling technique was utilized to obtain kaolin from the quarry site by crushing and grinding until it reaches the required mineral filler size.
2. The Belessa kaolin, which passed on number 200 sieve (0.075mm), was checked for PI test.
3. The physical properties such as specific gravity and chemical properties such as chemical composition were identified by XRD.
4. Six percentages of Belessa kaolin were investigated for marshal test, which were replaced at 10% incremental percentages of 0 %(control mix) 10, 20, 30, 40, and 50% by weight crushed stone dust filler with 3 samples for each percentage.
5. Six percentages of Belessa kaolin were investigated for indirect tensile test, which were replaced at 10% incremental percentages of 0 %(control mix) 10, 20, 30, 40, and 50% by weight crushed stone dust filler with 6 samples for each percentage.
6. The wheel truck test for control mix and optimum belessa kaolin to investigate performance of the samples.

7. The Belessa kaolin filler and aggregate are then heated to a temperature of 160 ºC before mixing with asphalt cement. Asphalt was heated up to 150 ºC to 155 ºC prior to mixing with aggregates.
8. The required amount of asphalt (i.e. Optimum bitumen content) was added to the heated aggregate and mixed for two minutes.
9. Standard Marshall Molds were heated in an oven up to 130 ºC, and then the hot mix is placed in the mold and compacted with 75 blows at each face of the specimen.
10. Specimens are prepared, compacted, and tested according to standard 75-blow Marshal Method designated as ASTM D 1559.
11. Specimens are prepared and compacted in roller compactor, then tested in wheel truck according to standard as per BS EN 12967-22.

3.12 Moisture susceptibility

After completing all marshal test method, the moisture susceptibility test was conducted in this sub section when AC mixes prepared at their optimum binder contents. The mechanical properties of asphalt mixes is depending on various variables particularly the presence of water in the mixes are a complex issue. There are several methods used to study the loss of adhesion of bitumen from aggregates. However, among varies methods, moisture-conditioning process is commonly using that recommended by AASHTO T-283 test method entitled: "Resistance of Compacted Bituminous Mixtures to Moisture Induced Damage." The test is using to evaluate the loss of strength of hot mix asphalt mixes after subjected to the moisture for a certain period. In this research, the indirect tensile strength test was used in order to evaluate the moisture susceptibility of the hot mix asphalt mixture by using Marshall Test machine. Under this indirect tensile strength test, the American Association of State Highway and Transportation Officials AASHTO T-283 (1993) method used.

The tensile strength ratio (TSR) result from the tensile strength test commonly used to evaluate the moisture sensitivity of the asphalt mixes. Therefore, in this thesis work, tensile strength ratio test used to determine the moisture induced damage properties of the asphalt mixture. Evaluation of moisture -induced damage according to AASHTO 283 has a major advantage to estimate effects of water/traffic action and pore pressure effects on the bituminous mix performance properties. But the method has major disadvantages such as the requirement of more elaborate testing equipment, longer testing time require and requiring much physical and mental efforts of test procedures. Keeping in mind, the advantage and disadvantage the objective of these tests on this research was to compare the properties of asphalt mixtures with and without Belessa kaolin filler at optimum binder content. The TSR value obtained from dry to moisture condition ratio under at least single freeze-thaw cycles.

The test is conducted as per AASHTO T283 specification. Compressive strength of compacted specimen is determined after conditioning them by keeping in water bath maintained at 60℃ for 24 hours prior to testing. Then remove the specimen from the water bath and the specimen placed in a 25°c water bath for 2 hours. The dry condition placed at 25℃ water bath by covering water leak-proof plastic bag for 2 hours. Finally, the specimens removed from 25℃ water bath and paced between the two bearing plates in the marshal test machine. This compressive strength, expressed as a percentage of the compressive Strength of Marshall Specimens determined under standard conditions, is the retained stability of the mix. A higher value indicates lower moisture susceptibility (higher moisture damage resistance). The tensile strength result calculated as follow:

$$St = \frac{2000P}{\pi t D}$$

Where: S_t= tensile strength (Kpa)

t= specimen thickness (mm)

P=maximum load (N)

D= specimen diameter (mm)

$$\text{Tensile Strength Ratio (TSR)} = \frac{St2}{St1}$$

Where: S_{t1} = average tensile strength of unconditioned or dry subset

S_{t2} = average tensile strength of conditioned subset

The Tensile Strength Ratio of the hot mix asphalt is recommended to have a minimum of 80% as per AASHTO T283 specification.

3.13 Permanent deformation (rutting)

Permanent deformation test is followed by moisture susceptibility test. This test is commonly introduced to examine the performance of HMA at optimum bitumen content. The susceptibility of bituminous materials to deform is assessed by the rut formed by repeated passes of a loaded wheel at constant temperature. Laboratory tests to assess rutting performance are conducted at high temperatures intended to represent the in-service temperature experienced by the asphalt mixture in the summer months. As the desire for mixture performance testing grew and technology advanced, other mixture performance tests became available and standardized for use by asphalt mix design technologists. Although mixture stiffness at high temperatures is considered important, most of the rutting tests commonly used involve some type of repeated loading (Standardization, 2020).

BS EN 12697-22 has three different test methods, two with the small size device (Procedures A and B) and one with the large size device. The large size device is used for materials designed for wheel loads greater than or equal to 13t and therefore we did not consider using this test in this research task.

Procedure A test method uses six material samples conditioned at the test temperature for 4-24 hours, and tracked for 1,000 cycles under a solid rubber tyre of width 50mm and load 700N at a rate of 26.5 ± 1 cycles per minute, with the first 5 cycles used for conditioning. A single measurement point at the center of the sample is used to calculate the rate of deformation over the last 300 cycles of the test in μm/cycle, and the total deformation for the maximum rut depth.

Procedure B test method uses two samples conditioned at the test temperature for at least 1 hour, and tracked for 10,000 cycles under a solid rubber tyre of width 50mm and load 700N at a rate of 26.5 ± 1 cycles per minute, with the first 5 cycles used for conditioning. The deformation is measured as the mean of 25 equally spaced measurement points and the wheel-tracking rate is calculated over the range of 5,000-10,000 cycles in mm/1000 cycles. Under this procedure, the proportional rut depth, as a percentage of the sample thickness, is calculated rather than the actual rut depth.

Loaded wheel testing is a common method used by some designers to evaluate the rutting susceptibility of an asphalt mixture. Although there are many different types of loaded wheel tests, with different loading configurations and test conditions, the principles of the test remain essentially the same. In a loaded wheel test, a wheel runs over an asphalt mixture specimen at an elevated temperature in a reciprocating manner. With each load cycle, a certain amount of deformation is created in the asphalt mixture specimen. After a specified number of load cycles, the permanent deformation (rutting) in the asphalt mixture is determined and compared to established criteria to determine the rutting susceptibility of the asphalt mixture. In this research I am going to introduce wheel tracking test to examine rutting.

3.13.1 Wheel Tracking Test

This test was performed according to EN 12697-22 test method using Wheel Tracking Device. The susceptibility of bituminous material to rut under wheel load is determined using the wheel tracking test. Specimens prepared in laboratory or cut from the real pavement can be tested for rutting due to loaded wheel cyclic passes at different temperatures. The apparatus consists of a loaded wheel which passes repeatedly over the sample held securely on a table and an attached device displays rut depth (mm) that occurs at the surface of specimen. Temperature control device is required so that the temperature of the test specimen during testing remains uniform. Test specimens were prepared in the laboratory using Roller Compactor. In this study, a load of 700 Newton (N) was applied. Mixes were tested at temperature of 55 °C for a period of 10,000 cycles.

Two slabs were prepared for each mixture type with the size of 300x260x50mm at the optimum bitumen content for crushed stone dust and Belessa kaolin respectively. The air void values was used in order to determine the number of roller passes for compaction purposes. The degree of compaction is measured by the ratio of specific gravity of Marshall properties to the specific gravity of rutting sample. Wessex Dry wheel tracking test was used to measure the rutting resistance of the mixture. The test was conducted according to BS EN 12697-22 specification. The rut depth was recorded at every 25 load cycles. Based on the specification, the sample was considered to reach failure if the rut depth exceeds 20 mm. The test was terminated at 10000 load cycles. The total rut depth was recorded by the Wessex software that comes together with the machine.

This device consists of a loaded wheel that repeatedly passes over the test specimen. The load applied is 700 N at a frequency of 26.5±1.0 load cycles/minute. Another mechanism measures the speed at which the rut forms on the surface of the specimen. The test ends after 10,000 passes of the loaded wheel or until the deformation depth reaches 20 mm. The deformation slope is determined based on the rut depth between 5,000 and 10,000 cycles. Procedure B in air used to compute rutting in this test. The rut depth and proportional rut depth is calculated as follow:

$WTS_{AIR} = \frac{d10000 - d5000}{5}$ ($^{mm}/_{10^3}$ load cycles)

Where: WTS_{AIR} = wheel truck slope in air

d10000 = rut depth at 10000 cycles

d5000 = rut depth at 5000 cycles

$PRD_{AIR} = \frac{dn - do}{h} \times 100\ \%$

Where: PRD_{AIR} = the proportional rut depth of i^{th} replicate, in percent (%)

dn = the vertical displacement after n load cycles, in millimetre (mm)

do = the vertical displacement initially, in millimetre (mm)

h = the specimen thickness, in millimetre (mm)

Table 3.3: European categories for wheel tracking in EN 13108

Device	Large Size	Small size				
		Procedure A		Procedure B		
Measure	Proportional rut depth (%)	Rate (µm/cycle)	Rut depth (mm)	Rate (µm/cycle)	Proportional rut depth (%)	Rut depth (mm)
Categories	<5.0	<5.0	<3.0	<0.02	<1.0	<1.0
				<0.03	<1.5	<1.5
	<7.5	<7.5	<5.0	<0.04	<2.0	<2.0
				<0.05	<2.5	<2.5
		<10.0	<7.0	<0.06	<3.0	<3.0
	<10.0			<0.07	<4.0	<3.5
		<12.5	<9.0	<0.08	<5.0	<4.0
				<0.09	<6.0	<4.5
	<15.0	<15.0	<11.0	<0.10	<7.0	<5.0
				<0.15	<8.0	<6.0
		<17.5	<13	<0.30	<9.0	<6.5
	<20.0			<0.40	<11.0	<7.0
		<20	<16	<0.50	<13.0	<8.0
				<0.60	<16.0	<9.0
				<0.80	<19.0	<10.0
				<1.00	<20.0	
					<25.0	

CHAPTER FOUR

RESULT AND DISCUSION

4.1 General

This chapter deals about the material quality test result and hot mix asphalt mixtures in both control mix and with Belessa kaolin filler. The control mix is used to identify the optimum binder content. The influence of non-conventional filler with different percentage and superpave aggregate gradation on the stability, flow and volumetric properties of hot-mix asphalt relative to the control bituminous mixtures is presented in this chapter. The moisture susceptibility test by using the indirect tensile strength test and permanent deformation test by wheel truck test results are also discussed. The result of the tests are presented, analyzed, discussed and compared with ERA 2013 flexible pavement design specification.

The first section described the result of material quality test and superpave gradation, in the second section presented bituminous mixes without Belessa kaolin content by using marshal test. In the third section, to investigate the effect of Belessa kaolin content at optimum bitumen content with the specific superpave aggregate gradation in the bituminous mixtures. The fourth section analyzed the result of moisture susceptibility based on the load steel strip indirect tensile strength test method and rutting result based on wheel truck test method. Finally, the test results are supported by different graphs and charts.

4.2 Material property

4.2.1 Aggregate physical properties

The material quality test is very crucial for the requirement of hot mix asphalt design. The physical properties test results of an aggregate is must satisfied minimum requirement of ERA 2013 flexible pavement specification limits. A different laboratory test was conducted on aggregate, including sieve analysis, specific gravity, aggregate crushing value, Aggregate impact value, Los Angles Abrasion Test was performed. The result of aggregate quality test presented in the following table.

Table 4.1: Physical properties of Aggregate

Test	Test Method	Test Result			Specification
		(25-14mm	(6-14mm)	(3-6mm)	
Bulk dry S.G	AASHTO T 85-91	2.589	2.594	2.601	_
Bulk SSD S.G		2.623	2.635	2.642	_
Apparent SG		2.682	2.703	2.711	_
Water absorption,%	BS 812, Part 2	1.333	1.553	1.557	<2
Aggregate Impact value	AASHTO T176-86	8.06			_
Flakiness index	BS 812 Part 105	29.90			<45
Aggregate Crushing Value (ACV),%	BS:812 Part 110	17.55			<25
Los Angeles Abrasion (LAA), %	AASHTO T 96`	11			<30

4.2.2 Physical properties of mineral aggregates

The mineral aggregate used in this research are Non-conventional (Belessa kaolin) and conventional filler (CSD). Different Laboratory tests have been conducted in order to determine their suitability via tests such as gradation parameters, plasticity index, and apparent specific gravity. The physical properties of crushed stone dust is generally non plastic. Tables 4.2 illustrate the physical properties of each type of filler according to ASTMD-854 using water pycnometer method.

Table 4.2: Physical properties of CSD and Belessa kaolin filler

Test	Properties of mineral filler		Specification ASTM D242
	Crushed stone dust	Belessa kaolin	
Apparent specific gravity (SG)	2.668	2.619	-
Liquid Limit	not determined	33	<4
Plastic Limit	not determined	29.76	
Plastic Index	NP	3.24	<4

NP: Non-Plastic

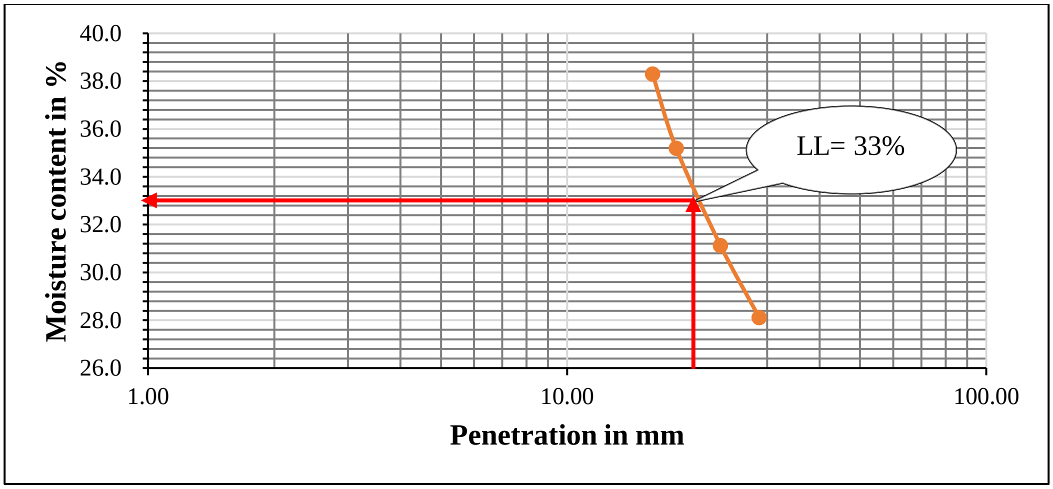

Figure 4.1: Liquid limit of Belessa kaolin

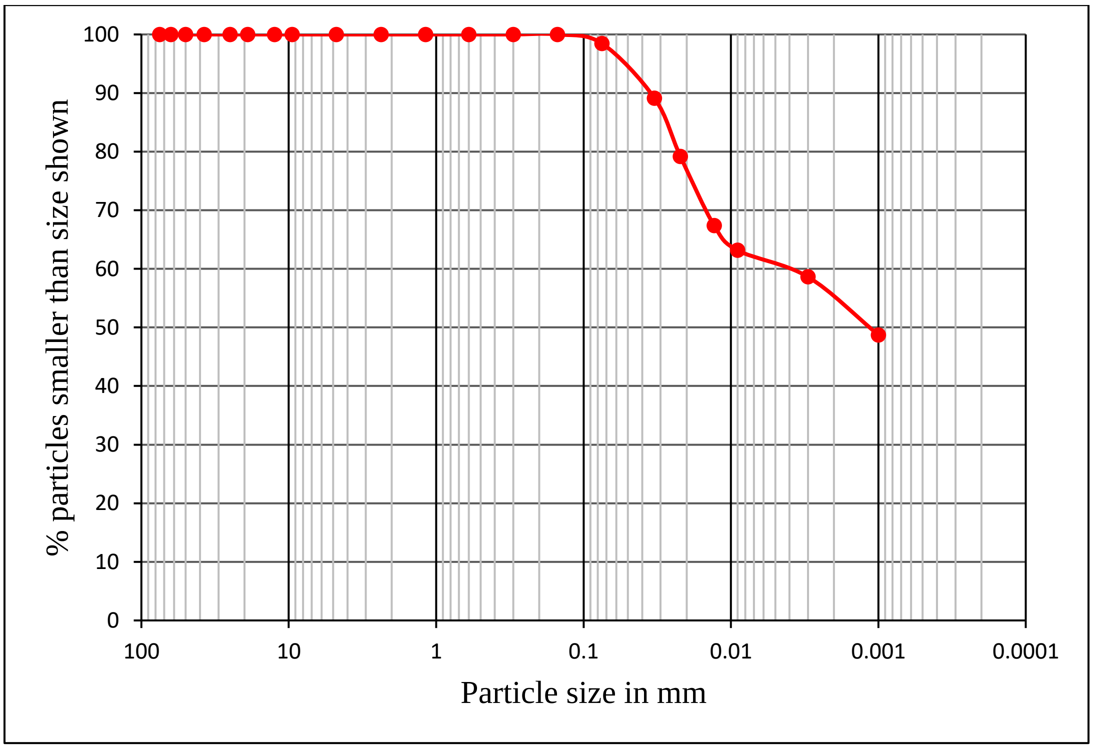

Figure 4.2: Particle size distribution of Belessa kaolin

Particle size distributions is the critical factors in assessing kaolin for HMA applications. Thus, the particle size distributions show that the kaolin is rich in terms of clay size fractions (55% <2 μm), while silt and sand are less abundant. The particle size of Belessa kaolin also contains acceptable critical points which are in agreement with the specifications.

4.2.3 Chemical properties of Belessa kaolin

The chemical composition carried out on kaolin was shown in Table 4.1. The results indicate the presence of important and suitable oxide composition for replacement. The combined percent composition of Al2O3, SiO2 and Fe2O3 was more than 70%. This was adequate to meet the requirement of ASTM C618 standard for pozzolanic materials to use as a filler.

Table 4.3: Chemical Composition of Belessa kaolin

Chemical Composition	Test results	Requirement ASTM C 618 (%)	Result status
SiO_2	63	35 and above	Pass
Al_2O_3	24.1		
Fe_2O_3	2.84		
$SiO_2 + Al_2O_3 + Fe_2O_3$	89.94	70 and above	Pass
MgO	0.03	5 and below	Pass
CaO	1.05	3 and below	Pass
Na_2O	0.03		
K_2O	0.06		
TiO_2	0.47		
MnO	0.03		
Total	90.61		
LoI	9.69		

The XRD pattern shows Belessa kaolin in rich of Silicon Oxides, Aluminimum Oxides and Iron Oxides. This shows the material has Pozzolonic property.

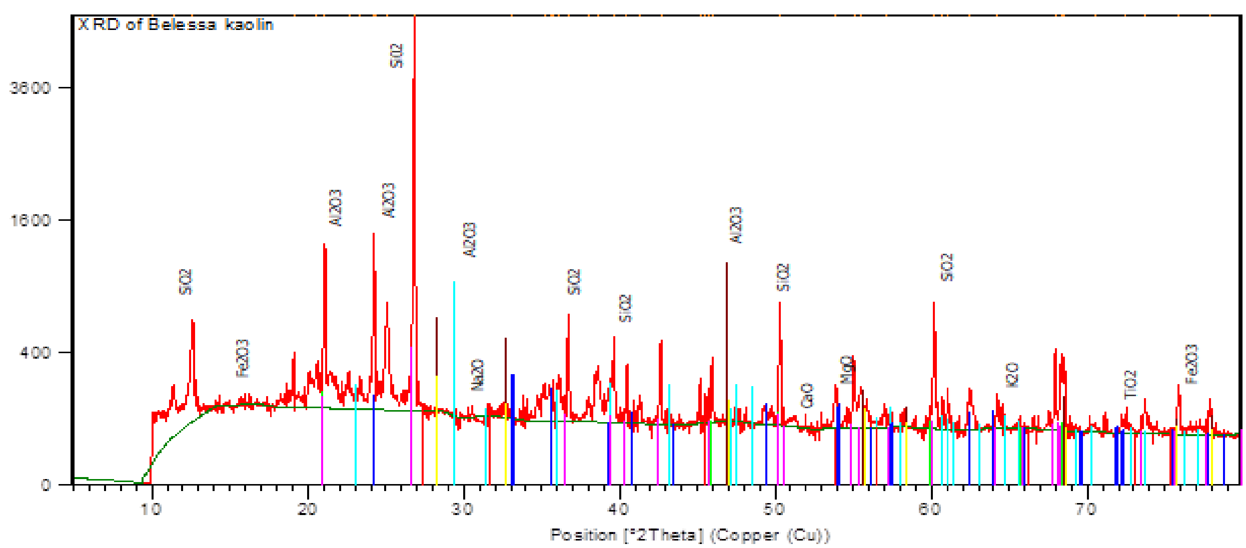

Figure 4.3: XRD pattern of Belessa kaolin.

4.2.4 Properties of asphalt binder

Bitumen grade of 60/70 were selected for the study area. Plenty of tests including, specific gravity, ductility, penetration, flash and fire point and softening point were conducted for the basic characterization of properties of penetration grade asphalt. The test results are discussed in table 4.4, which met criteria with the requirement of ERA Specification.

Table 4.4: Asphalt binder quality test

Test	Test Method ASTM	Test Result	Specification as per ERA,2013
Penetration	ASTM D5	63.06	60-70
Ductility	ASTM D113	96.33	Min. 50
Softening Point	ASTM D36	51.4	46-56
Flash point	ASTM D92	293.67	Min.232
Fire point	ASTM D92	353.5	Min. 280
Specific Gravity	ASTM D70	1.040	-

4.2.5 Aggregate Blending and Gradation of mix design

The aggregate blending and gradation is the most important parameters in the preparation of the hot mix asphalt mixtures. The aggregate gradation is expressed as the percentage by weight of the total sample that passes through each sieve. In this study, Superpave gradation was used to prepare the Marshall mix design. Superpave aggregate gradation is differs from conventional aggregate gradation by the incorporation of restricted zone and control points set by FHWA. The plotting of the aggregate particle distribution also differs from the conventional graph, and it is drawn on the 0.45 power chart.

There are three types of gradation as per Superpave, namely, above restricted zone (ARZ), through the restricted zone (TRZ), and below restricted zone (BRZ). In this study, three below restrict zone (BRZ) gradation were chosen because particle distribution which passes below restricted zone normally provide the most effective material for road carrying heavy traffic and for the severe site.

Superpave specification recommends, but does not require, mixtures to be graded below the restricted zone. It also recommends that as project traffic level increase, gradation move closer to the coarse (lower) control points. In addition, a gradation below restricted zone have better resistance provided by the coarser aggregate skeleton. For this study, three trial blends were adopted. Three various gradations are composed by varying the filler proportion or content, based on Superpave specification by considering the recommendation of avoiding the restricted zone and following the control points.

Available aggregate or used materials, coarse aggregate (9- 25mm), intermediate aggregate (4.75-9), fine aggregate (0- 4.75mm) and filler, were Combined in order to determine the proper gradation within the allowable limits according to ASTM specifications using the mathematical trial method. The percentage of each size of aggregates is to be computed and compared to specification limits. Table 4.5 shows the mix type and blending proportions of the different aggregate sizes to produce the desired combined gradation for different filler content of the asphalt binder course.

Generally, in this research, gradation passing below restricted zone with a nominal maximum aggregate size of 19 mm were selected as recommended by asphalt institute. The adopted aggregate blending proportion of three gradations are presented in table 4.6. The blended aggregate gradations are designated as BRZ5, BRZ6, and BRZ7, which describe below the restricted zone of Superpave aggregate gradation with 5%, 6%, and 7% filler proportion respectively.

Table 4.5: Aggregate blending proportion

Filler Content	Bin 1 (Coarse Aggregate) (%)	Bin 2 (Intermediate Aggregate) (%)	Bin 3 (Fine Aggregate) (%)	Total (%)
5%	24	30	46	100
6%	26	26	48	100
7%	22	32	46	100

Table 4.6: Adopted Superpave Aggregate Gradation of Asphalt mix for 19 mm nominal size

Sieve size in (mm)	Sieve size raised to 0.45 power	Percentage passing for three superpave gradation			Specifications of superpave gradation			
					Control points		Restricted zone	
		5%	6%	7%	Lower	Upper	Lower	Upper
25	4.257	100	100	100	100			
19	3.762	92.5	92	93	90	100		
12.5	3.116	80	81.5	81		90		
9.5	2.754	69	72	70				
4.75	2.016	51	52.5	51.5				
2.36	1.472	33	32	31	23	49	34.6	34.6
1.18	1.077	20	21	20			22.3	28.3
0.6	0.795	14	15	14			16.7	20.7
0.3	0.582	11	12	11.5			13.7	13.7
0.15	0.426	8	9	9.5				
0.075	0.312	5	6	7			2	8

The above table illustrate the final proportion of each aggregate material in asphalt binder and the proposed aggregates gradation blending have met the requirement of Superpave aggregate gradation. Using these gradations, the asphalt mixture is prepared and evaluated by using the Marshall Mix design method.

Figures 4.4 to 4.6 shows the three types of superpave aggregate gradations on the basis of three varying percentages of filler (5%, 6% and 7%) with 19mm maximum aggregate size were designed from percent passing.

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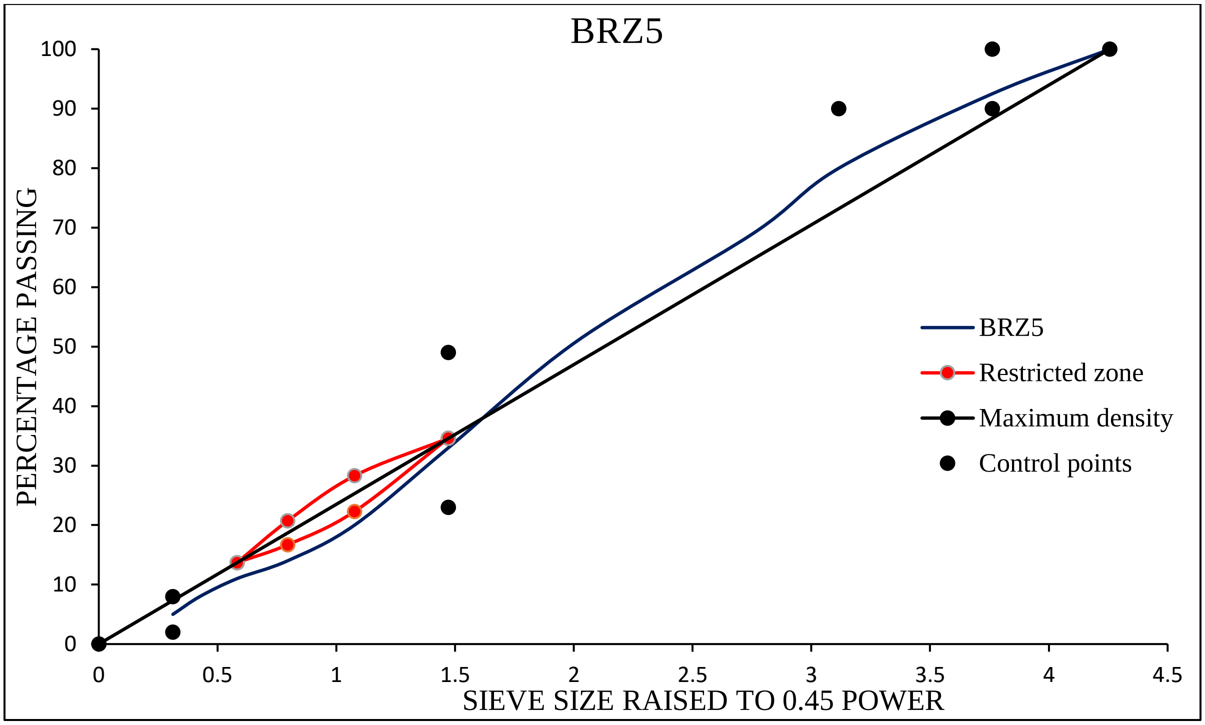


Figure 4.4: Superpave Gradation using 0.45 Power chart for 5% CSD filler

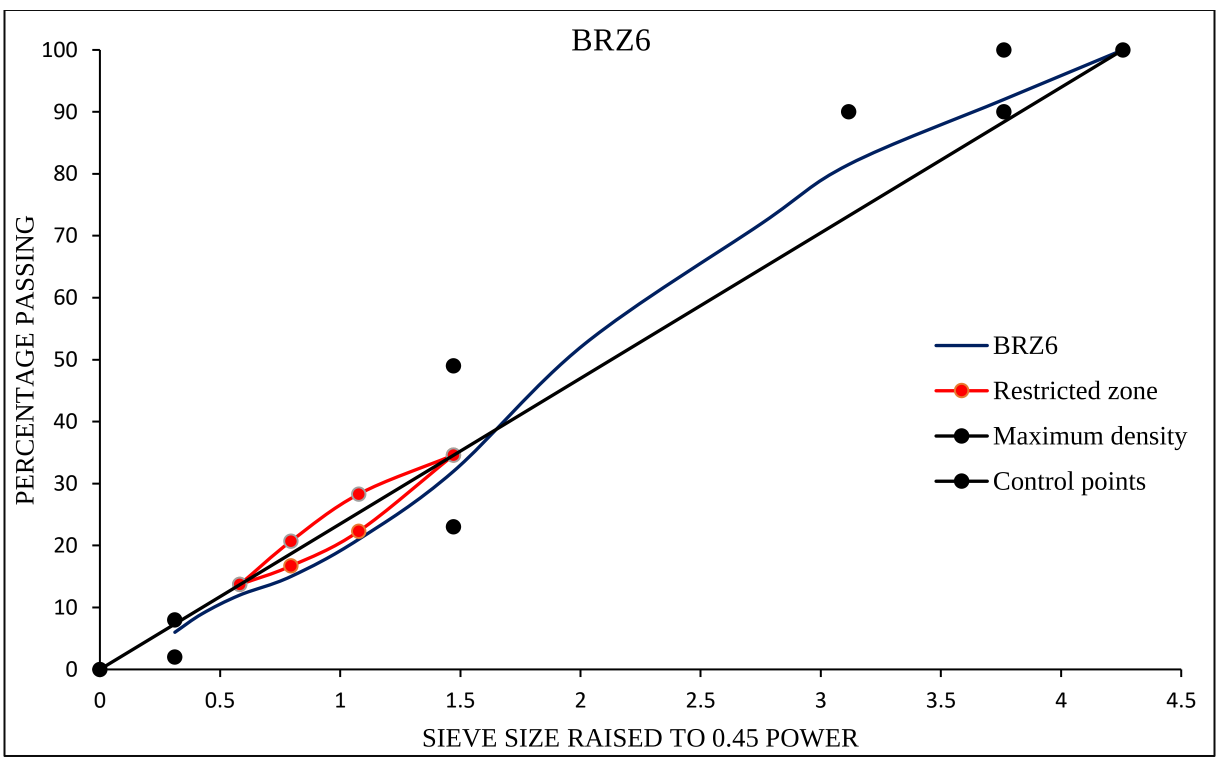


Figure 4.5: Superpave Gradation using 0.45 Power chart for 6% CSD filler

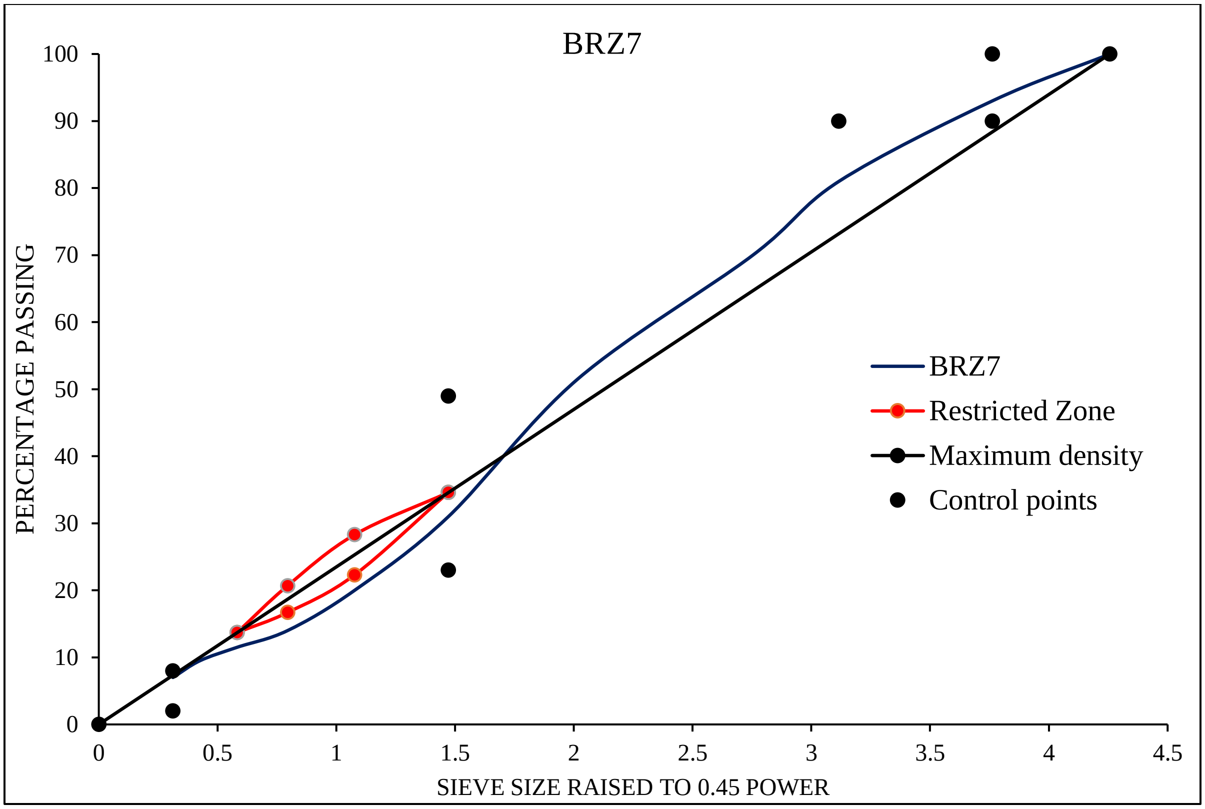


Figure 4.6: Superpave Gradation using 0.45 Power chart for 7% CSD filler

4.3 Analysis of asphalt mixture properties

4.3.1 Marshal tests results

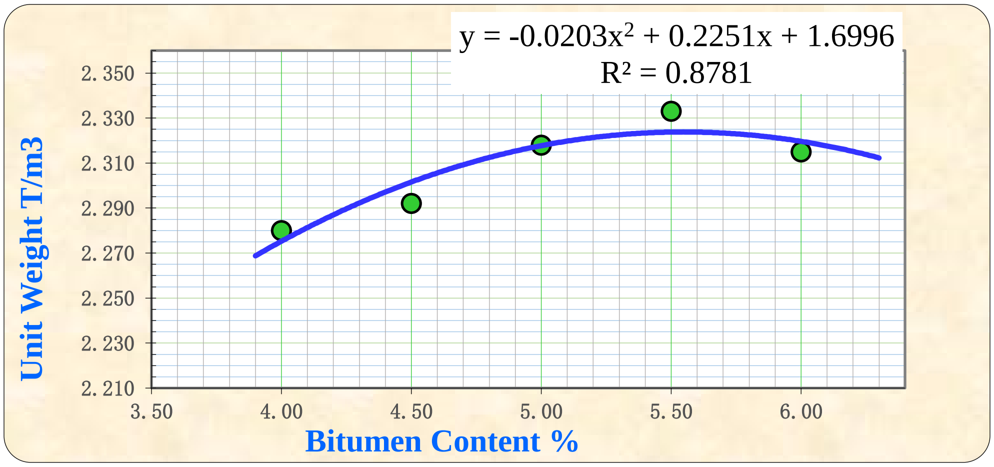
Marshal Mix Design method was used to determine the optimum asphalt content and evaluate the stability of the mixtures in the laboratory. The marshal test of a specimen prepared with varying amount conventional filler at 5%, 6 %, and 7% of crushed stone dust as filler by weight of aggregate with different bitumen contents (4 %, 4.5 %, 5 %, 5.5 % and 6 %). In this manner totally 45 samples, each of them weighs 1200 grams, were prepared. Optimum filler content and bitumen content were determined from those prepared specimens and results of marshal tests. Based on the 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 VFB, unit weight and flow increases. Table 4.7 indicates the properties of the mixture at various asphalt content for mixes with different conventional filler content (CSD). Further details are presented in Appendix.

Table 4.7: Marshall Test result for Mixes with 5% CSD filler and different bitumen content

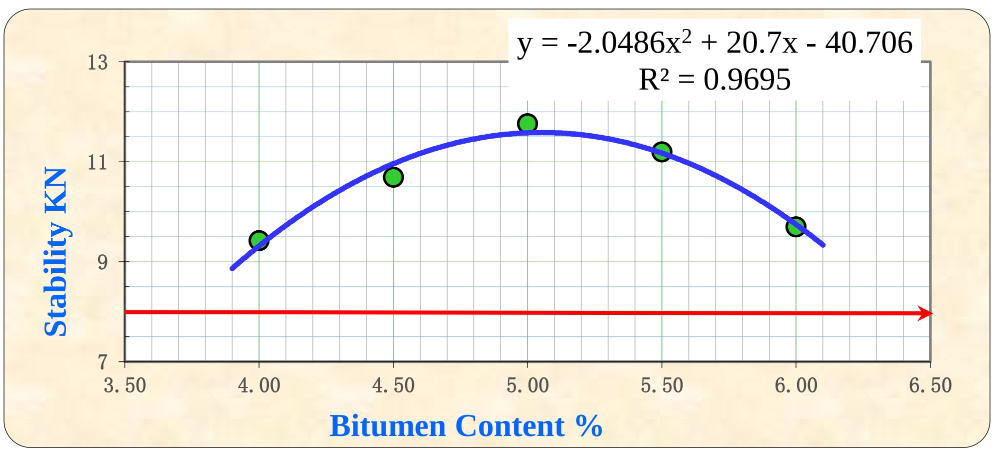
Specimen No	Bitumen Content (%)	Gsb	VA (%	VMA (%)	VFB (%)	Stability	Flow
1	4%	2.275	8.10	14.67	44.80	9.18	1.97
2		2.279	7.91	14.49	45.45	9.65	2.45
3		2.285	7.66	14.26	46.30	9.42	2.23
Average		2.280	7.89	14.47	45.51	9.42	2.22
1	4.50%	2.283	6.31	14.79	57.36	9.16	2.64
2		2.290	6.02	14.53	58.57	12.22	2.85
3		2.303	5.48	14.04	60.96	10.70	2.75
Average		2.292	5.93	14.45	58.93	10.69	2.75
1	5%	2.327	3.67	14.60	74.88	10.94	3.08
2		2.313	4.28	15.15	71.72	12.35	2.96
3		2.315	4.18	14.06	70.25	12.00	3.01
Average		2.318	4.04	14.60	72.30	11.76	3.02
1	5.50%	2.341	2.59	14.56	82.24	12.13	3.56
2		2.328	3.11	15.01	79.30	10.31	2.83
3		2.331	3.02	14.93	79.80	11.15	3.20
Average		2.333	2.90	14.84	80.43	11.20	3.20
1	6%	2.318	2.61	15.84	83.53	9.24	5.44
2		2.312	2.84	16.04	82.29	10.15	4.21
3		2.315	2.73	15.94	82.90	9.70	4.83
Average		2.315	2.73	15.94	82.90	9.70	4.83

Table 4.7 illustrate marshal test result of a mix with 5% conventional filler (CSD) and the corresponding values of marshal properties such as stability, flow value, Air Void, Voids in mineral Aggregate, Voids filled with bitumen and unit weight at different bitumen content. In

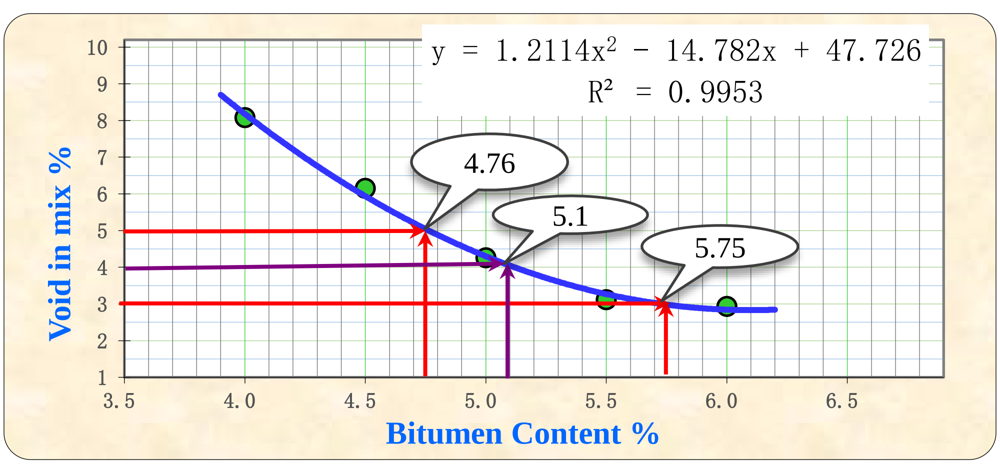
addition, Figure 4.7 shows the relationships between the different marshal properties with different bitumen content.



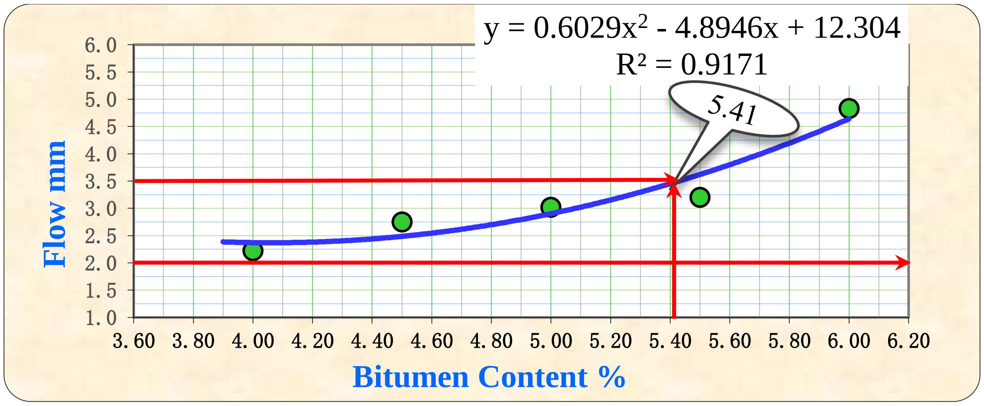
A) Unit weight vs Bitumen content at 5% CSD



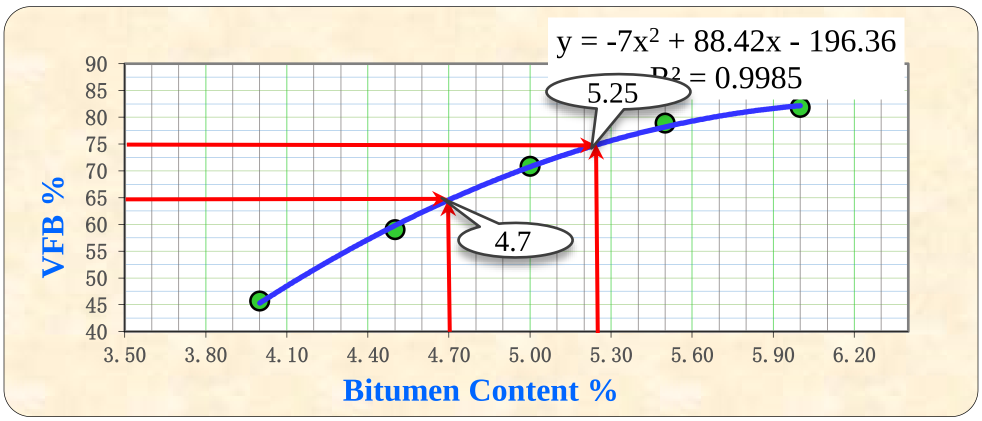
B) Marshal Stability vs Bitumen content at 5% CSD



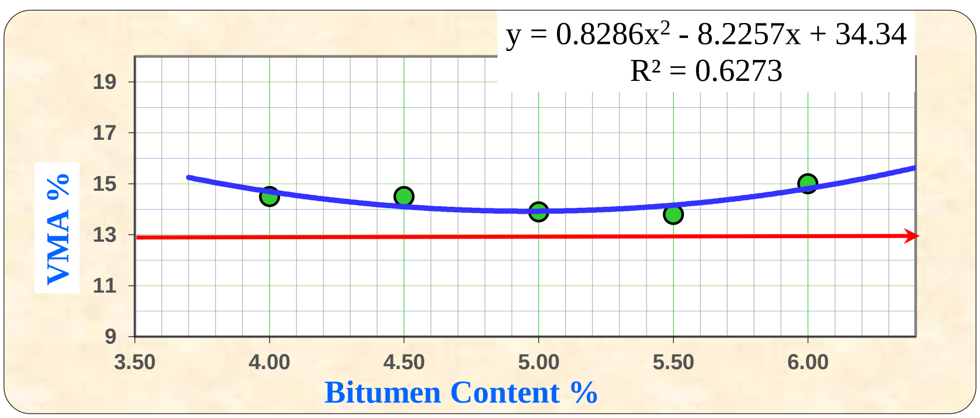
C) Air Voids vs Bitumen content at 5% CSD



D) Flow vs Bitumen content at 5% CSD



E) VFB vs Bitumen content at 5% CSD



F) VMA vs Bitumen content at 5% CSD

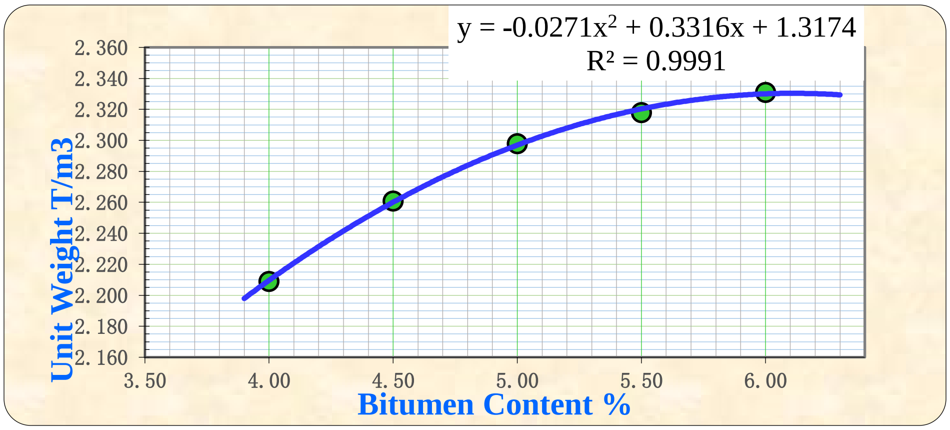
Figure 4.7: Marshall Properties of HMA design data with 5% filler gradation: A) Unit weight vs Bitumen content at 5% CSD, B) Marshal Stability vs Bitumen content at 5% CSD, C) Air Voids vs Bitumen content at 5% CSD, D) Flow vs Bitumen content at 5% CSD, E) VFB vs Bitumen content at 5% CSD and F) VMA vs Bitumen content at 5% CSD.

Based on the figures shown above, the relation between Marshall Property of mixture with 5% crushed stone dust and different bitumen content values are discussed below. When the bitumen content increases, the air void decreases in reverse the VFB and flow increases. Stability and unit weight increase with the increase of asphalt content up to maximum value and then decrease with the increase of asphalt content. Whereas, the percent of voids in the mineral aggregate (VMA) decrease to the minimum value then increases with higher bitumen content. The optimum bitumen content at 4% VIM is 5.1% by weight of the mix.

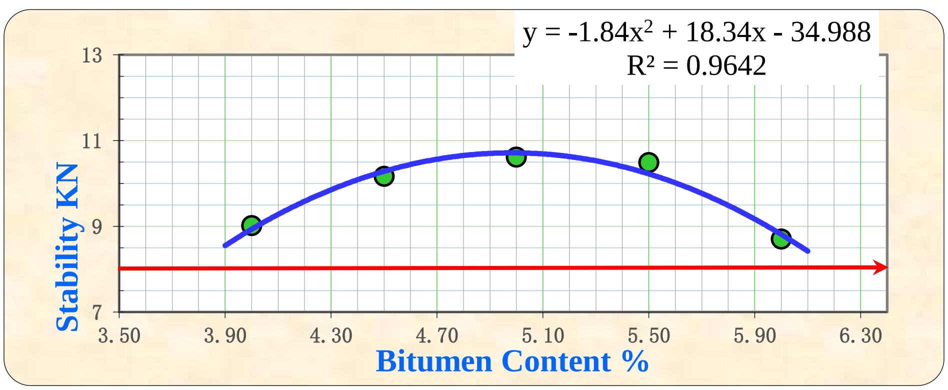
Table 4.8: Marshall Test result for Mixes with 6% CSD filler and different bitumen content

Specimen No	Bitumen Content (%)	Gsb	VA (%	VMA (%)	VFB (%)	Stability	Flow
1	4%	2.209	10.22	17.72	42.34	8.95	1.85
2		2.222	9.68	17.23	43.81	8.35	2.30
3		2.197	10.69	18.16	41.11	9.72	2.62
Average		2.209	10.20	17.70	42.40	9.01	2.26
1	4.50%	2.230	8.70	17.37	49.94	9.45	2.86
2		2.266	7.21	16.03	55.03	10.79	3.33
3		2.288	6.32	15.23	58.46	10.24	3.21
Average		2.261	7.41	16.21	54.28	10.16	3.13
1	5%	2.301	4.62	15.19	69.60	9.84	2.89
2		2.291	5.00	15.53	67.82	10.42	3.01
3		2.301	4.59	15.16	69.73	11.58	3.42
Average		2.298	4.73	15.29	69.04	10.61	3.11
1	5.50%	2.326	3.34	14.72	77.29	10.56	3.35
2		2.317	3.71	15.04	75.34	9.54	3.30
3		2.312	3.89	15.20	74.42	11.34	3.20
Average		2.318	3.65	14.99	75.67	10.48	3.28
1	6%	2.330	2.66	15.00	82.25	8.25	3.63
2		2.333	2.56	14.91	82.83	8.65	3.92
3		2.329	2.73	15.06	81.89	9.20	3.52
Average		2.331	2.65	14.99	82.32	8.70	3.69

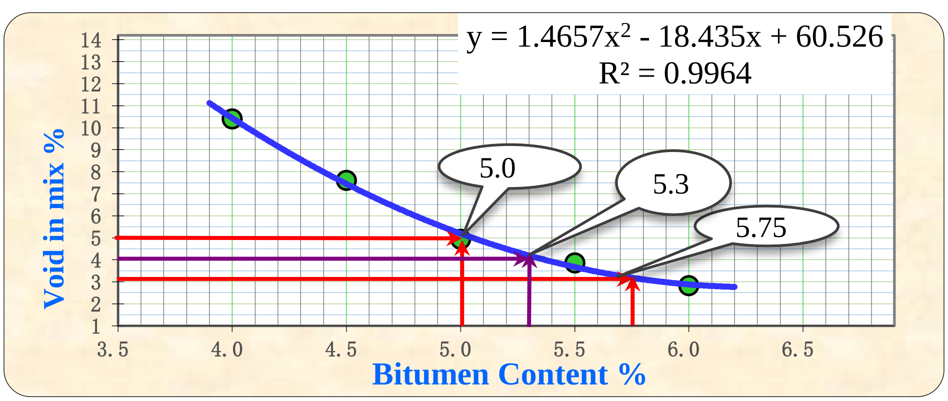
Table 4.8 illustrate marshal test result of a mix with 6% conventional filler (CSD) and the corresponding values of marshal properties such as stability, flow value, Air Void, Voids in mineral Aggregate, Voids filled with bitumen and unit weight at different bitumen content. In addition, Figure 4.8 shows the relationships between the different marshal properties with different bitumen content.



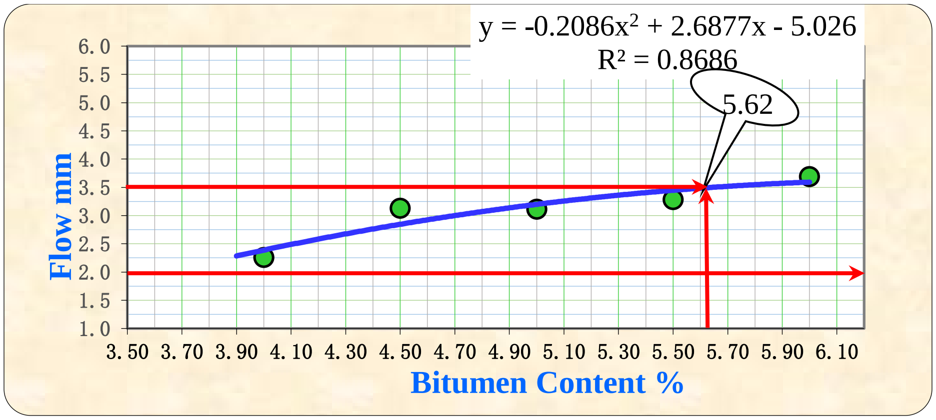
A) Unit weight vs Bitumen content at 6% CSD



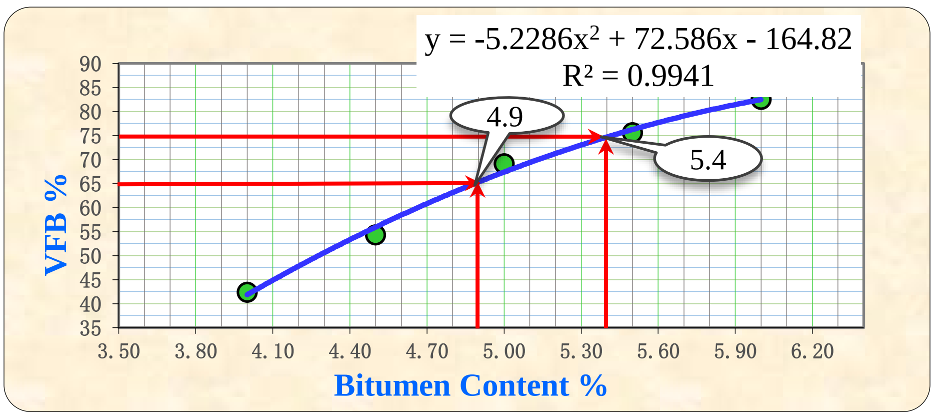
B) Marshal Stability vs Bitumen content at 6% CSD



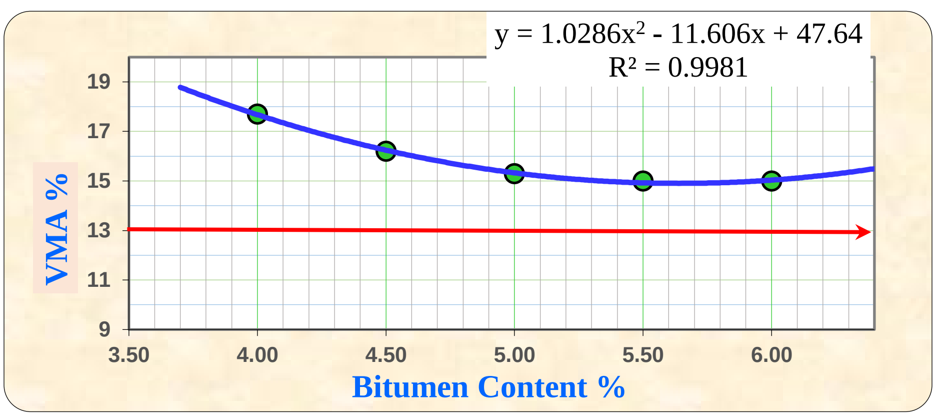
C) Air Voids vs Bitumen content at 6% CSD



D) Flow vs Bitumen content at 6% CSD



E) VFB vs Bitumen content at 6% CSD



F) VMA vs Bitumen content at 6% CSD

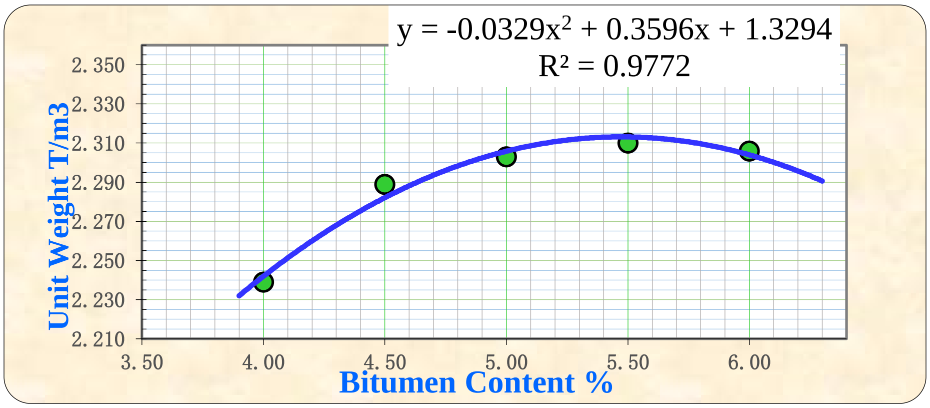
Figure 4.8: Marshall Properties of HMA design data with 6% filler gradation: A) Unit weight vs Bitumen content at 6% CSD, B) Marshal Stability vs Bitumen content at 6% CSD, C) Air Voids vs Bitumen content at 6% CSD, D) Flow vs Bitumen content at 6% CSD, E) VFB vs Bitumen content at 6% CSD and F) VMA vs Bitumen content at 6% CSD.

Based on the figures shown above, the relation between Marshall Property of mixture with 6% crushed stone dust and different bitumen content values are discussed below. When the bitumen content increases, the air void decreases in reverse the VFB and flow increases. Stability and unit weight increase with the increase of asphalt content up to maximum value and then decrease with the increase of asphalt content. Whereas, the percent of voids in the mineral aggregate (VMA) decrease to the minimum value then increases with higher bitumen content. The optimum bitumen content at 4% VIM is 5.3% by weight of the mix.

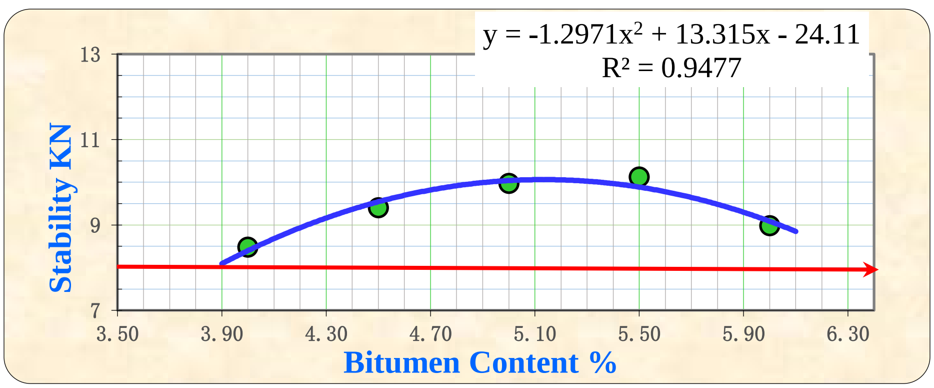
Table 4.9: Marshall Test result for Mixes with 7% CSD filler and different bitumen content

Specimen No	Bitumen Content (%)	Gsb	VA (%	VMA (%)	VFB (%)	Stability	Flow
1	4%	2.238	9.20	15.90	42.14	8.20	2.45
2		2.246	8.88	15.60	43.10	9.35	2.20
3		2.233	9.39	16.08	41.59	7.89	2.64
Average		2.239	9.16	15.86	42.27	8.48	2.43
1	4.50%	2.287	6.48	14.53	55.43	10.35	2.71
2		2.288	6.41	14.47	55.71	9.65	3.21
3		2.291	6.28	14.35	56.22	8.21	2.64
Average		2.289	6.39	14.45	55.79	9.40	2.85
1	5%	2.293	5.10	14.40	64.58	10.87	3.31
2		2.256	5.02	14.33	64.94	9.85	3.13
3		2.305	5.06	14.36	64.78	9.18	2.71
Average		2.285	5.06	14.36	64.77	9.97	3.05
1	5.50%	2.311	4.23	14.67	71.14	10.12	2.90
2		2.309	3.96	14.43	72.56	11.18	3.25
3		2.309	4.17	14.62	71.47	9.06	3.42
Average		2.310	4.12	14.57	71.72	10.12	3.19
1	6%	2.307	3.48	15.13	77.00	8.85	3.81
2		2.303	3.48	15.13	77.02	9.19	3.61
3		2.298	3.59	15.23	76.42	8.89	3.45
Average		2.302	3.52	15.16	76.81	8.98	3.62

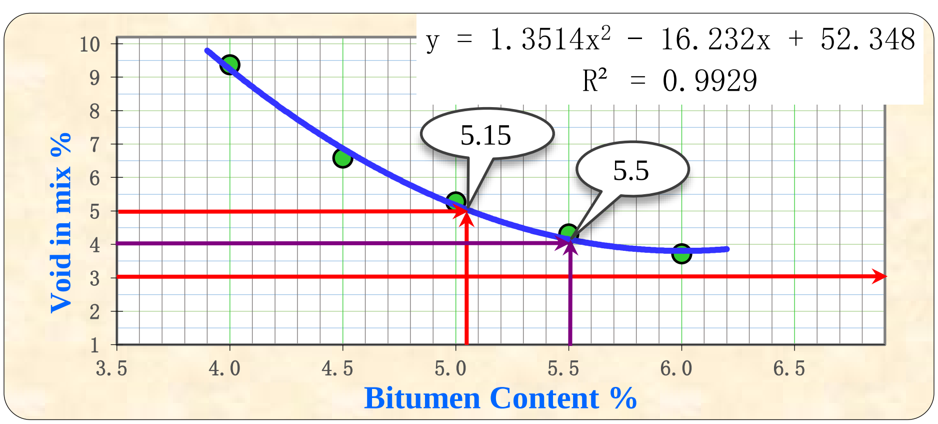
Table 4.9 illustrate marshal test result of a mix with 7% conventional filler (CSD) and the corresponding values of marshal properties such as stability, flow value, Air Void, Voids in mineral Aggregate, Voids filled with bitumen and unit weight at different bitumen content. In addition, Figure 4.9 shows the relationships between the different marshal properties with different bitumen content.



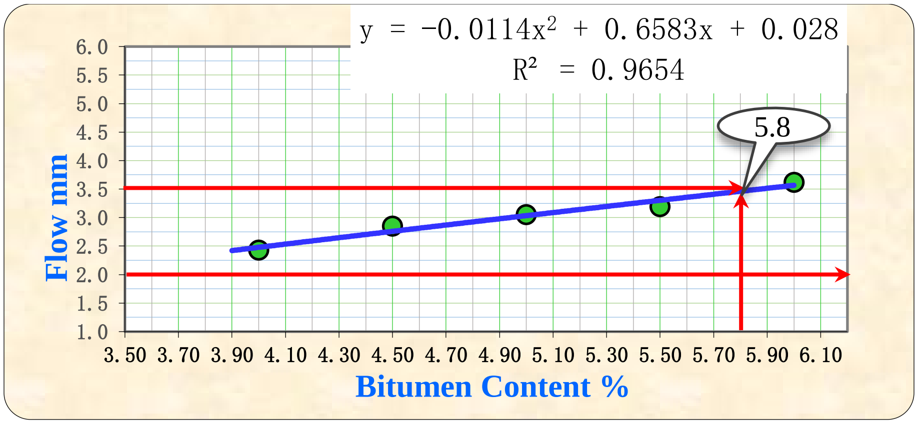
A) Unit weight vs Bitumen content at 7% CSD



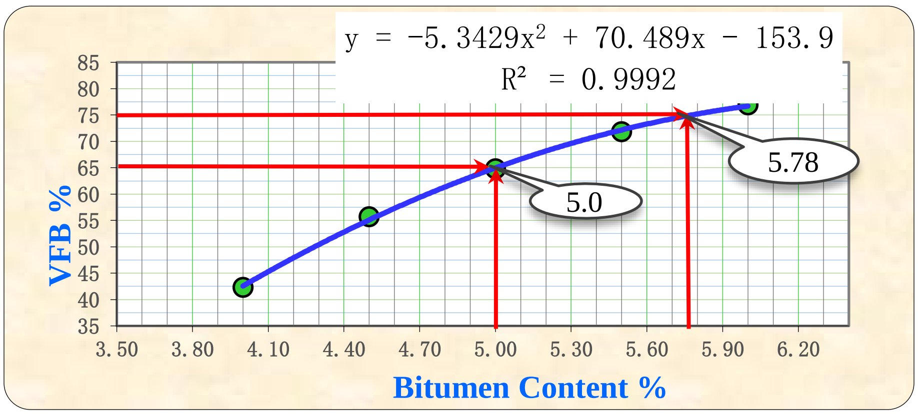
B) Marshal Stability vs Bitumen content at 6% CSD



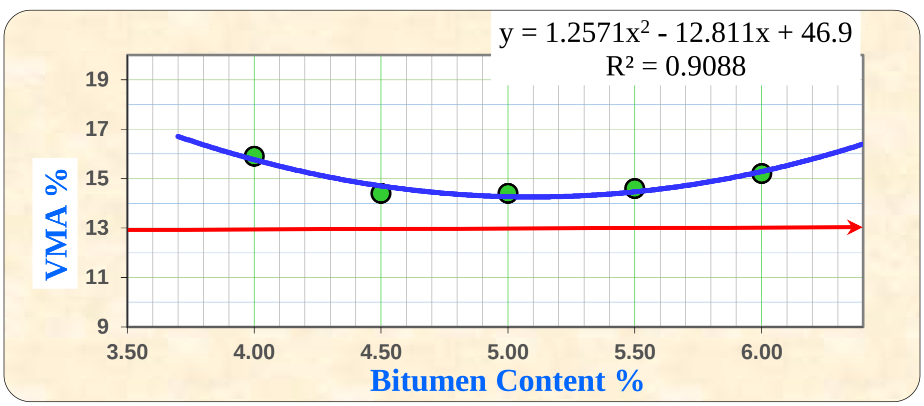
C) Air Voids vs Bitumen content at 7% CSD



D) Flow vs Bitumen content at 7% CSD



E) VFB vs Bitumen content at 7% CSD



F) VMA vs Bitumen content at 7% CSD

Figure 4.9: Marshall Properties of HMA design data with 7% filler gradation: A) Unit weight vs Bitumen content at 7% CSD, B) Marshal Stability vs Bitumen content at 7% CSD, C) Air Voids vs Bitumen content at 7% CSD, D) Flow vs Bitumen content at 7% CSD, E) VFB vs Bitumen content at 7% CSD and F) VMA vs Bitumen content at 7% CSD.

Based on the figures shown above, when the bitumen content increases, the air void decreases in reverse the VFB and flow increases. Stability and unit weight increase with the increase of asphalt content up to maximum value and then decrease with the increase of asphalt content. Whereas, the percent of voids in the mineral aggregate (VMA) decrease to the minimum value then increases with higher bitumen content. Based on asphalt institute method (MS-2), mix design method, the marshal properties must fall with in criteria to identify optimum binder content. The optimum bitumen content at 4% VIM is 5.3% by weight of the mix.

4.4 Determination of optimum bitumen content and design gradation

The air void, stability, flow and bulk density are factor for deciding the optimum binder content of the bituminous mixtures, but the stability, flow and bulk density are not suitability factor for deciding the optimum binder content of the hot mix asphalt mixtures as per ERA 2013 specification. Because this criteria increase the amount of binder and these conditions is uneconomical. The suggested air void as per ERA2013 flexible pavement design specification should be within the range of 3-5%. In general, the optimum binder content decided based on the volumetric properties and marshal properties as per ERA2013 flexible pavement design specification. The specification says at all properties must fulfill the criteria and air voids of 4% or near to obtain the optimum binder content from bitumen content versus all mix design parameters graph. The all three gradation passes the requirement needed by superpave gradation as per ERA specification.

Optimum bitumen contents for all proposed gradation with three varying filler proportions were determined as per recommended by MS-2 with reference to ERA specification procedure methods. As an initial starting point it is recommended that the bitumen content giving 4% air voids is chosen as the design bitumen content. All of the calculated and measured mix properties at this bitumen content are determined by interpolation from the graphs shown above. The individual properties are then compared to the mix design criteria as specified in MS-2. In this method, the values of corresponding BCs are determined by using the plotted graph of bitumen content versus mix design parameters to each properties. The corresponding values of Marshall Stability, flow, VMA, VFB, and VIM for each gradation with varied filler contents are determined and compared against local specification tabulated in table to check whether it meets the requirement. According to test results, optimum bitumen contents are obtained to be 5.1%, 5.3%, and 5.5% for BRZ5, BRZ6, and BRZ7 gradation, respectively. Furthermore, the summary of Marshall Properties of asphalt mixtures with respect to their OBC and three gradations are tabulated in the following figures and tables.

Table 4.10: Mix properties of 5% filler gradation at 4% Air Void.

Mix properties	Values extrapolated from graph at 4% air void
VMA (%)	14.0
VFB (%)	71.5
BSG (Mg/m^3)	2.32
Stability (KN)	11.2
Flow (mm)	3.0

Table 4.11: Percent bitumen range complying with MS-2 mix property criteria

Mix properties	MS-2 Critera	percent range of bitumen giving compliance
VIM	3% - 5%	4.76% - 5.75%
VFB (%)	65% - 73%	4.7% -5.25%
VMA	13% minimum	4% - 6%
Stability (KN)	8KN minimum	4% - 6%
Flow (mm)	2 -3.5 mm	4% - 5.41%

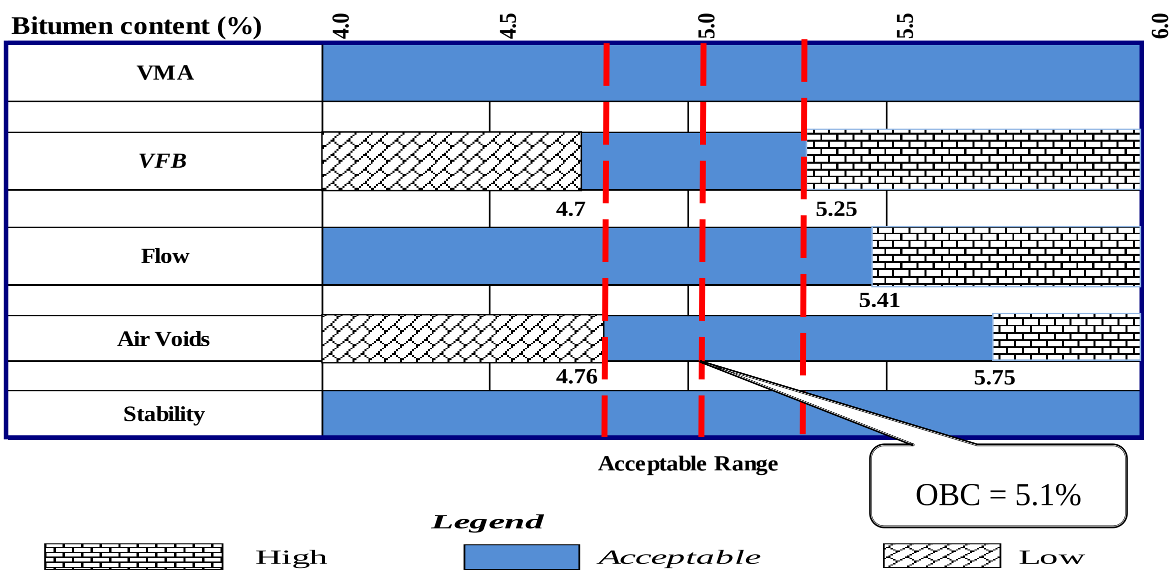


Figure 4.10: Acceptable bitumen range complying with design criteria

Based on the above figures, all mix properties of 5% filler have compliance with asphalt institute method (MS-2) mix design criteria. Also all mix properties are within the range at 4% air voids. Therefore there is no adjustment needed for design bitumen content at 4% air voids. Finally the design optimum content is 5.1% by the weight of the mix.

Table 4.12: Mix properties of 6% filler gradation at 4% Air Void.

Mix properties	Values extrapolated from graph 4% air void
VMA (%)	14.8
VFB (%)	72
BSG (Mg/m^3)	2.31
Stability (KN)	10.5
Flow (mm)	3.4

Table 4.13: Percent bitumen range complying with MS-2 mix property criteria

Mix properties	MS-2 Critera	percent range of bitumen giving compliance
VIM	3% - 5%	5% - 5.75%
VFB (%)	65% - 73%	4.9% -5.4%
VMA	13% minimum	4% - 6%
Stability (KN)	8KN minimum	4% - 6%
Flow (mm)	2 -3.5 mm	4% - 5.62%

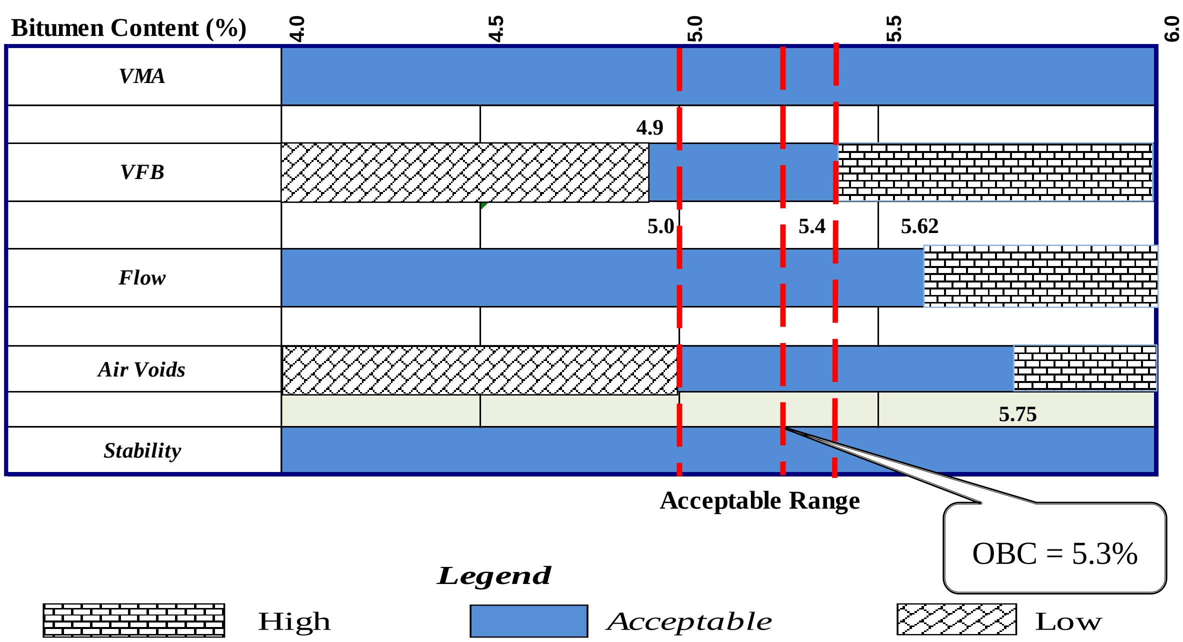


Figure 4.11: Acceptable bitumen range complying with design criteria

Based on the above figures, all mix properties of 6% filler have compliance with asphalt institute method (MS-2) mix design criteria. Also all mix properties are within the range at 4% air voids. Therefore there is adjustment needed for design bitumen content at 4% air voids. Finally the design optimum content is 5.3% by the weight of the mix.

Table 4.14: Mix properties of 7% filler gradation at 4% Air Void.

Mix properties	Values extrapolated from graph at 4% air void
VMA (%)	14.5
VFB (%)	72.5
BSG (Mg/m^3)	2.31
Stability (KN)	9.85
Flow (mm)	3.25

Table 4.15: Percent bitumen range complying with MS-2 mix property criteria

Mix properties	MS-2 Critera	percent range of bitumen giving compliance
VIM	3% - 5%	5.15% - 6%
VFB (%)	65% - 73%	5% -5.78%
VMA	13% minimum	4% - 6%
Stability (KN)	8KN minimum	4% - 6%
Flow (mm)	2 -3.5 mm	4% - 5.8%

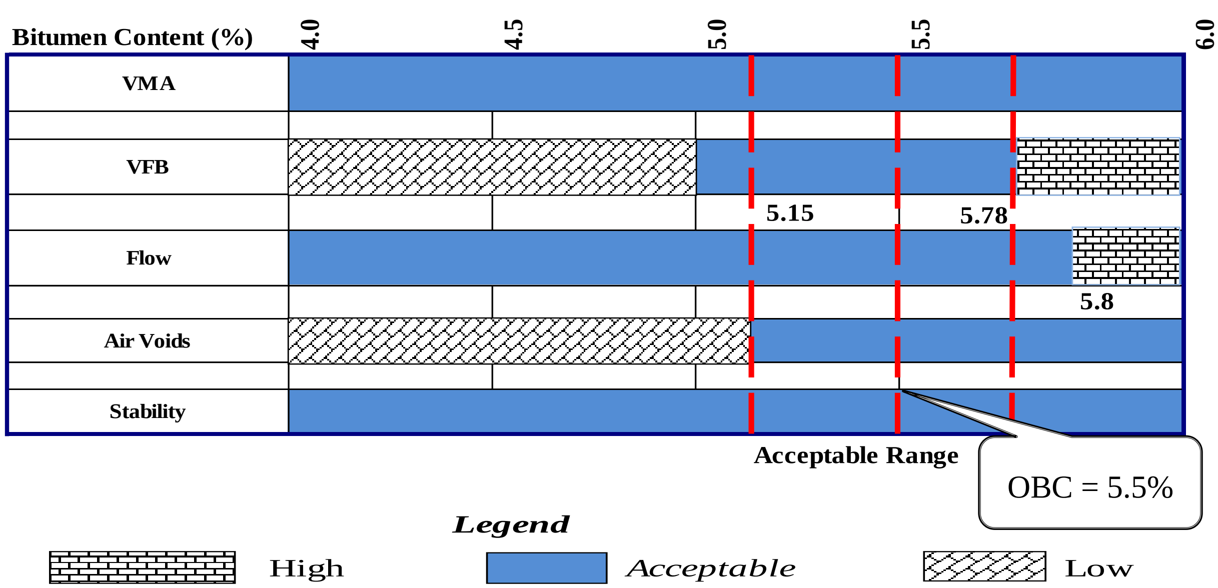


Figure 4.12: Acceptable bitumen range complying with design criteria

Based on the above figures, all mix properties of 7% filler have compliance with asphalt institute method (MS-2) mix design criteria. Also all mix properties are within the range at 4% air voids. Therefore there is no adjustment needed for design bitumen content at 4% air voids. Finally the design optimum content 7% filler is 5.4% by the weight of the mix.

By comparing all the mix properties of mixtures, it was found that gradation with 5% crushed stone dust filler specimen provided better performance than all other mixtures. Thus, for this study, the mixture with gradation of 5% filler is selected as design aggregate gradation with 5% optimum filler content according to mix properties of mix design. Hence the replacement of Belessa kaolin filler material for further study, the selected gradation corresponding to 5% optimum filer content and its OBC 5.1% remain unchanged and kept constant. The following table shows the summary of different superpave aggregate gradation mix properties.

Table 4.16: Summary of Marshal Test results for different percentage of CSD filler at 4% VIM

Mix properties	Percent of CSD filler content			Specifications	
	5%	6%	7%	ERA	Asphalt Inst.
OBC (%)	5.1	5.3	5.5	4 - 10	4 - 10
VFB (%)	71.5	72	72.5	65 - 75	65 - 75
VMA (%)	14	14.8	14.5	Min. 13	Min. 13
Stability (KN)	11.2	10.5	9.85	Min. 8	Min. 7
Flow (mm)	3.0	3.40	3.25	2 -3.5	2 -3.5
BSG (Mg/m^3)	2.32	2.31	2.31	-	-
VIM (%)	4	4	4	3 - 5	3 - 5

From the above table we conclude that, at 5% filler the Stability is greater than both 6% and 7% filler. Also the flow in 5% filler is found almost at halfway of the specification. This enables gradation with 5% is favorable than the other gradation.

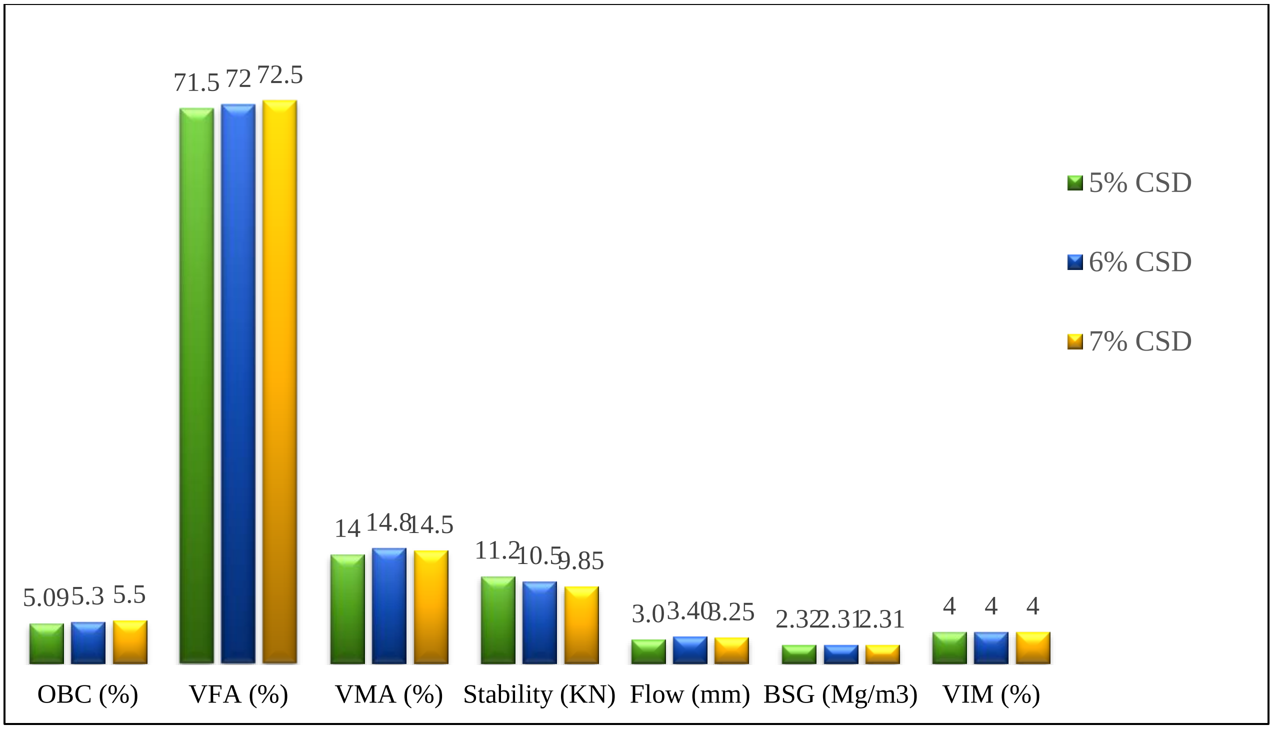


Figure 4.13: Summary of Marshal Test results for different percentage of CSD filler at 4% VIM

4.5 Effect of partial replacement of Belessa kaolin on HMA

The effect of the Belessa kaolin on the HMA mix is evaluated by using the Marshall mix design and performance measuring parameters. Depending on the selected optimum bitumen content, and design gradation with 5% optimum filler content, stone dust filler was partially replaced by Belessa kaolin filler with five different proportion at replacement rate of (10%, 20%, 30%, 40%, 50%) by the mass of total conventional filler content. The replacement rate is selected based on non-probable data analysis, different literature and material abundancy. Three samples were fabricated for each filler proportion, and the average values of bulk specific gravity of mix, Marshall stability, flow, air void, void in mineral aggregate, void filled with asphalt, moisture susceptibility and rutting depth were determined and compared with control mix as well as with specification. The mix with 0 % of Belessa Kaolin was used as a control mixture to evaluate the effect of Belessa kaolin in a mixture.

Table 4.17: Marshall Test result for Mixes with Belessa kaolin filler at OBC of 5% CSD filler

Specimen No	Belessa Kaolin (%)	Gsb	VA (%	VMA (%)	VFB (%)	Stability	Flow
1	0%	2.315	4.28	14.08	69.59	12.32	3.12
2		2.323	3.98	13.80	71.20	10.21	2.77
3		2.321	4.04	13.86	70.86	10.45	3.22
Average		2.320	4.10	13.91	70.54	10.99	3.04
1	10.00%	2.316	4.27	14.51	70.60	11.05	2.95
2		2.320	4.08	14.34	71.58	11.24	3.34
3		2.310	4.52	14.74	69.33	9.78	3.16
Average		2.315	4.29	14.53	70.49	10.69	3.15
1	20%	2.317	4.24	14.90	71.53	9.84	3.42
2		2.320	4.14	14.81	72.06	13.21	2.67
3		2.315	4.33	14.98	71.08	10.00	3.21
Average		2.317	4.24	14.90	71.56	11.02	3.10
1	30.00%	2.319	4.16	15.27	72.79	12.07	2.91
2		2.319	4.17	15.28	72.73	11.92	3.32
3		2.319	4.17	15.29	72.73	10.87	3.01
Average		2.319	4.16	15.28	73.75	11.62	3.08
1	40%	2.309	4.52	16.11	71.94	9.72	3.21
2		2.320	4.06	15.71	74.14	10.15	3.52
3		2.310	4.48	16.08	72.13	11.09	3.70
Average		2.313	4.35	15.97	72.73	10.32	3.48
1	50%	2.310	4.57	16.06	71.51	10.59	3.82
2		2.313	4.45	15.94	72.10	8.45	3.35
3		2.310	4.60	16.08	71.40	9.87	4.02
Average		2.311	4.54	16.03	71.67	9.64	3.73

Tables 4.17 shows the test result of HMA mixture with different proportions of CSD and Belessa kaolin filler and the corresponding values of mix properties at a design bitumen of 5.1%. The relationship and effects of varying amounts of kaolin on asphalt mixture performance were discussed in the following section.

Table 4.18: Summary of Marshal Properties at the different proportion of Belessa kaolin and CSD

Percentage of Belessa kaolin replacement (%)	GSB (Mg/m^3)	VIM (%)	VMA (%)	VFB (%)	Stability (KN)	Flow (mm)
0	2.320	4.10	13.91	70.54	10.99	3.04
10	2.315	4.29	14.53	70.49	10.69	3.15
20	2.317	4.24	14.90	71.56	11.02	3.10
30	2.319	4.16	15.28	72.73	11.62	3.08
40	2.313	4.35	15.97	72.73	10.32	3.48
50	2.311	4.54	16.03	71.67	9.64	3.73

4.5.1 Effect of partial replacement of Belessa kaolin on Marshal Stability

The stability of the mix is the maximum load required to produce failure. The effect of Belessa kaolin on the stability is shown in Figure 4.14 below. The figure illustrate that all test results of stability with different proportion of both conventional and non-conventional filler content has satisfied the specification requirement. Marshal Stability decreases at 10% of replacement and starts increasing at 20% and 30% of Belessa kaolin replacement. At 40% and 50% it starts decreasing. Based on the result replacement of CSD by Belessa kaolin has positive impact at 20% and 30%. Although, other percentage of replacement are less than the control mix, all meet the requirement as per ERA specifications. Generally the replacement of Belessa kaolin at 30% has significant effect on mixture.

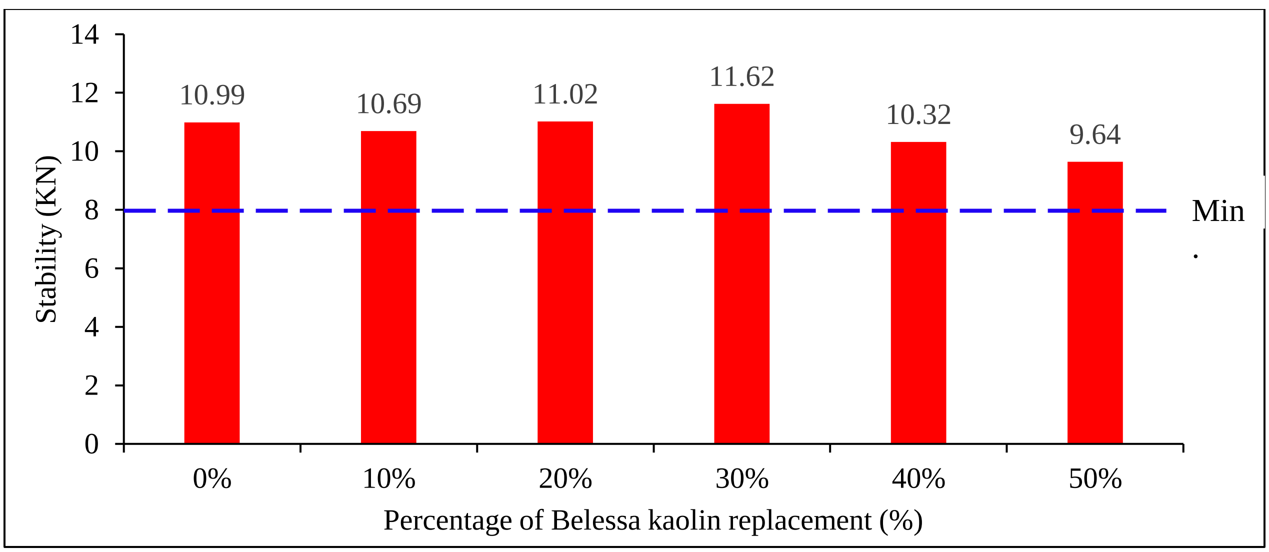


Figure 4.14: Relationship between stability and replacement rate of Belessa kaolin at OBC.

4.5.2 Effect of partial replacement of Belessa kaolin on Flow

The Marshall flow is the vertical deformation of the specimen at the failure point. As it is clearly shown in Figure 4.15 below, the Marshal Flow values obtained from the laboratory prepared mixes using all of Belessa kaolin percentage, meet the Marshal criteria (2.0mm – 3.5mm) except for 50% replacement. For mixes prepared using 0%, 10%, 20% and 30% of Belessa kaolin replacement rate, the flow values obtained are relatively the same. Higher values of flow were also obtained for mixtures prepared using 40% Belessa kaolin replacement rate. At 50% replacement rate the flow doesn't meet the requirement as per as ERA specifications.

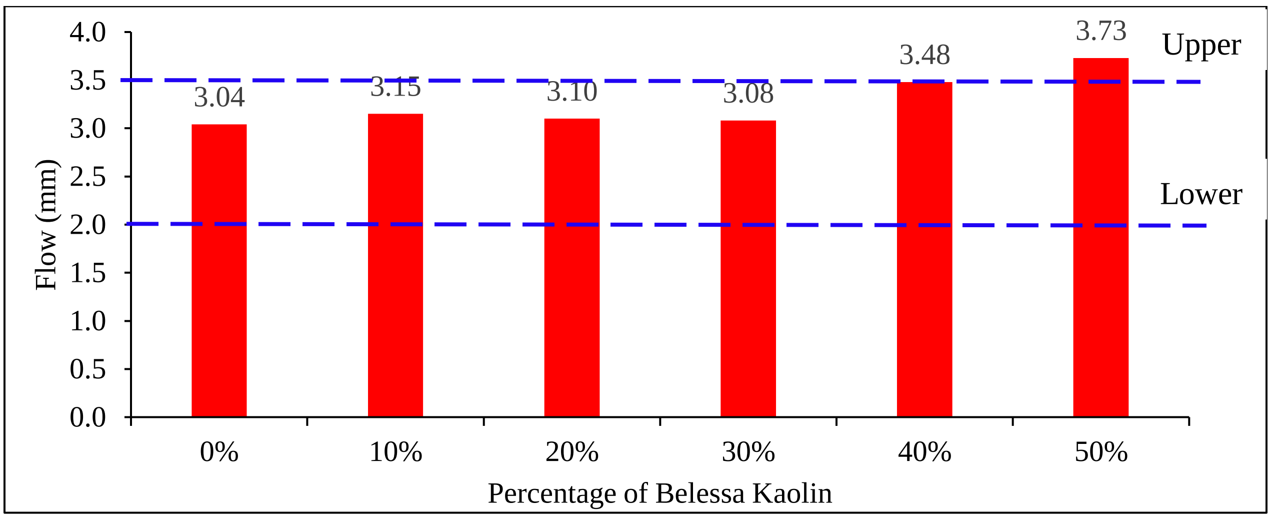


Figure 4.15: Relationship between Flow and replacement proportion of Belessa kaolin at OBC.

4.5.3 Effect of partial replacement of Belessa kaolin on Air Void of the mix

The voids in total mix refer to the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture. Based on the figures below each mixes don't follow a general pattern. According to the test results, all HMA mixtures prepared with partially replacement by Belessa kaolin filler provided the air void content within the range of 3% - 5% specified by ERA, pavement design manual, as well as Asphalt institute specification. Figure 4.16 shows that at 30% Belessa kaolin filler content, the air void percentage was 4.16%, which is the least air void and nearest to the air void value 4.10% of the control mix. Therefore the replacement at 30% provides better result when compared with the other mix percentages.

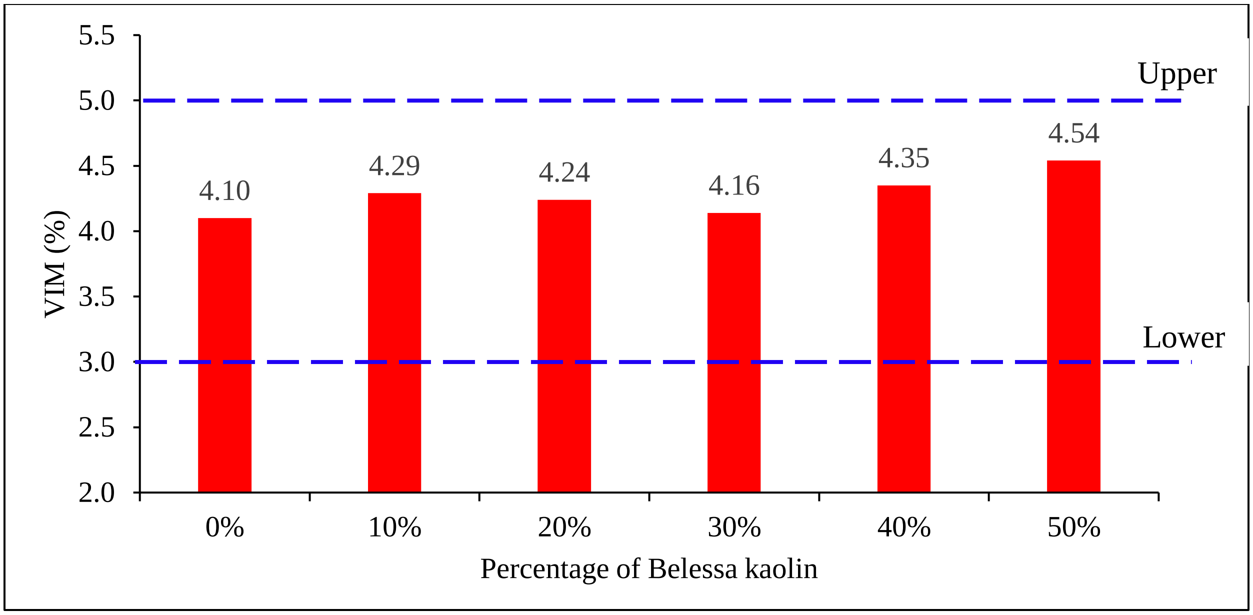


Figure 4.16: Relationship between VIM and replacement proportion of Belessa kaolin at OBC

4.5.4 Effect of partial replacement of Belessa kaolin on Void filled with Asphalt

A void filled with asphalt is measured as the proportion of VMAs that are occupied with asphalt binder. Effect of different replacement percentage of Belessa Kaolin on the voids filled with bitumen property of the mixture is indicated on Figure 4.17. All the mixes except 50% replacement, follow a general trend that with an increasing replacement rate of Belessa kaolin the VFB in the total mix increases. According to the experimental results, VFB values increase with an increase replacement rate of Belessa kaolin filler until it reaches 40% replacement rate. Then starts decreasing when it reaches 50% replacement rate. According to ERA pavement design, manual VFB values in hot mix asphalt mixtures are within a range of 65% - 75%. Thus, as illustrated on figure 4.17, all mixture with Belessa kaolin combined with Superpave gradation are satisfied the requirement.

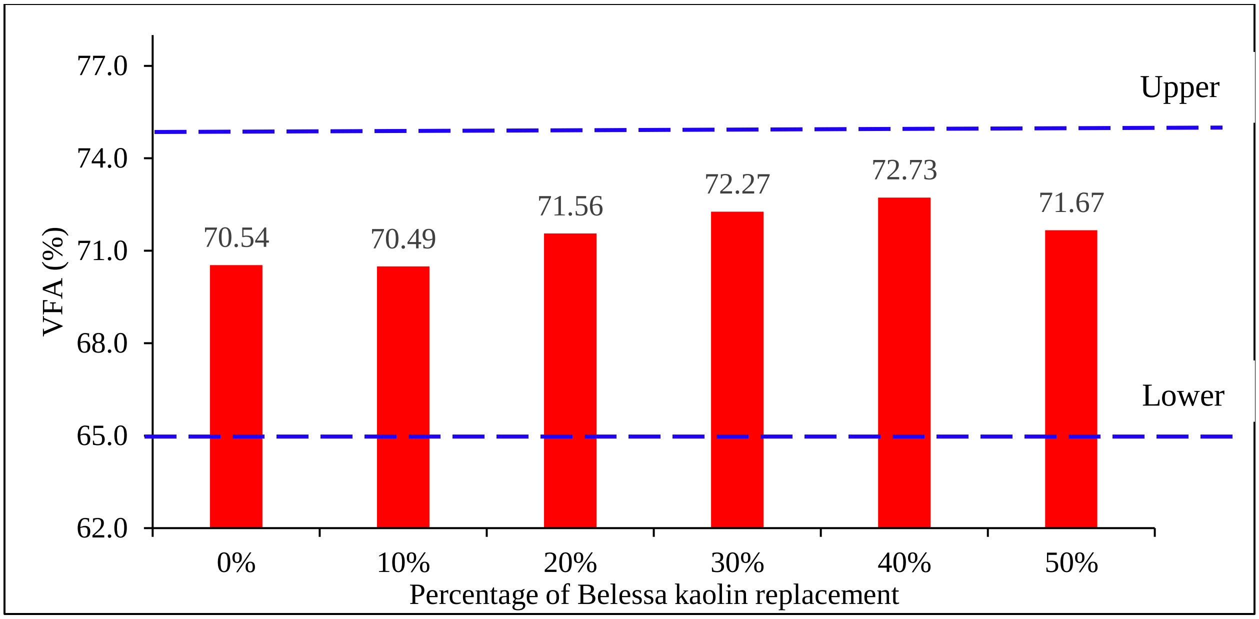


Figure 4.17: Relationship between VFB and replacement proportion of Belessa kaolin at OBC

4.5.5 Effect of partial replacement of Belessa kaolin on Void in Mineral Aggregate

The Void in mineral aggregate is the volume of inter granular void space between the aggregate particles of a compacted paving mixture. The effects of different percentage of Belessa kaolin filler on the VMA of the bituminous paving mixture is demonstrated in figure 4.18. The general pattern of the figure is as replacement rate of Belessa kaolin increases the VMA of the paving mixture also increases. Based on the laboratory results, VMA values increase with an increase replacement rate of Belessa kaolin filler. Though it is indicated that the VMA of all hot mix asphalt mixtures is within the allowable limits specified in the ERA pavement design manual. According to ERA pavement design, manual VMA values in hot mix asphalt mixtures has to be greater than 13%. Thus, as illustrated on figure 4.18, all mixture with Belessa kaolin combined with Superpave gradation are satisfied the requirement.

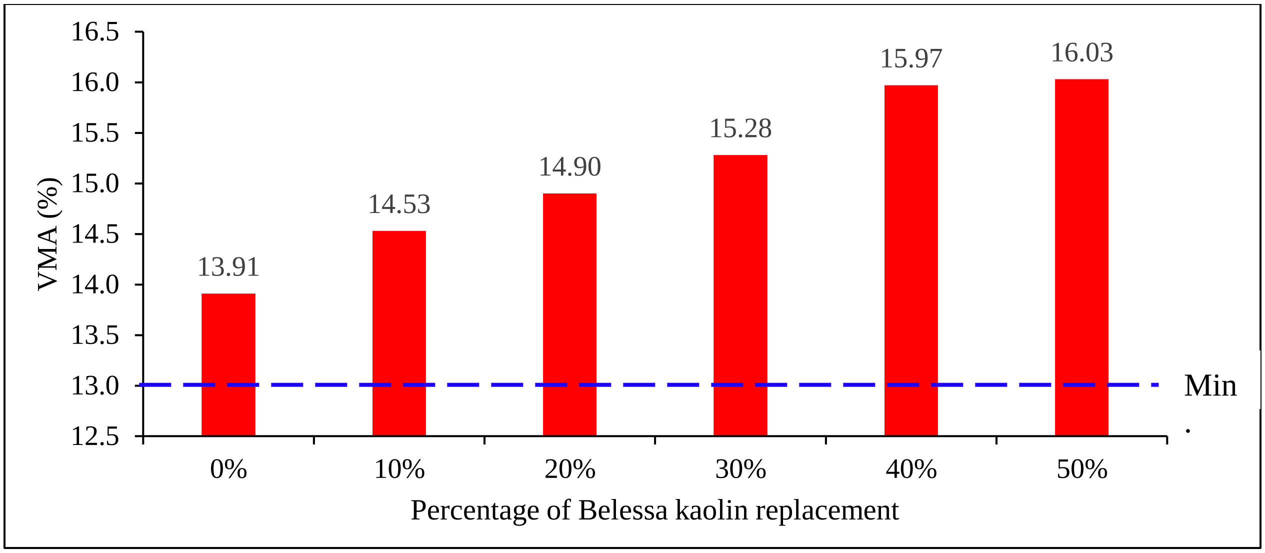


Figure 4.18: Relationship between VMA and replacement proportion of Belessa kaolin at OBC

4.5.6 Effect of partial replacement of Belessa kaolin on Bulk Density

The unit weight of the mix is not affected by the amount of Belessa kaolin significantly. The unit weight of each mixes with different replacement rate of Belessa kaolin is within the range of requirement. Figure 4.19 shows the bulk density increase with an increase of Belessa kaolin until it reaches 30% of Belessa kaolin filler content. Then, the bulk density starts decreasing as the replacement rate increases. Based on the investigation results the replacement rate of 30% of Belessa kaolin provide greater bulk density when compared with other replacement rate.

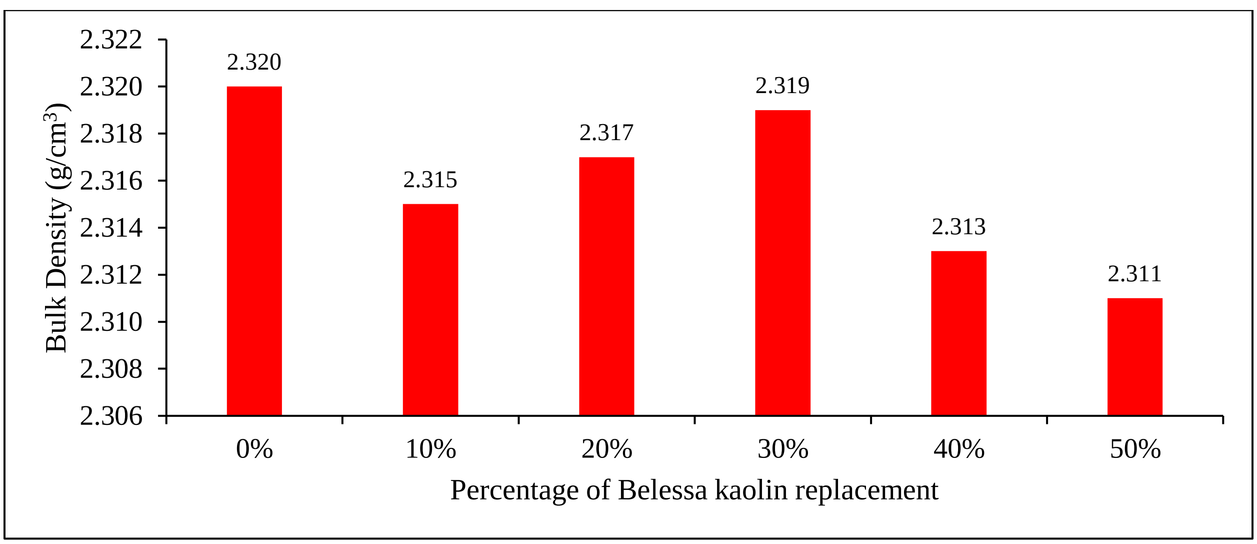


Figure 4.19: Relationship between Bulk Density and replacement rate of Belessa kaolin at OBC

4.6 Effect of partial replacement of Belessa kaolin Moisture Susceptibility

4.6.1 Tensile Strength Ratio (TSR) Test Results

The moisture susceptibility of the mix was conducted using tensile strength ratio test method. The test was conducted by preparing six Marshall specimen for each different replacement rate mix at optimum asphalt content. The six samples are then divided into two groups of three specimen each as control and test. The control group was stored at room temperature for 24 hours before the compressive strength was undertaken. The test group were immersed in water at 60℃ for twenty four hours and then moved to a water bath at 25℃ for two hours before the tensile strength test was performed.

The indirect tensile strength (ITS) of unconditioned and conditioned samples were determined for this study. The TSR value expressed as the percentage of ratio of these two values. The effects of different percentage of Belessa kaolin filler on the moisture susceptibility of the bituminous paving mixture is demonstrated in figure 4.20. Based on the laboratory results the tensile strength ratio increase with an increase of Belessa kaolin until it reaches 30% of Belessa kaolin filler content. Then, the TSR starts decreasing as the replacement rate increases. According to AASHTO pavement design, manual TSR values in hot mix asphalt mixtures are minimum of 80%. Thus, as illustrated on figure below, all mixture with Belessa kaolin combined with Superpave gradation are satisfied the requirement except for 50% replacement rate. Based on the investigation results the replacement rate of 30% of Belessa kaolin provide greater moisture susceptibility when compared with other replacement rate.

Table 4.19: Summary of TSR results at the different proportion of Belessa kaolin and CSD

Percentage of Belessa Kaolin Replacement (%)	Tensile strength of Conditioned (Kpa)	Tensile strength of Unconditioned (Kpa)	Tensile Strength Ratio (%)
0	717.19	877.34	81.75
10	697.43	857.55	81.33
20	717.83	880.49	81.53
30	727.13	882.77	82.37
40	705.3	877.5	80.38
50	657.05	894.61	73.45

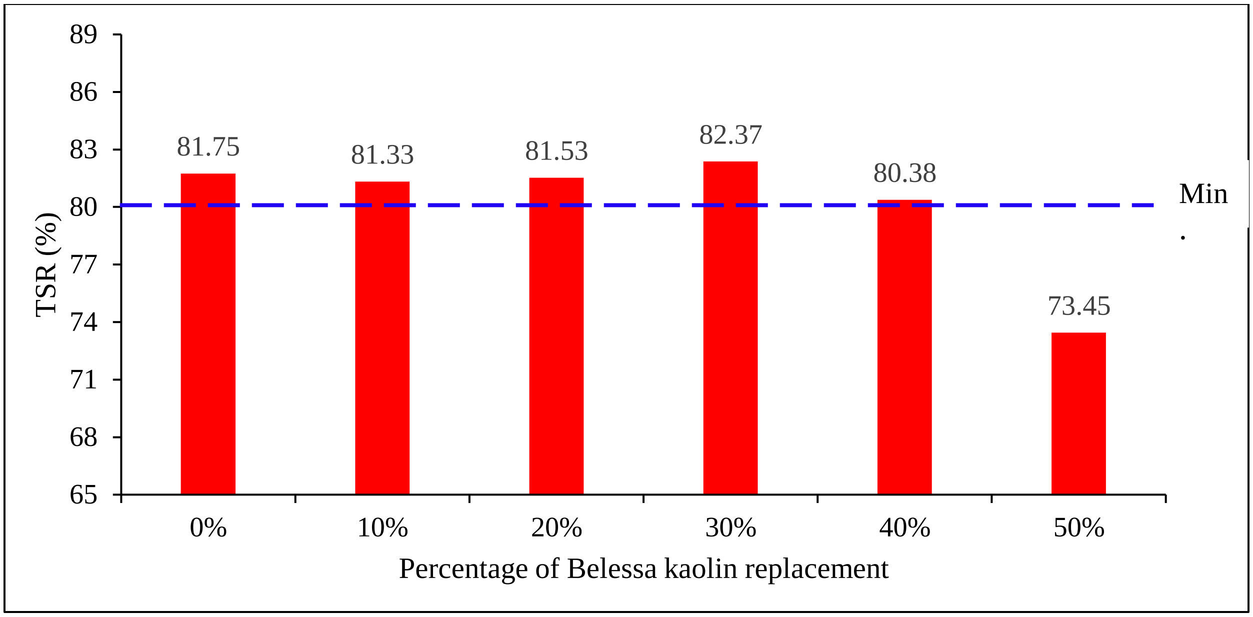


Figure 4.20: Relationship between TSR and replacement proportion of Belessa kaolin at OBC

4.7 Selection of Optimum Belessa kaolin filler content

The control mix with 0% of Belessa kaolin was reference as the control for the determination of optimum filler proportion. Marshal properties and moisture susceptibility are used to find the optimum filler content that produces an HMA mixture with the best performance. Asphalt mixture with an optimum filler content satisfies the following conditions: Maximum stability, Maximum bulk density, air void and tensile strength ratio are within the allowed range of specifications.

Table 4.20 shows stability values of all HMA mixture for different percentage of Belessa kaolin filler content met both local and international specifications. However, the maximum stability value was found from the mixture corresponding to 30% of Belessa kaolin filler relative to other proportions. Also the corresponding result of the air void, and bulk density values are 4.16% and 2.319 gm/cm3, respectively, which are almost the same with the control mix. The moisture susceptibility of 30% Belessa kaolin which is 82.38%, is the largest result obtained from each mix. This shows Belessa kaolin with this percentage improve the moisture susceptibility of the mix with 100% CSD. Therefore the replacement of crushed stone dust at the rate of 30% of Belessa kaolin provides better result than the other mix rate.

Table 4.20: Comparison of optimum replacement proportion of Belessa kaolin with specifications

HMA parameters	Control Mix (0% Belessa kaolin)	Belessa kaolin at 30% replacement	ERA pavement design manual, 2013		International Specification (Asphalt		Remarks
			Min.	Max.	Min.	Max.	
Stability (KN)	10.99	11.62	8	-	8	-	pass
Bulk density (g/cm^3)	2.32	2.319	-	-	-	-	pass
VIM (%)	4.1	4.16	3	5	3	5	pass
VFB (%)	70.54	72.73	65	75	65	75	pass
VMA (%)	13.91	15.28	13		13		pass
Flow (mm)	3.04	3.08	2	3.5	2	3.5	pass
TSR (%)	81.75	82.37	80	-	80	-	pass

Table 4.20 shows that, the HMA mixture prepared with partial replacement of Belessa kaolin filler at 30% replacement rate blended with below restricted zone of Superpave gradation satisfies the requirement of both local and international specification limits for all tested hot mix asphalt parameters. Stability and moisture susceptibility of the control mix is improved at 30% Belessa kaolin replacement by the weight of crushed stone dust. However the other replacement rate satisfied the specification, 30% of Belessa kaolin content is selected to be best filler replacement proportion based on the study results.

4.8 Effect of optimum Belessa kaolin on permanent deformation (rutting)

Rutting resistance is one of the most important property of well-designed asphalt mixture. In this study rutting resistance is measured by wheel tracking apparatus, which consists of a loaded wheel, which bears on a sample held on a moving table.

Procedure B is used to determine the rut depth of the HMA specimen. This method is applicable when the test is executed on the air. In this study the rutting resistance of control mix (0% Belessa kaolin) and mix with optimum Belessa kaolin (30% Belessa kaolin) is compared. All of the results obtained in wheel-tracking test meet the limit value in UNE-EN requirements for this test. Figures 4.21 and 4.22 shows the specimen after testing with the rut depth and graph of the rut depth versus the load cycles for both mixture types. Based on the figures below, sample with 100% crushed stone dust has 3.17mm mean rut depth. Whereas sample with 30% of Belessa kaolin filler reached 3.09mm mean rut depth. The rut depth of optimum Belessa kaolin is less than that of 100% CSD. Also the wheel tracking slope for each test specimen per 1000 cycles are investigated. The WTS of the control mix and 30% Belessa kaolin is 0.112 and 0.11 respectively. The proportional rut depth for each specimen under test at different cycles in % also examined. The mean proportional rut depth of control mix and 30% Belessa kaolin is 5.89 and 5.86 respectively.

Table 4.21: Summary of Wheel Truck Test result at optimum Belessa kaolin and control mix

Specimen Type	Mean Rut Depth (mm)	Mean WTS (μmm/cycles)	Mean PDR (%)	Specification as per EN 13108		
				Rate (μmm/cycle)	PRD (%)	RD(mm)
Control Mix (0% Belessa kaolin)	3.17	0.112	5.89	<0.15	<8	<6
30% Belessa kaolin	3.09	0.11	5.86	<0.15	<8	<6

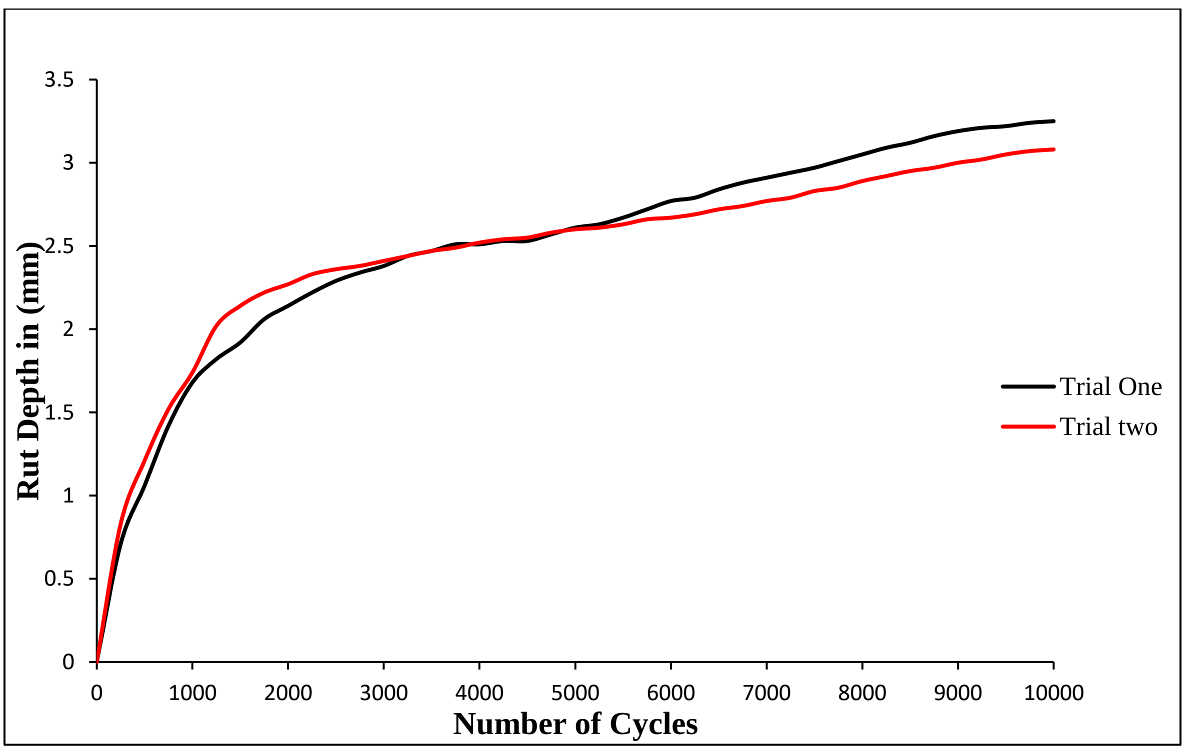


Figure 4.21: Rutting test result of Control mix (0% Belessa Kaolin)

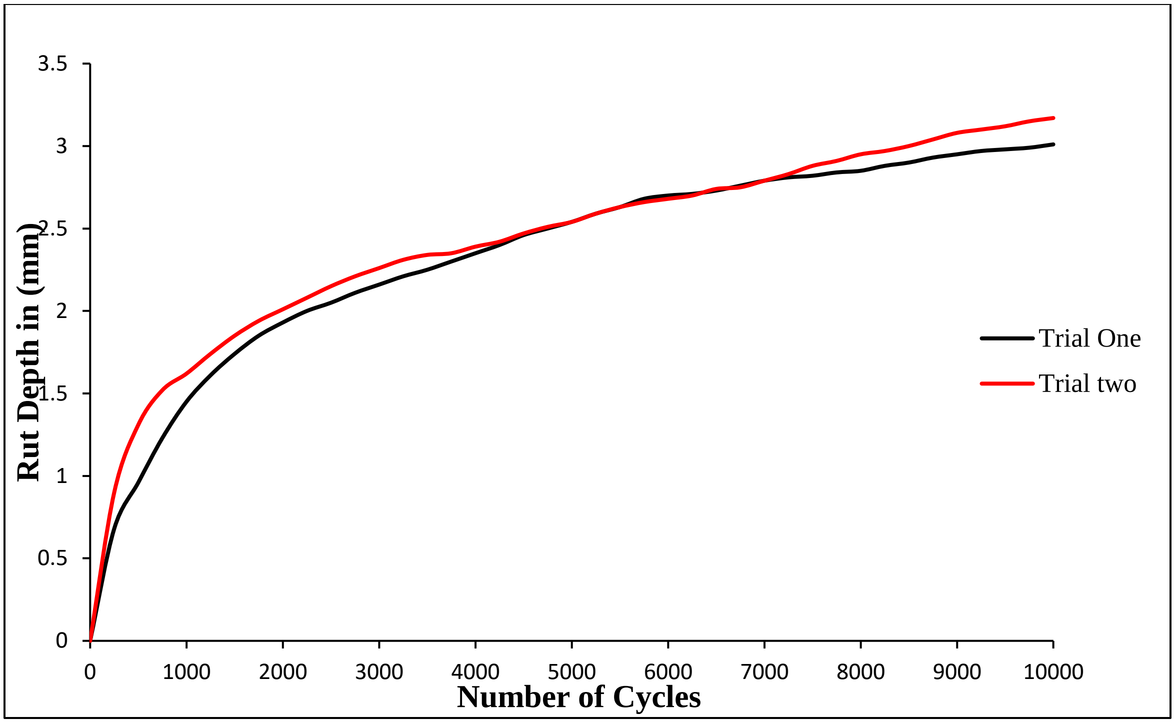


Figure 4.22: Rutting test result of Optimum Belessa kaolin (30% Belessa Kaolin)

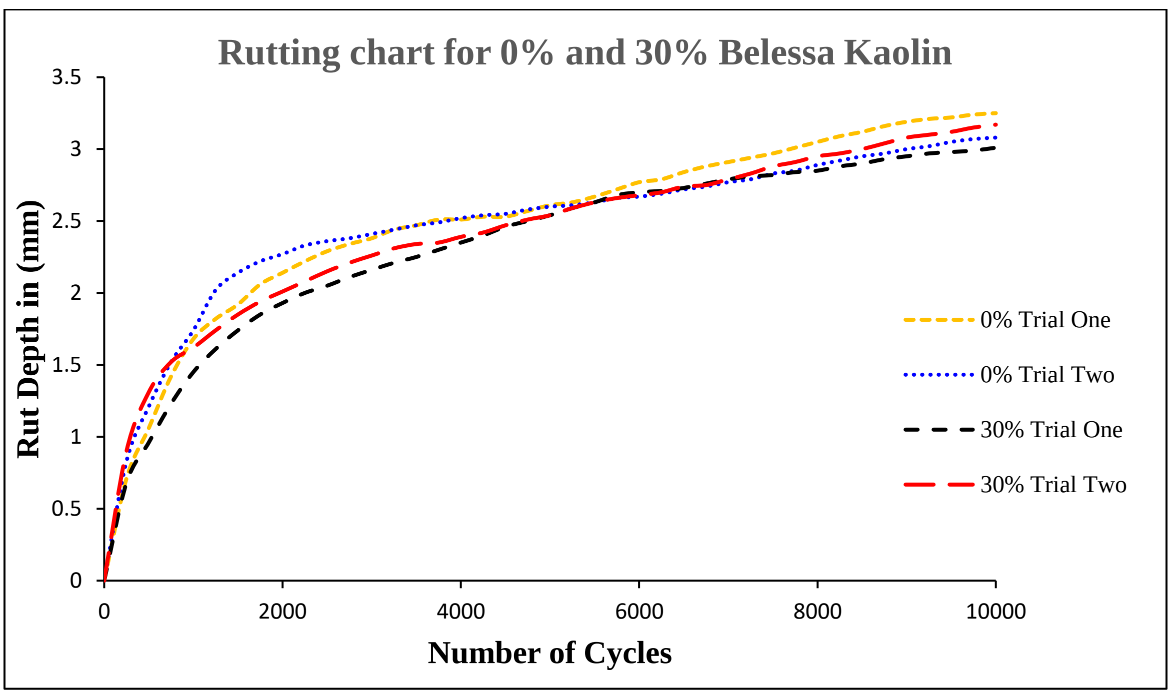


Figure 4.23: Rutting test result of Control mix and 30% Belessa kaolin

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main objective of the study is to investigate the performance of Belessa Kaolin as a filler with superpave aggregate gradation during a hot mix asphalt production. In this study, the conventional crushed stone dust filler had been replaced with different proportions of non-conventional filler (Belessa kaolin), the optimum replacement proportion, and some engineering properties of materials have been examined as stated in the objectives of the research. The experimental works are done to evaluate the properties of HMA performance using the Marshall Design method. Based on the experiment results of the study, the following conclusions are drawn.

- ❖ The physical and chemical properties of Belessa kaolin were investigated and were found suitable for replacement. The specific gravity, Plastic Index and the particle size distribution of Belessa kaolin met the requirement specified on specification. Moreover, Belessa Kaolin satisfies the minimum requirement of Natural Pozzolan materials for use as a Mineral Admixture specified by ASTM having the combined percentage chemical composition of main oxides (SiO_2 + Al_2O_3 + Fe_2O_3) of 89.64% which is satisfactory to encounter as filler material in hot mix asphalt.
- ❖ All the Marshal mix properties namely stability, flow values, and all volumetric properties for all mixtures from varying filler proportion at 5%, 6% and 7% with three different below restricted zone of Superpave aggregate gradation satisfy both local and international specification. The design aggregate gradation was determined according to maximum Marshall stability. Gradation with 5% crushed stone dust filler content is selected as design gradation with an optimum bitumen content of 5.1%. Based on this study the design bitumen contents of each gradation was 5.1%, 5.3%, and 5.5% for gradation 5%, 6% and 7% filler proportion respectively.
- ❖ Hence, below-restricted zone Superpave aggregate gradation can be used in Marshall mix design under local specification.
- ❖ Partial replacement of crushed stone dust by Belessa kaolin filler with different proportion satisfied the requirement for hot mix asphalt mixture as per ERA specification.

- ❖ Partially replaced Belessa kaolin mix fulfill the requirements for moisture sensitivity, however at replacement rate of 50% Belessa kaolin mix have a lower moisture resistance compared to the specification.
- ❖ The TSR value of control mix (0% Belessa kaolin) and 30% of Belessa kaolin is 81.75 and 82.35 respectively. Thus at 30% of replacement the non-conventional material improves the moisture susceptibility of the HMA.
- ❖ Based on marshal parameters and moisture susceptibility results the optimum replacement proportion was at 30% of Belessa kaolin and 70 % of CSD of filler content, which is satisfying the control specification having Maximum bulk density, Maximum stability and VIM within the allowed range of specification.
- ❖ Therefore, for this study, a 30% of Belessa kaolin with below restricted zone of Superpave gradation is selected as the best replacement proportion of non-conventional filler.
- ❖ The overall rutting behavior of the mix prepared with 30% of Belessa kaolin was almost similar with the mix prepared with control mix. Both mixtures fulfills the requirement as per specifications. This proves that the use of Belessa kaolin as replacement filler at optimum content in asphalt mixture provides better performance as mixture with 100% CSD filler.
- ❖ From this study, the test results obtained from mixes with Belessa kaolin have relatively similar trend with that of using crushed stone fillers. Better performance was obtained from mixes using Belessa kaolin when compared to crushed stone fillers. As a result, this shows us that Belessa kaolin fillers can be used as alternative filler type in bituminous mixtures to the widely used crushed stone.

5.2 Recommendation

The test results obtained during this study revealed that the Marshal properties, moisture susceptibility and permanent deformation of mixes vary considerably due to variation of filler type and content in the mixes. Depending on this study results and on standard engineering considerations, the following special provisions have developed.

- The partial replacement of Belessa kaolin at 30% with below restricted zone superpave aggregate gradation can be utilized to obtain better HMA performance.
- The local agencies are advised to use Belessa kaolin as partial replacement of conventional filler (CSD) in hot mix asphalt with a maximum percentage of 30 % by weight of optimum CSD filler. Which enables to reduces the consumption of conventional filler (CSD).
- Superpave aggregate gradation with below restricted zone which is comparable with local gradation specification, can be used in marshal mix design with ERA specifications.
- Further studies are needed using through restricted zone and above restricted zone superpave aggregate at various percentages of Belessa kaolin filler.
- The performance analysis of the Belessa kaolin filler is limited on moisture susceptibility and rutting for this study. In order to strengthen this research the performance of the mix has to be evaluated using additional performance parameters such as fatigue resistance and resilient modulus test.
- Further studies studies are needed on Belessa kaolin at different percentage rather than percentage proportion used in this research paper.
- This studies focuses only on the comparision of CSD and Belessa kaolin. Further studies are needed on comparision of Belessa kaolin with other non-conventional material such as Marble, Lime and cement.

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APPENDIX

APPENDIX A: Particle Size Distribution and Gradation of Aggregates

Table A1: Aggregate Gradation for coarse aggregate (25mm-9.5mm)

Weight of oven dry sample before washing (g)			5000
Weight of oven dry sample after washing (g)			4986
Sieve size (mm)	Retained Mass (g)	Cumulative Passing (g)	Cumulative Passing (%)
25	0	5000	100
19	1562.5	3437.5	68.75
12.5	2694	1043.5	20.87
9.5	561	482.5	9.65
4.75	463.5	19	0.38
2.36	3	16	0.32
1.18	2	14	0.28
0.6		14	0.28
0.3		14	0.28
0.15		14	0.28
0.075		14	0.28
Pan	0		
Wash Lose	14		
Total	5000		

Table A2: Aggregate Gradation for coarse aggregate (9.5mm-4.75mm)

Weight of oven dry sample before washing (g)			5000
Weight of oven dry sample after washing (g)			4973
Sieve size (mm)	Retained Mass (g)	Cumulative Passing (g)	Cumulative Passing (%)
25	0	5000	100
19	0	5000	100
12.5	167.5	4832.5	96.65
9.5	1326	3506.5	70.13
4.75	1855	1651.5	33.03
2.36	1541.5	110	2.2
1.18	75	35	0.7
0.6	5	30	0.6
0.3	3	27	0.54
0.15		27	0.54
0.075		27	0.54
Pan	0		
Wash Lose	27		
Total	5000		

Table A3: Aggregate Gradation for coarse aggregate (9.5mm-4.75mm)

Weight of oven dry sample before washing (g)			5000
Weight of oven dry sample after washing (g)			4569
Sieve size (mm)	Retained Mass (g)	Cumulative Passing (g)	Cumulative Passing (%)
25	0	5000	100
19	0	5000	100
12.5	0	5000	100
9.5	39.5	4960.5	99.21
4.75	504.5	4456	89.12
2.36	2098.5	2357.5	47.15
1.18	795	1562.5	42.87
0.6	466.5	1096	29.89
0.3	271	825	23.41
0.15	254	571	16.89
0.075	140	431	10.37
Pan	0		
Wash Lose	431		
Total	5000		

APPENDEX B: Physical properties, Aggregate quality test, Bitumen quality test and Mineral filler quality test

Table B1: Aggregate impact value test

Trial No.	1	2	3
Mold (g)	2745	2745	2745
Mold + sample	3428.5	3472.5	3489.5
Sample (M1)	683.5	727.5	744.5
Weight of aggregate passing on seive 2.34mm(gm) (M2)	53.7	60.1	60.1
Aggregate impact value (%)=(M2/M1)*100	7.86	8.26	8.07
Average impact value (%)	8.06		

Table B2: Aggregate Crushing Value Test

Trial No.	1	2	3
Mass of mold and plate (gm)	11921	11921	11921
Mass of sample (14mm pass and 10mm Retain)(M1)	2645	2618.5	2632.5
Mass of sample passing B.S Sieve,2.36mm (gm) (M2)	472	452.5	461.5
Aggregate Crushing Value (ACV) (%)=(M2/M1)*100	17.84	17.28	17.53
Average ACV (%)	17.55		

Table B3: Flakiness Index test

Separated fraction Size, mm	Mass		individual fraction % of M1(g)	Sum of masses after discarding 5% or less. M2(g)	Mass of flaky passing(g)	Sum, M3(g)
	individual fraction(g)	Sum, M1 (g)				
28 to 20	820.5	5000.5	16.41	5000.5	165	1495
20 to 14	1045		20.90		256	
14 to 10	796		15.92		197.5	
10 to 6.3	2339		46.8		876.5	
Flakiness Index (%)=(M3/M2)*100						29.90

Table B4: Los Angeles abrasion Test

Trial No.	1	2	3
Number of revolution	500	500	500
Total weight of sample tested	5000	5000	5000
Weight of sample retained on No. 12 sieve (g)	4435.5	4462.5	4452.5
Percent Loss (%)	11.3	10.8	11.0
Average los angeles abrasion (%)	11.0		

Table B5: Specific gravity and Water Absorption of Coarse Aggregate (19mm – 9.5mm)

Trial					1		2		3		Average	
Mass of SSD sample in air (g)					2000		2000		2000			
B. Mass of basket in water (g)					689.0		687.0		689.0			
C Bs+C Basket + Sample in water (g)					1932.5		1941.5		1936.0			
S.Mass of saturated sample in water (g)					2013.5		2018.0		2015.0			
A. Mass of oven dry sample in air					1990.50		1985.00		1991.5			
^0C	18	19	20	21	22	23	24	25	26	27	28	29
K	1.0004	1.0002	1	0.9998	0.9996	0.999	0.9991	0.9991	0.9986	0.9986	0.998	0.9977
Bulk sp. gravity (oven dry) Sd = A*k/S-(C-B)					2.583		2.596		2.588		2.589	
Bulk sp. gravity (SSD) Ss = S*k/S-(C-B)					2.613		2.639		2.618		2.623	
Apparent specific gravity Sr = A*k/A-(C-B)					2.662		2.714		2.670		2.682	
Water Absorption Aw = (S-A)*100/A					1.155		1.662		1.180		1.333	

Table B6: Specific gravity and Water Absorption of Intermediate Aggregate (9.5mm – 4.75mm)

Trial					1		2		3		Average	
Mass of SSD sample in air (g)					2000		2000		2000			
B. Mass of basket in water (g)					655.50		665.50		675.5			
C Bs+C Basket + Sample in water (g)					1912.50		1923.50		1929.5			
S.Mass of saturated sample in water (g)					2021.00		2025.00		2023.5			
A. Mass of oven dry sample in air					1990.20		1992.00		1994.5			
^0C	18	19	20	21	22	23	24	25	26	27	28	29
K	1.0004	1.0002	1	0.9998	0.9996	0.9993	0.999	0.9991	0.9986	0.999	0.998	0.998
Bulk Sp. gravity (oven dry) Sd = A*k/S-(C-B)					2.603		2.593		2.587		2.594	
Bulk Sp. gravity (SSD) Ss = S*k/S-(C-B)					2.643		2.636		2.624		2.635	
Apparent specific gravity Sr = A*k/A-(C-B)					2.712		2.710		2.688		2.703	
Water Absorption (%) Aw = (S-A)*100/A					1.548		1.657		1.454		1.553	

Table B7: Specific gravity and Water Absorption of Fine Aggregate (4.75mm –0mm)

<table>
<tr><td colspan="5">Trial</td><td colspan="2">1</td><td colspan="2">2</td><td colspan="2">3</td><td colspan="2">Average</td></tr>
<tr><td colspan="5">B. Mass of Pycnometer+Water (g)</td><td colspan="2">1556.50</td><td colspan="2">1554</td><td colspan="2">1555.5</td><td colspan="2" rowspan="4"></td></tr>
<tr><td colspan="5">S. Mass of SSD Sample (g)</td><td colspan="2">500</td><td colspan="2">500</td><td colspan="2">500</td></tr>
<tr><td colspan="5">C. Mass of Pycnometer+Water +Sample (g)</td><td colspan="2">1868.5</td><td colspan="2">1864.5</td><td colspan="2">1866</td></tr>
<tr><td colspan="5">A. Mass of Oven dry sample in air (g)</td><td colspan="2">491.50</td><td colspan="2">492.50</td><td colspan="2">493</td></tr>
<tr><td colspan="13">Water Temperature</td></tr>
<tr><td>^{0}C</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td></tr>
<tr><td>K</td><td>1.0004</td><td>1.0002</td><td>1</td><td>0.9998</td><td>1</td><td>0.9993</td><td>0.9991</td><td>0.9991</td><td>0.9986</td><td>0.9986</td><td>0.998</td><td>0.9977</td></tr>
<tr><td colspan="5">Bulk sp. gravity (oven dry) Sd = A*k/(B+S-C)</td><td colspan="2">2.612</td><td colspan="2">2.595</td><td colspan="2">2.596</td><td colspan="2">2.601</td></tr>
<tr><td colspan="5">Bulk sp. gravity (SSD) Ss = S*k/(B+S-C)</td><td colspan="2">2.657</td><td colspan="2">2.635</td><td colspan="2">2.633</td><td colspan="2">2.642</td></tr>
<tr><td colspan="5">Apparent specific gravity Sr = A*k/(A+B-C)</td><td colspan="2">2.736</td><td colspan="2">2.702</td><td colspan="2">2.696</td><td colspan="2">2.711</td></tr>
<tr><td colspan="5">Water Absorption (%) Aw = (S-A)*100/A</td><td colspan="2">1.729</td><td colspan="2">1.523</td><td colspan="2">1.420</td><td colspan="2">1.557</td></tr>
</table>

Table B8: Specific Gravity of CSD and Belessa kaolin

<table>
<tr><td colspan="5">1. Specific Gravity of Crushed Stone Dust or Filler</td></tr>
<tr><td>Material Type</td><td colspan="3">Crushed Stone Dust</td><td>ASTMD242</td></tr>
<tr><td>Trial No</td><td>1</td><td>2</td><td>3</td><td></td></tr>
<tr><td>A. Mass of oven dry sample in air (gm)</td><td>20</td><td>20</td><td>20</td><td></td></tr>
<tr><td>B. Mass of Pycnometer with Water</td><td>124.65</td><td>128.28</td><td>122.92</td><td></td></tr>
<tr><td>Initial Temperature in degree Celicuous,Ti</td><td>21</td><td>21</td><td>21</td><td></td></tr>
<tr><td>C. Mass of pycnometer with Soil and Water</td><td>137.19</td><td>140.86</td><td>135.36</td><td></td></tr>
<tr><td>Final Temperature in degree Celicuous,Tx</td><td>23</td><td>23</td><td>23</td><td></td></tr>
<tr><td>Apparent Specific Gravity ,Gs=A*K/(A+B-C)</td><td>2.675</td><td>2.690</td><td>2.640</td><td></td></tr>
<tr><td>Average Apparent Specific Gravity</td><td colspan="3">2.668</td><td></td></tr>
<tr><td>Plastic Index</td><td colspan="3">NP</td><td><4</td></tr>
<tr><td colspan="5">2. Specific Gravity of Belessa kaolin</td></tr>
<tr><td>Material Type</td><td colspan="3">Belessa kaolin</td><td>ASTMD242</td></tr>
<tr><td>Trial No</td><td>1</td><td>2</td><td>3</td><td></td></tr>
<tr><td>A. Mass of oven dry sample in air (gm)</td><td>20</td><td>20</td><td>20</td><td></td></tr>
<tr><td>B. Mass of Pycnometer with Water</td><td>127.03</td><td>122.58</td><td>125.48</td><td></td></tr>
<tr><td>Initial Temperature in degree Celicuous,Ti</td><td>26</td><td>26</td><td>26</td><td></td></tr>
<tr><td>C. Mass of pycnometer with Soil and Water</td><td>139.42</td><td>134.96</td><td>136.45</td><td></td></tr>
<tr><td>Final Temperature in degree Celicuous,Tx</td><td>28</td><td>28</td><td>28</td><td></td></tr>
<tr><td>Apparent Specific Gravity ,Gs=A*K/(A+B-C)</td><td>2.622</td><td>2.619</td><td>2.616</td><td></td></tr>
<tr><td>Average Apparent Specific Gravity</td><td colspan="3">2.619</td><td></td></tr>
<tr><td>Plastic Index</td><td colspan="3">NP</td><td><4</td></tr>
</table>

Table B9: Bitumen quality test

<table>
<tr><td rowspan="5">Penetration</td><td rowspan="2">Test Method</td><td rowspan="2">Test No</td><td rowspan="2">Test Temp(degree celcious)</td><td rowspan="2">Time of Test (S)</td><td rowspan="2">Test Load (g)</td><td colspan="3">Reading Date (0.1mm)</td><td rowspan="2">Average (0.1mm)</td></tr>
<tr><td>1st Time</td><td>2nd time</td><td>3rd time</td></tr>
<tr><td rowspan="3">AASHTO T 49</td><td>1</td><td>25</td><td>5</td><td>100</td><td>62.12</td><td>60.78</td><td>63.45</td><td>62.12</td></tr>
<tr><td>2</td><td>25</td><td>5</td><td>100</td><td>64.15</td><td>63.47</td><td>62.78</td><td>63.47</td></tr>
<tr><td>3</td><td>25</td><td>5</td><td>100</td><td>61.25</td><td>63.96</td><td>65.54</td><td>63.58</td></tr>
<tr><td colspan="9">Average Penetration</td><td>63.06</td></tr>
<tr><td colspan="10"></td></tr>
<tr><td rowspan="4">Ductility</td><td>Test Method</td><td>Test No</td><td>Test Temp(degree celcious)</td><td>Speed (cm/min)</td><td colspan="3">Ductility (cm)</td><td colspan="2">Average Ductility (cm)</td></tr>
<tr><td rowspan="3">AASHTO T 51</td><td>1</td><td>25</td><td>5</td><td colspan="3">96</td><td colspan="2" rowspan="3">96.33</td></tr>
<tr><td>2</td><td>25</td><td>5</td><td colspan="3">98</td></tr>
<tr><td>3</td><td>25</td><td>5</td><td colspan="3">95</td></tr>
<tr><td colspan="10"></td></tr>
<tr><td rowspan="6">Softening point</td><td rowspan="2">Test Method</td><td rowspan="2">Test No</td><td rowspan="2" colspan="2">Temp.when starting heating (degree celcious)</td><td colspan="3">Record of liquid Temp in beaker</td><td rowspan="2" colspan="2">Softening point</td></tr>
<tr><td>4min</td><td>5min</td><td>6min</td></tr>
<tr><td rowspan="2">AASHTO T 53</td><td>1</td><td colspan="2"></td><td></td><td>5min</td><td></td><td colspan="2">51.4</td></tr>
<tr><td>2</td><td colspan="2"></td><td></td><td></td><td>6min</td><td colspan="2">51.6</td></tr>
<tr><td></td><td></td><td colspan="2"></td><td></td><td>5min</td><td></td><td colspan="2">51.2</td></tr>
<tr><td colspan="7">Average Softening Point</td><td colspan="2">51.4</td></tr>
</table>

<table>
<tr><td rowspan="5">Flash and Fire Point</td><td>Test Method</td><td>Test No</td><td>Flash point Result</td><td>Fire point Result</td></tr>
<tr><td rowspan="3">AASHTO T 48</td><td>1</td><td>290</td><td>355</td></tr>
<tr><td>2</td><td>294</td><td>360</td></tr>
<tr><td>3</td><td>297</td><td>352</td></tr>
<tr><td colspan="2">Average</td><td>293.67</td><td>356.75</td></tr>
</table>

Specific Gravity of Bitumen	Test No.	1	2
	1. Weight of Pycnometer , g	103.73	104.13
	2. Weight of Pycnometer Filled With Sample,g	168.16	167.58
	3. Weight of Pycnometer Filled with Water , g @ 25 ± 0.10C	245.58	248.42
	4. Weight of Pycnometer + Sample + Water , g @ 25± 0.10C	248.80	250.19
	5. Weight of Water replaced by Sample , g {(3-1)+2} – 4	61.21	61.7
	6. Specific Gravity ,(2-1)/5	1.052	1.027
	7. Average Specific Gravity (g/ cm3)	1.040	
	8. Density , 7*wT (25 ^{o}C,wT =0.9971 g/cm3)	1.036	
	9. Density , 7*wT (15.6 ^{o}C, wT =0.9990 g/cm3)	1.038	

Table B10: Liquid Limit, Plastic Limit and Plastic Index of Belessa kaolin.

a) Liquid Limit by cone penetrometer test method

Determination	Liquid Limit			
penetration in (mm)	15.99	18.21	23.23	28.72
Test No	1	2	3	4
Container No	3L	A16	F5	A17
Wt. of container + wet soil, g	27.23	24.97	25.86	32.01
Wt. of container + dry soil, g	25.12	22.95	24.03	29.80
Wt. of container, g	19.61	17.21	18.15	21.94
Wt. of water, g	2.11	2.02	1.83	2.21
Wt. of dry soil, g	5.51	5.74	5.88	7.86
Moisture content, %	38.3	35.2	31.1	28.1

b) Plastic Limit and Plastic Index of Belessa kaolin

Plastic Limit		
Test	1	2
Container	F5	A17
Wt. of container + wet soil, g	26.57	30.78
Wt. of container + dry soil, g	24.75	28.64
Wt. of container, g	18.15	21.94
Wt. of water, g	1.82	2.14
Wt. of dry soil, g	6.60	6.70
Moisture container, %	27.58	31.9
Average Moisture Content, %	29.76	
Liquid limit	33	
Plastic limit	29.76	
Plastic Index	3.24	

c) Particle size distribution of Belessa kaolin.

Sieve size in mm	% passing
75	100
63	100
50	100
37.5	100
25	100
19	100
12.5	100
9.5	100
4.75	100
2.36	100
1.18	100
0.6	100
0.3	100
0.15	100
0.075	98.45
0.033	89.12
0.022	79.16
0.013	67.38
0.009	63.15
0.003	58.62
0.001	48.73

APPENDIX C: Aggregate Blending

Table C1: Superpave Aggregate Gradation with 5% filler

Sieve size in mm	Sieve size raised to 0.45 power	Superpave gradation specification limit					Percentage passing			Blended percentage corresponding to each bin			Total passing (%)
		Control points		Density line	Restricted Zone								
		Lower	Upper		Lower	Upper	Bin 1 (19-12.5)	Bin 2 (12.5-4.75)	Bin 3 (4.75-0)	Bin 1 (24%)	Bin 2 (30%)	Bin 3 (46%)	
25	4.257	100		100			100	100	100	24	30	46	100
19	3.762	90	100				68.75	100	100	16.78	30	46	92.5
12.5	3.116		90				20.87	96.65	100	5.01	28.99	46	80
9.5	2.754						9.65	70.13	99.21	2.316	21.04	45.64	69
4.75	2.016						0.38	33.03	89.12	0.103	9.91	40.99	51
2.36	1.472	23	49		34.6	34.6	0.32	2.2	47.15	0.077	0.66	21.69	33
1.18	1.077				22.3	28.3	0.28	0.7	42.87	0.067	0.21	19.72	20
0.6	0.795				16.7	20.7	0.28	0.6	29.89	0.067	0.18	13.752	14
0.3	0.582				13.7	13.7	0.28	0.54	23.41	0.067	0.162	10.77	11
0.15	0.426						0.28	0.54	16.89	0.067	0.162	7.77	8
0.08	0.312				2	8	0.28	0.54	10.37	0.067	0.162	4.77	5
Pan	0			0									

Table C2: Superpave Aggregate Gradation with 6% filler

Sieve size in mm	Sieve size raised to 0.45 power	Superpave gradation specification limit											
		Control points		Density line	Restricted Zone		Percentage passing			Blended percentage corresponding to each bin			Total passing (%)
		Lower	Upper		Lower	Upper	Bin 1 (19-12.5)	Bin 2 (12.5-4.75)	Bin 3 (4.75-0)	Bin 1 (26%)	Bin 2 (26%)	Bin 3 (48%)	
25	4.257	100		100			100	100	100	26	26	48	100
19	3.762	90	100				68.75	100	100	18	26	48	92
12.5	3.116		90				20.87	96.65	100	7.42	26.079	48	81.5
9.5	2.754						9.65	70.13	99.21	3.26	20.79	47.94	72
4.75	2.016						0.38	33.03	89.12	0.098	8.87	43.54	52.5
2.36	1.472	23	49		34.6	34.6	0.32	2.2	47.15	0.083	0.572	31.351	32
1.18	1.077				22.3	28.3	0.28	0.7	42.87	0.073	0.182	20.749	21
0.6	0.795				16.7	20.7	0.28	0.6	29.89	0.073	0.156	14.76	15
0.3	0.582				13.7	13.7	0.28	0.54	23.41	0.073	0.14	11.79	12
0.15	0.426						0.28	0.54	16.89	0.073	0.14	8.78	9
0.08	0.312				2	8	0.28	0.54	10.37	0.073	0.14	5.79	6
Pan	0			0									

Table C3: Superpave Aggregate Gradation with 7% filler

Sieve size in mm	Sieve size raised to 0.45 power	Superpave gradation specification limit											
		Control points		Density line	Restricted Zone		Percentage passing			Blended percentage corresponding to each bin			Total passing (%)
		Lower	Upper		Lower	Upper	Bin 1 (19-12.5)	Bin 2 (12.5-4.75)	Bin 3 (4.75-0)	Bin 1 (22%)	Bin 2 (32%)	Bin 3 (46%)	
25	4.257	100		100			100	100	100	22	32	46	100
19	3.762	90	100				68.75	100	100	15	32	46	93
12.5	3.116		90				20.87	96.65	100	4.17	30.92	46	81
9.5	2.754						9.65	70.13	99.21	1.93	22.44	45.64	70
4.75	2.016						0.38	33.03	89.12	0.076	10.44	40.99	51.5
2.36	1.472	23	49		34.6	34.6	0.32	2.2	47.15	0.064	0.704	30.21	31
1.18	1.077				22.3	28.3	0.28	0.7	42.87	0.056	0.24	19.72	20
0.6	0.795				16.7	20.7	0.28	0.6	29.89	0.056	0.19	13.752	14
0.3	0.582				13.7	13.7	0.28	0.54	23.41	0.056	0.17	11.22	11.5
0.15	0.426						0.28	0.54	16.89	0.056	0.17	9.23	9.5
0.08	0.312				2	8	0.28	0.54	10.37	0.056	0.17	6.77	7
Pan	0			0									

APPENDIX D: Theoretical Maximum Specific Gravity of HMA Mixtures

Table C1: Theoretical Maximum Specific Gravity of HMA Mixtures with 5% filler

Bitumen content	4%		4.50%		5%		5.50%		6%	
No. of Trials	1	2	1	2	1	2	1	2	1	2
Wp+w (g)	2398	2398	2378.2	2378.2	2371.4	2371.4	2393.7	2393.7	2429.8	2429.8
Ws (g)	1258.2	1260	1258.9	1257.4	1256.4	1259.1	1266.7	1262.1	1267.9	1261.8
Wp+w+s (g)	3148.1	3148.4	3121.5	3118.4	3107.2	3110	3132.8	3131	3166.1	3160.4
Gmm, (g/cm3)	2.476	2.473	2.442	2.431	2.413	2.419	2.401	2.405	2.385	2.375
Average	2.475		2.437		2.416		2.403		2.380	

Table C2: Theoretical Maximum Specific Gravity of HMA Mixtures with 6% filler

Bitumen content	4%		4.50%		5%		5.50%		6%	
No. of Trials	1	2	1	2	1	2	1	2	1	2
Wp+w (g)	2398	2398	2378.2	2378.2	2371.4	2371.4	2393.7	2393.7	2429.8	2429.8
Ws (g)	1263.5	1261	1266.3	1260.3	1254.3	1261.5	1259.8	1256.4	1263.8	1259
Wp+w+s (g)	3148.6	3148.1	3127	3121.3	3106.5	3109	3130.8	3127.1	3164.9	3163.8
Gmm, (g/cm3)	2.463	2.457	2.447	2.437	2.416	2.408	2.410	2.402	2.39	2.398
Average	2.460		2.442		2.412		2.406		2.394	

Table C3: Theoretical Maximum Specific Gravity of HMA Mixtures with 7% filler

Bitumen content	4%		4.50%		5%		5.50%		6%	
No. of Trials	1	2	1	2	1	2	1	2	1	2
Wp+w (g)	2398	2398	2378.2	2378.2	2371.4	2371.4	2393.7	2393.7	2429.8	2429.8
Ws (g)	1260.2	1263.1	1262.1	1257.3	1254.9	1264.3	1259.6	1255.4	1258.3	1263.5
Wp+w+s (g)	3146	3149.8	3124.9	3121.4	3108.2	3115.2	3130.1	3128.2	3160.8	3165.5
Gmm, (g/cm3)	2.460	2.470	2.449	2.441	2.422	2.429	2.407	2.410	2.386	2.394
Average	2.465		2.445		2.426		2.409		2.39	

Table C3: Theoretical Maximum Specific Gravity of HMA Mixtures with different Belessa kaolin replacement

Belessa Kaolin Percentage	0%		10%		20%		30%		40%		50%	
No. of Trials	1	2	1	2	1	2	1	2	1	2	1	2
A.Wp+w (g)	2428.2	2428.2	2428.2	2428.2	2428.2	2428.2	2428.2	2428.2	2428.2	2428.2	2428.2	2428.2
B.Ws (g)	1257	1259	1261.9	1259.4	1263	1260	1256.4	1258.8	1261.5	1258	1262.7	1259
C.Wp+w+s (g)	3166	3167	3169	3167.2	3169.5	3168	3165.5	3167.5	3170.3	3167.2	3170.5	3167.6
Gmm, (g/cm3)	2.418	2.420	2.421	2.417	2.422	2.418	2.419	2.420	2.415	2.421	2.418	2.424
Average	2.419		2.419		2.420		2.420		2.418		2.421	

APPENDIX E: Marshal Test Data

Table E1: Marshall test data of mixture with 5% filler gradation

Type of bituminous mixture: Wearing Course						5% CSD	Specific Gravity of Bitumen: 1.040							
Bitumen Grade: 60/70							App. Specific Gravity of Aggrgate: 2.657							
Bulk Specific gravity of mixed aggrgate: 2.589							Effective Specific Gravity of mixed aggregate:2.61							
	A	B	C	D	E	F	G	H	I	J	K	L	N	O
Speci men No	Bitume n content %	Height of specimen (cm)	Weight of Specimen (gm)			Bulk volume (cc)	Bulk SG compact ed mix(Gmb	Max SG of the mix (Gmm)	Air void (H-G) *100/H	VMA (%) (100-[(Gmb/Gsb) *(100-A)]	VFA 100*(J-I)/J	Marshal stability KN		Flow (mm)
			Air Dry	Water	Air SSD	E-D	C/F					Maximum Load	Corrected load	
1	4%	6.65	1226	689	1228	539	2.275	2.475	8.10	14.67	44.80	10.32	9.18	1.97
2		6.75	1224	690	1227	537	2.279		7.91	14.492	45.45	10.74	9.65	2.45
3		6.80	1225	691.5	1227.5	536	2.285		7.66	14.26	46.30	10.62	9.42	2.23
Average		6.73	1225.0	690.17	1227.50	537.33	2.280		7.89	14.47	45.51	10.56	9.42	2.22
1	4.50%	6.90	1233	696	1236	540	2.283	2.437	6.31	14.79	57.36	10.59	9.16	2.64
2		7.05	1234.5	698	1237	539	2.290		6.02	14.53	58.57	14.49	12.22	2.85
3		7.00	1233.5	701.5	1237	535.5	2.303		5.48	14.04	60.96	12.54	10.70	2.75
Average		6.98	1233.7	698.50	1236.67	538.17	2.292		5.93	14.45	58.93	12.54	10.69	2.75
1	5%	6.90	1240.5	708.5	1241.5	533	2.327	2.416	3.67	14.60	74.88	12.94	10.94	3.08
2		6.75	1239.5	705	1241	536	2.313		4.28	15.15	71.72	14.47	12.35	2.96
3		6.85	1238.5	705	1240	535	2.315		4.18	14.06	70.25	13.96	12.00	3.01
Average		6.83	1239.5	706.17	1240.83	535	2.318		4.04	14.60	72.30	13.79	11.76	3.02
1	5.50%	6.85	1243	713.5	1244.5	531	2.341	2.403	2.59	14.56	82.24	13.71	12.13	3.56
2		6.65	1241	711.5	1244.5	533	2.328		3.11	15.01	79.30	10.88	10.31	2.83
3		6.70	1241	710	1242.5	532.5	2.331		3.02	14.93	79.80	11.63	11.15	3.20
Average		6.73	1241.7	711.67	1243.83	532.17	2.333		2.90	14.84	80.43	12.07	11.20	3.20
1	6%	6.90	1250.5	712.5	1252	539.5	2.318	2.380	2.61	15.84	83.53	10.74	9.24	5.44
2		6.95	1251	711.5	1252.5	541	2.312		2.84	16.04	82.29	11.58	10.15	4.21
3		7.10	1249	712	1251.5	539.5	2.315		2.73	15.94	82.90	11.13	9.70	4.83
Average		6.98	1250.2	712.00	1252.00	540.00	2.315		2.73	15.94	82.90	11.15	9.70	4.83

Table E2: Marshall test data of mixture with 6% filler gradation

Type of bituminous mixture: Wearing Course	6% CSD	Specific Gravity of Bitumen: 1.040
Bitumen Grade: 60/70		App. Specific Gravity of Aggrgate: 2.655
Bulk Specific gravity of mixed aggrgate: 2.587		Effective Specific Gravity of mixed aggregate:2.61

	A	B	C	D	E	F	G	H	I	J	K	L	N	O
Specimen No	Bitumen content %	Height of specimen (cm)	Weight of Specimen (gm)			Bulk volume (cc)	Bulk SG compacted mix(Gmb	Max SG of the mix (Gmm)	Air void	VMA (%)	VFA	Marshal stability KN		Flow (mm)
			Air Dry	Water	Air SSD	E-D	C/F		(H-G) *100/H	(100-[(Gmb/Gsb)*(100-A)]	100*(J-I)/J	Maximum Load	Corrected load	
1	4%	6.66	1228	675	1231	556	2.209	2.460	10.22	17.72	42.34	10.24	8.95	1.85
2		6.7	1232	681	1235.5	554.5	2.222		9.68	17.23	43.81	9.75	8.35	2.30
3		6.73	1232.5	674	1235	561	2.197		10.69	18.16	41.11	11.01	9.72	2.62
Average		6.70	1230.83	676.67	1233.83	557.17	2.21		10.20	17.70	42.40	10.33	9.01	2.26
1	4.50%	6.95	1243	692.5	1250	557.5	2.230	2.442	8.70	17.37	49.94	10.79	9.45	2.86
2		6.85	1239.5	696	1243	547	2.266		7.21	16.03	55.03	11.56	10.79	3.33
3		6.90	1241	701.5	1244	542.5	2.288		6.32	15.23	58.46	11.32	10.24	3.21
Average		6.90	1241.17	696.67	1245.67	549	2.261		7.41	16.21	54.28	11.22	10.16	3.13
1	5%	6.73	1243.5	704.5	1245	540.5	2.301	2.412	4.62	15.19	69.60	10.79	9.84	2.89
2		6.73	1250	707.5	1253	545.5	2.291		5.00	15.53	67.82	11.87	10.42	3.01
3		6.76	1245	706.5	1247.5	541	2.301		4.59	15.16	69.73	12.65	11.58	3.42
Average		6.74	1246.17	706.17	1248.50	542	2.30		4.73	15.29	69.04	11.77	10.61	3.11
1	5.50%	6.66	1250	714	1251.5	537.5	2.326	2.406	3.34	14.72	77.29	11.68	10.56	3.35
2		6.70	1258	716	1259	543	2.317		3.71	15.04	75.34	10.33	9.54	3.30
3		6.66	1254.5	713.5	1256	542.5	2.312		3.89	15.20	74.42	12.78	11.34	3.20
Average		6.67	1254.17	714.50	1255.50	541.00	2.32		3.65	14.99	75.67	11.60	10.48	3.28
1	6%	6.70	1263	722	1264	542	2.330	2.394	2.66	15.00	82.25	9.41	8.25	3.63
2		6.63	1258.5	719.5	1259	539.5	2.333		2.56	14.91	82.83	10.01	8.65	3.92
3		6.73	1261	720.5	1262	541.5	2.329		2.73	15.06	81.89	10.22	9.20	3.52
Average		6.69	1260.83	720.67	1261.67	541.00	2.33		2.65	14.99	82.32	9.88	8.70	3.69

Table E3: Marshall test data of mixture with 7% filler gradation

Type of bituminous mixture: Wearing Course | 7% CSD | Specific Gravity of Bitumen: 1.040

Bitumen Grade: 60/70 | App. Specific Gravity of Aggrgate: 2.657

Bulk Specific gravity of mixed aggrgate: 2.590 | Effective Specific Gravity of mixed aggregate:2.61[illegible]

	A	B	C	D	E	F	G	H	I	J	K	L	N	O
Specimen No	Bitumen content %	Height of specimen (cm)	Weight of Specimen (gm)			Bulk volume (cc)	Bulk SG compacted mix(Gmb	Max SG of the mix (Gmm)	Air void (H-G) *100/H	VMA (%) (100-[(Gmb/Gsb)*(100-A)]	VFA 100*(J-I)/J	Marshal stability KN		Flow (mm)
			Air Dry	Water	Air SSD	E-D	C/F					Maximum Load	Corrected load	
1	4%	6.70	1231.0	685.0	1235.0	550.0	2.238	2.465	9.20	15.90	42.14	9.21	8.20	2.45
2		6.73	1236.5	689.5	1240.0	550.5	2.246		8.88	15.60	43.10	10.35	9.35	2.20
3		6.73	1234.0	685.0	1237.5	552.5	2.233		9.39	16.08	41.59	8.45	7.89	2.64
Average		6.72	1233.8	686.5	1237.5	551.0	2.239		9.16	15.86	42.27	9.34	8.48	2.43
1	4.50%	6.83	1240.5	701.5	1244.0	542.5	2.287	2.445	6.48	14.53	55.43	11.01	10.35	2.71
2		6.76	1238.0	699.5	1240.5	541.0	2.288		6.41	14.47	55.71	10.25	9.65	3.21
3		6.80	1246.5	704.0	1248.0	544.0	2.291		6.28	14.35	56.22	9.33	8.21	2.64
Average		6.80	1241.7	701.7	1244.2	542.5	2.289		6.39	14.45	55.79	10.20	9.40	2.85
1	5%	6.70	1249.0	709.0	1251.5	542.5	2.302	2.426	5.10	14.40	64.58	12.15	10.87	3.31
2		6.80	1250.0	709.5	1252.0	542.5	2.304		5.02	14.33	64.94	10.59	9.85	3.13
3		6.76	1253.0	710.5	1254.5	544.0	2.303		5.06	14.36	64.78	11.32	9.18	2.71
Average		6.75	1250.7	709.7	1252.7	543.0	2.303		5.06	14.36	64.77	11.35	9.97	3.05
1	5.50%	6.83	1255.0	712.0	1256.0	544.0	2.307	2.409	4.23	14.67	71.14	11.56	10.12	2.90
2		6.73	1254.0	712.5	1254.5	542.0	2.314		3.96	14.43	72.56	12.89	11.18	3.25
3		6.76	1257.0	714.0	1258.5	544.5	2.309		4.17	14.62	71.47	10.27	9.06	3.42
Average		6.77	1255.3	712.8	1256.3	543.5	2.310		4.12	14.57	71.72	11.57	10.12	3.19
1	6%	6.80	1263.0	716.0	1263.5	547.5	2.307	2.39	3.48	15.13	77.00	9.89	8.85	3.81
2		6.83	1266.5	718.5	1267.5	549.0	2.307		3.48	15.13	77.02	10.31	9.19	3.61
3		6.90	1265.0	717.0	1266.0	549.0	2.304		3.59	15.23	76.42	9.74	8.89	3.45
Average		6.84	1264.8	717.2	1265.7	548.5	2.306		3.52	15.16	76.81	9.98	8.98	3.62

Table E4: Marshall test data of mixture with Belessa kaolin filler combined with 5% filler gradation at OBC

Type of bituminous mixture: Wearing Course	Replace ment	Specific Gravity of Bitumen: 1.040
Bitumen Grade: 60/70		App. Specific Gravity of Aggrgate: 2.657
Bulk Specific gravity of mixed aggrgate: 2.587		Effective Specific Gravity of mixed aggregate:2.61

	A	B	C	D	E	F	G	H	I	J	K	L	N	O
Speci men No	Percent age of Belessa Kaolin	Height of specimen (cm)	Weight of Specimen (gm)			Bulk volume (cc)	Bulk SG compact ed mix(Gmb	Max SG of the mix (Gmm)	Air void	VMA (%)	VFA	Marshal stability KN		Flow (mm)
			Air Dry	Water	Air SSD				(H-G) *100/H	(100-[(Gmb/Gsb) *(100-A)]	100*(J-I)/J	Maximum Load	Corrected load	
						E-D	C/F							
1	0%	6.80	1251.5	712.0	1252.5	540.5	2.315	2.419	4.28	14.08	69.59	13.56	12.32	3.12
2		6.83	1252.0	714.0	1253.0	539.0	2.323		3.98	13.80	71.20	11.12	10.21	2.77
3		6.90	1253.5	714.5	1254.5	540.0	2.321		4.04	13.86	70.86	11.65	10.45	3.22
Average		6.84	1252.3	713.5	1253.3	539.8	2.320		4.10	13.91	70.54	12.11	10.99	3.04
1	10%	6.90	1254.0	714.5	1256.0	541.5	2.316	2.419	4.27	14.51	70.60	12.56	11.05	2.95
2		7.00	1256.5	716.5	1258.0	541.5	2.320		4.08	14.34	71.58	12.37	11.24	3.34
3		6.93	1253.0	712.0	1254.5	542.5	2.310		4.52	14.74	69.33	11.01	9.78	3.16
Average		6.94	1254.5	714.3	1256.2	541.8	2.315		4.29	14.53	70.49	11.98	10.69	3.15
1	20%	6.80	1256.0	716.0	1258.0	542.0	2.317	2.420	4.24	14.90	71.53	10.97	9.84	3.42
2		6.83	1262.0	719.5	1263.5	544.0	2.320		4.14	14.81	72.06	14.19	13.21	2.67
3		6.86	1252.5	713.0	1254.0	541.0	2.315		4.33	14.98	71.08	11.07	10.00	3.21
Average		6.83	1256.8	716.2	1258.5	542.3	2.317		4.24	14.90	71.56	12.08	11.02	3.10
1	30%	6.83	1252.5	713.5	1253.5	540.0	2.319	2.420	4.16	15.27	72.79	13.38	12.07	2.91
2		6.83	1253.5	714.0	1254.5	540.5	2.319		4.17	15.28	72.73	13.02	11.92	3.32
3		6.80	1250.0	712.0	1251.0	539.0	2.319		4.17	15.29	72.73	11.92	10.87	3.01
Average		6.82	1252.0	713.2	1253.0	539.8	2.319		4.16	15.28	72.75	12.77	11.62	3.08
1	40%	7.00	1249.0	711.0	1252.0	541.0	2.309	2.418	4.52	16.11	71.94	10.83	9.72	3.21
2		6.93	1255.0	715.5	1256.5	541.0	2.320		4.06	15.71	74.14	11.08	10.15	3.52
3		6.93	1253.0	714.0	1256.5	542.5	2.310		4.48	16.08	72.13	12.31	11.09	3.70
Average		6.95	1252.3	713.5	1255.0	541.5	2.313		4.35	15.97	72.73	11.41	10.32	3.48
1	50%	7.00	1251.0	713.0	1254.5	541.5	2.310	2.421	4.57	16.06	71.51	11.16	10.59	3.82
2		7.33	1251.5	714.0	1255.0	541.0	2.313		4.45	15.94	72.10	9.87	8.45	3.35
3		6.90	1253.0	715.5	1258.0	542.5	2.310		4.60	16.08	71.40	10.94	9.87	4.02
Average		7.08	1251.8	714.2	1255.8	541.7	2.311		4.54	16.03	71.67	10.66	9.64	3.73

APPENDIX F: Indirect Tensile Strength Test Data

Table F1: TSR results of different percentage of Belessa kaolin

Resistance of Compacted Bituminious Mixture to Moisture Damage													
layer asphalt: wearing course								Source of bitumen **ERA**					
Compaction 75 blow per side								Grade of bitumen **60/70**					
Specific gravity of Bitumen: 1.040 Mix type 19mm NMAS													
Trial	Belessa kaolin(%)	WetP(KN)	WetP(N)	Dry P(KN)	Dry P(N)	PI (Π)	Thickness wet (mm)	Thickness dry (mm)	Diameter (mm)	St_2	St_1	TSR	Average TSR (%)
1	OBC (0%)	7.64	7640	9.45	9450	3.14	68.66	69.66	100	708.74	864.07	0.82	**81.75%**
2		8.01	8010	9.78	9780	3.14	69	70.33	100	739.407	885.72	0.83	
3		7.62	7620	9.51	9510	3.14	69	68.66	100	703.406	882.22	0.80	
										Mean		0.82	
Trial	Belessa kaolin(%)	WetP(KN)	WetP(N)	Dry P(KN)	Dry P(N)	PI (Π)	Thickness wet (mm)	Thickness dry (mm)	Diameter (mm)	St_2	St_1	TSR	Average TSR (%)
1	10	7.67	7670	9.21	9210	3.14	69.33	68.66	100	704.65	854.39	0.82	**81.31%**
2		7.31	7310	9.01	9010	3.14	70	69	100	665.15	831.72	0.80	
3		7.94	7940	9.65	9650	3.14	70	69.33	100	722.47	886.56	0.81	
										Mean		0.81	
Trial	Belessa kaolin(%)	WetP(KN)	WetP(N)	Dry P(KN)	Dry P(N)	PI (Π)	Thickness wet (mm)	Thickness dry (mm)	Diameter (mm)	St_2	St_1	TSR	Average TSR (%)
1	20	7.63	7630	9.45	9450	3.14	69.33	69.33	100	700.98	868.18	0.81	**81.58%**
2		8.35	7840	9.87	9870	3.14	69.66	69	100	716.86	911.10	0.79	
3		7.93	7930	9.62	9520	3.14	68.66	70.33	100	735.65	862.18	0.85	
										Mean		0.82	

Trial	Belessa kaolin(%)	WetP(KN)	WetP(N)	Dry P(KN)	Dry P(N)	PI (Π)	Thickness wet (mm)	Thickness dry (mm)	Diameter (mm)	St_2	St_1	TSR	Average TSR (%)
1	30	7.742	7742	9.52	9520	3.14	69.33	69	100	711.27	878.80	0.81	**82.38%**
2		7.84	7840	9.42	9420	3.14	69.66	70	100	716.86	857.14	0.84	
3		8.12	8120	9.931	9931	3.14	68.66	69.33	100	753.27	912.37	0.83	
										Mean		0.82	

Trial	Belessa kaolin(%)	WetP(KN)	WetP(N)	Dry P(KN)	Dry P(N)	PI (Π)	Thickness wet (mm)	Thickness dry (mm)	Diameter (mm)	St_2	St_1	TSR	Average TSR (%)
1	40	7.45	7450	9.51	9510	3.14	68	69.33	100	697.827	873.695	0.799	**80.37%**
2		8.12	8120	9.63	9630	3.14	69.33	69.66	100	745.994	880.528	0.847	
3		7.21	7210	9.56	9560	3.14	68.33	69.33	100	672.085	878.288	0.765	
										Mean		0.804	

Trial	Belessa kaolin(%)	WetP(KN)	WetP(N)	Dry P(KN)	Dry P(N)	PI (Π)	Thickness wet (mm)	Thickness dry (mm)	Diameter (mm)	St_2	St_1	TSR	Average TSR (%)
1	50	7.255	7255	9.847	9847	3.14	69.66	69.33	100	663.37	904.66	0.73	**73.46%**
2		7.13	7130	9.51	9510	3.14	70.33	69.66	100	645.73	869.56	0.74	
3		7.38	7380	9.901	9901	3.14	71	69.33	100	662.06	909.62	0.73	
										Mean		0.73	

APPENDIX G: Test Data for Single Wheel Truck test (Rutting Test)

Table G1: Rutting results of Control Mix and 30% Belessa kaolin

Rutting Test by using Single Wheel Tracking Test								
TEST METHOD : UNE-EN: 12697-22								
	0% Belessa Kaolin Replacement				30% Belessa Kaolin Replacement			
	Trial One		Trial Two		Trial One		Trial Two	
Date of test	22/05/2021		23/05/2021		24/05/2021		27/05/2021	
Cycle	Rutting depth(mm)	Rpm	Rutting depth(mm)	Rpm	Rutting depth(mm)	Rpm	Rutting depth(mm)	Rpm
0	0	26.65	0	26.66	0	26.65	0	26.65
250	0.71	26.63	0.83	26.64	0.68	26.63	0.9	26.67
500	1.06	26.65	1.21	26.65	0.96	26.65	1.31	26.66
750	1.42	26.64	1.52	26.64	1.23	26.66	1.52	26.62
1000	1.68	26.65	1.74	26.64	1.45	26.67	1.62	26.64
1250	1.82	26.64	2.02	26.65	1.61	26.66	1.74	26.63
1500	1.92	26.63	2.14	26.68	1.74	26.67	1.85	26.66
1750	2.06	26.65	2.22	26.67	1.85	26.66	1.94	26.68
2000	2.14	26.65	2.27	26.68	1.93	26.69	2.01	26.67
2250	2.22	26.66	2.33	26.65	2	26.69	2.08	26.67
2500	2.29	26.66	2.36	26.65	2.05	26.67	2.15	26.69
2750	2.34	26.67	2.38	26.64	2.11	26.68	2.21	26.67
3000	2.38	26.65	2.41	26.65	2.16	26.67	2.26	26.68
3250	2.44	26.66	2.44	26.65	2.21	26.69	2.31	26.67
3500	2.47	26.66	2.47	26.67	2.25	26.68	2.34	26.7
3750	2.51	26.65	2.49	26.66	2.3	26.7	2.35	26.69
4000	2.51	26.64	2.52	26.66	2.35	26.69	2.39	26.67

4250	2.53	26.65	2.54	26.65	2.4	26.69	2.42	26.65
4500	2.53	26.65	2.55	26.65	2.46	26.7	2.47	26.66
4750	2.57	26.67	2.58	26.64	2.5	26.69	2.51	26.68
5000	2.61	26.68	2.6	26.65	2.54	26.69	2.54	26.67
5250	2.63	26.68	2.61	26.65	2.59	26.7	2.59	26.68
5500	2.67	26.67	2.63	26.65	2.63	26.7	2.63	26.69
5750	2.72	26.66	2.66	26.64	2.68	26.69	2.66	26.69
6000	2.77	26.65	2.67	26.64	2.7	26.7	2.68	26.65
6250	2.79	26.64	2.69	26.63	2.71	26.69	2.7	26.66
6500	2.84	26.67	2.72	26.65	2.73	26.68	2.74	26.68
6750	2.88	26.66	2.74	26.65	2.76	26.7	2.75	26.66
7000	2.91	26.65	2.77	26.66	2.79	26.69	2.79	26.67
7250	2.94	26.66	2.79	26.68	2.81	26.69	2.83	26.68
7500	2.97	26.65	2.83	26.67	2.82	26.71	2.88	26.67
7750	3.01	26.64	2.85	26.65	2.84	26.7	2.91	26.68
8000	3.05	26.63	2.89	26.65	2.85	26.71	2.95	26.67
8250	3.09	26.63	2.92	26.66	2.88	26.7	2.97	26.65
8500	3.12	26.64	2.95	26.66	2.9	26.71	3	26.66
8750	3.16	26.65	2.97	26.67	2.93	26.71	3.04	26.69
9000	3.19	26.66	3	26.69	2.95	26.69	3.08	26.66
9250	3.21	26.63	3.02	26.69	2.97	26.68	3.1	26.65
9500	3.22	26.65	3.05	26.67	2.98	26.69	3.12	26.65
9750	3.24	26.68	3.07	26.66	2.99	26.68	3.15	26.66
10000	3.25	26.66	3.08	26.65	3.01	26.69	3.17	26.65
Average rutting depth			3.17		3.09			

Table G2: Wheel Tracking Slope and Proportional Rut depth of Control Mix and 30% Belessa kaolin

	Results of the UNE-EN 12697- 22 wheel-tracking test							
	0% Belessa kaolin			30% Belessa Kaolin			specification as per EN 13108	
Mix Name	Wheel-Tracking Slope (WTS_{AIR}) (μmm/cycle)	Proportional Rut Depth (%)	Average Rut Depth (mm)	Wheel-Tracking Slope (WTSAIR) (μmm/cycle)	Proportional Rut Depth (%)	Average Rut Depth (mm)	Proportional Rut Depth (%)	Rut depth (mm)
Trial one	0.128	5.96	3.25	0.094	5.79	3.01	<7	<5
Trial two	0.096	5.81	3.08	0.126	5.93	3.17	<8	<6
Avereage	0.112	5.89	3.17	0.110	5.86	3.09	<8	<6

APPENDIX H: Laboratory Activities Illustrated by Pictures

Sieve Analysis

Aggregate Blending

Bitumen Specific Gravity

HMA for Compaction

HMA Compaction

Extraction of HMA Specimen from Mould


Specimen Height Determination


Weighing Compacted Specimen

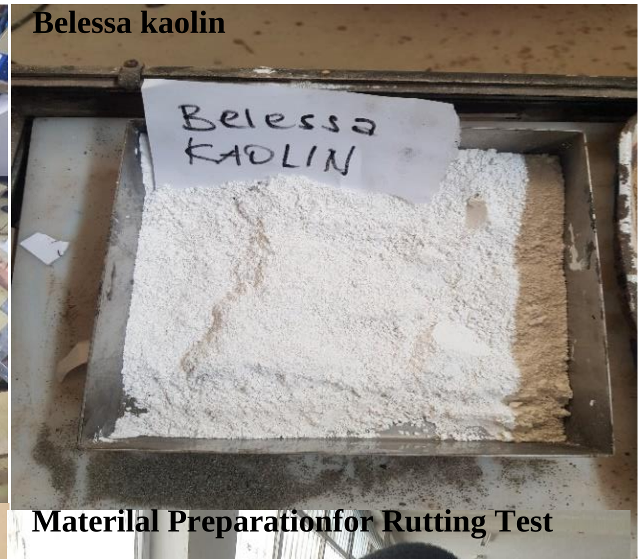

Compacted Specimen in Water bath


Marshal Test


Specimen after Test

Uncompacted HMA for Gmm

Belessa kaolin



TSR Test

Materilal Preparationfor Rutting Test

HMA Mixture for Rutting Test

HMA in Roller Compactor

Roller Compactor

Rutting Samples after Compaction

Rutting Depth Test by Single Wheel Truck

Calibration of Single Wheel Truck