JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
CONSTRUCTION ENGINEERING AND MANAGEMENT CHAIR

INVESTIGATION ON THE SUITABILITY OF DIFFERENT QUARRY SITE CRUSHED AGGREGATE FOR BASE COURSE AGGREGATE OF ASPHALT PAVEMENT CONSTRUCTION IN CASE OF JIMMA CITY

A Thesis Submitted to School of Graduate Studies, Jimma University, Jimma Institute of Technology, Faculty of Civil and Environmental Engineering in Partial Fulfilment of the Requirements for the Degree Master of Science in Construction Engineering and Management

BY
EBRAHIM AKILE KEMAL

February 4, 2020
Jimma, Ethiopia

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Main Advisor: Dr. Zeinu Ahmed (PhD)

Co Advisor: Eng. Mamaru Dessalegn (MSc)

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BY EBRAHIM AKILE KEMAL

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DECLARATION

I declare that this thesis entitled "*investigation on the suitability of different quarry site crushed aggregate for Base course aggregate of asphalt pavement construction in case of Jimma city*" is my own original work, and has not been submitted and present as a requirement for the award of any degree in Jimma University or elsewhere.

Ebrahim Akile Kemal	____________	Feb/ 10 / 2020
Name	Signature	Date

As research advisor, I hereby certify that I have read and evaluated this thesis paper prepared under my guidance, by Ebrahim Akile Kemal entitled "*investigation on the suitability of different quarry site crushed aggregate for Base course aggregate of asphalt pavement construction in case of Jimma city*" recommended and would be accepted as a fulfilling requirement for the degree master of science in construction engineering and management

Main Advisor:

Dr. Zeinu Ahmed (PhD)	____________	10 / 02 / 2020
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ABSTRACT

Flexible pavements constructed for heavy duty vehicles are composed of asphaltic layers, base course, Sub-base and sub grade foundation. Base course serves as the principal structural of flexible pavement and distributes the imposed wheel load to the pavement foundation (sub grade). The quality of the base layer is an important impact on the lifetime of a pavement, particularly for flexible pavement. Pavement distress, will be reduced if the base layer is made properly using acceptable aggregates that maintain their integrity throughout the lifetime. General objective of this research was Investigation on the suitability of different quarry site aggregate for base course aggregate of asphalt pavement construction in case of Jimma city.

The study was achieved by conducting physical (Gradation, Specific Gravity & Water Absorption and shape) and mechanical properties (Aggregate Crushing Value, Aggregate Impact Value and Los Angeles Abrasion Value) laboratory tests which were started visiting quarry sites aggregate production and samples was extracted and brought according to AASHTO T-2 sampling procedure from five different quarry sites to Jimma Institution of Technology, Highway Engineering laboratory where qualities of aggregates investigated and evaluated according to ERA, AASHTO, ASTM and BS.

The results from this study have shown that, Both Jemila and Welda Mikrbete Quarry Site Base Course Crushed Aggregate were fulfilled gradation requirement. In term of Aggregate Crushing Value, Aggregate Impact Value and Los Angeles Abrasion Value all are within the requirement. Specific gravity and Water absorption of all quarry site aggregate were in the same range from 2.76 to 2.81 and 1.30% to 1.55% respectively, all are acceptable. Flakiness and Elongation Index was achieved by all quarry site which from 17.84% to 23.91% and from 26.88% to 29.68% for FI and EI respectively.

Based on the findings in this thesis concluded that, the results of overall aggregate physical and mechanical properties pointed out that all Five quarry site crushed aggregates are within the standard specification limits and it is suitable for use in base course aggregate of asphalt pavement construction except three quarry site gradation requirements is failed.

Key words: *Asphalt pavement layers, Base course aggregate, Mechanical properties, Physical properties, Quarry site, Standards*

ACKNOWLEDGMENT

In The name of ALLAH, the Most Gracious, the Most Merciful. Praise be to God, the Cherisher and Sustainer of the Worlds. Peace and Mercy be upon our beloved Prophet MUHAMMAD (PBUH).

First of all, I grateful to ***ALLAH*** *for giving me the courage and determination, as well as guidance in conducting this thesis all difficulties.*

Secondly, I would like to acknowledge and send appreciation to my main advisor Dr. Zeinu Ahmed and co-advisor Eng. Mamaru Dessalegn (MSc) for their professional guidance, useful advice, continuous encouragement, and motivate support to make this thesis possible.

I would also like to thanks the minister of education and Jimma University, School of Graduate Studies, Jimma Institute of Technology, Civil Engineering Department, Construction Engineering and Management Stream.

Lastly, I would like to thanks my families (special to my lovely mother Rahmete Jemal).

May ALLAH bless you all. Amin…

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ABBREVIATIONS

AACRA	Addis Ababa City Road Authority
AASHTO	Association of American Society Highway and transportation officials
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
ASTM	American Society for Testing and Materials
BS	British Standard
BQSBCCA	Babu Quarry Site Base Course Crushed Aggregate
EI	Elongation Index
ERA	Ethiopian Road Authority
ERCC	Ethiopian Road Construction Cooperation
FI	Flakiness Index
FQSBCCA	Frustal Quarry Site Base Course Crushed Aggregate
Gsb	Bulk Dry Specific Gravity
Gsa	Apparent Specific Gravity
GQSBCCA	Geruke Quarry Site Base Course Crushed Aggregate
HMA	Hot Mix Asphalt
ISO	International Standard Organization
JQSBCCA	Jemila Quarry Site Base Course Crushed Aggregate
KQSBCCA	Kisho Quarry Site Base Course Crushed Aggregate
LAAV	Los Angeles Abrasion Value
NCHRP	National Cooperative High Research Program
PCC	Portland cement Concrete
SQSBCCA	Suse Quarry Site Base Course Crushed Aggregate
SG	Specific Gravity
SSD	Surface Saturated Dry
TFV	Ten percent Fine Value
WA	Water Absorption
WMQSBCCA	Welda Mikrbete Quarry Site Base Course Crushed Aggregate

CHAPTER ONE

INTRODUCTION

1.1 Background

According to (Canning & Bennathan, 2000) revealed that the road infrastructure developments were positively associated with economic growth. Generally, road infrastructure plays a crucial role by providing mobility for the efficient movements of people, goods and services as well as providing accessibility to land and a wide variety of commercial and social activities (Meyer & Miller, 2001). The provision of road infrastructure not only lower the physical barrier by stimulating the movements of people, goods (Motamed, Florax R J G M, & Masters, 2014) and services but also improve access to markets, social services and employment by reducing the overall transportation times and costs. The development or provision of high accessibility road infrastructure such as local road allow easy land access and promote commercial and social activities at local level (C P Ng, T H Law, F, & S, 2018).

The road network in Ethiopia provides the dominant mode of freight and passenger transport and thus plays a vital role in the economy of the country. The network comprises a huge national asset that requires adherence to appropriate standards for design, construction and maintenance in order to provide a high level of service. As the length of the road network is increasing, appropriate choice of methods to preserve this investment becomes increasingly important (ERA, 2013).

A road pavement is a structure of superimposed layers of selected and processed materials that are placed on the basement soil or subgrade. Flexible pavements constructed for heavy duty vehicles are composed of asphaltic layers, base course and sound sub base layer that laid over a well compacted and robust sub grade foundation. The most structural functions of a pavement are to support the wheel loads applied to the carriageway and ultimately distribute them to the underlying sub grade layer (Robel, 2006).

Base course is the principal structural part of the flexible pavement. It distributes the imposed wheel load to the pavement foundation, the sub base, and/or the subgrade. It should have adequate quality and thickness to stop failure within the subgrade and/or sub base, withstand the stresses made within the base itself, and resist vertical pressures that tend to produce consolidation and result in distortion of the surface course, and resist volume changes caused by fluctuations in its moisture content (Vinod, 2019).

Aggregate is a collective term for the mineral materials such as sand, gravel, and crushed stone that are used with a binding medium (such as water, bitumen, Portland cement, lime, etc.) to form compound materials (such as bituminous concrete and Portland cement concrete). By volume, aggregate generally accounts for 92 to 96 percent of Bituminous concrete and about 70 to 80 percent of Portland cement concrete (Ndukauba & Akaha, 2012). Aggregate is also used for base and sub-base courses for both flexible and rigid pavements. Aggregates can either be natural or manufactured. Natural aggregates are generally extracted from larger rock formations through an open excavation (quarry). Extracted rock is typically reduced to usable sizes by mechanical crushing. Manufactured aggregate is often a bye product of other manufacturing industries. Course aggregate is usually greater than 4.75 mm while fine aggregate is less than 4.75 mm (Tom, 2010).

The materials composing the base course are choose hard and durable aggregates. The standard of the base course is a performance of its physical and mechanical properties of the material (Vinod, 2019). Physical and Mechanical characteristics of the aggregate that governing load dissipating and particle-interlocking aspects differentiate “good” and “poor” quality aggregates with respect to the suitability for application in pavement base course (Saeed, Hall, & Barker, 2001), summarizes the most important tests that relate to the performance of aggregates in pavement base course: Among the tests highlighted, the screening tests (sieve analysis, flat and elongated particles), toughness and abrasion resistance tests (Los Angeles Abrasion Value), strength and porosity (specific gravity and water absorption) and strength (aggregate crushing value and aggregate impact value) are the most relevant for unbound aggregate pavement base course.

1.2 Statement of the Problem

The employment of substandard or low quality of base course aggregate have an effect on pavement performance (Hagos, 2006), He found that these materials might accelerate deterioration of the pavement and sometimes lead to rutting cracking, shoving, raveling, and aggregate abrasion, low skid resistance, low strength, shortened service life, or some combination of those issues. The base materials with high fines content area unit vulnerable to loss of strength and load supporting capability upon wetting (DOTSOF, 2002). However, substandard base materials usually lead to distress and may cause premature failure within the form of severe shrinkage cracking followed by accelerated fatigue cracking and a general loss of stability (Hudson, Monismith, Dougan, & Visser, 2003).

Selecting the correct aggregate is very important to beat the frequent problem of pavement failure. Within the numerous ways that during which aggregate is used, it's exposed to a variety of stresses, and also the response of the structure during which it's used will largely rely upon the properties of the aggregate. It needs to resist heavy loads, high impacts and severe abrasion, and it has to be durable within the prevailing environmental conditions. The performance of base course is deeply affected by aggregate properties because of the asphalt pavement has no longer service life & lower maintenance activities. These properties will be got to be tested and guaranteed before the road is constructed. (Ndukauba & Akaha, 2012).

Pavement failure of roads in Ethiopia is becoming a common problem and great challenge, consuming a lot of money, in some cases failure is appearing even before the completion of a project in certain road projects (Simeneh, 2012). Road failure of study area or Jimma city road could be in the forms of cracks, potholes, surface deformation, surface defects which make the road network unsafe and not suitable to the road users (Robel, 2006).

There was the reason to choose Jimma city as the Study area; that this research was conceded to find out the quality level of the base course aggregate of asphalt pavement construction material, especially in the case of base course crushed aggregate from different quarry.

1.3 Research Question

- ✓ What are physical properties of different quarry of crushed aggregate?
- ✓ What are mechanical properties of different quarry of crushed aggregate?
- ✓ Which was more suitable when compare to each quarry site aggregate for base course aggregate in pavement construction?

1.4 Objective of the Study

1.4.1 General Objective

The general objective of this research was to Investigate the suitability of different quarry sites crushed aggregate for base course aggregate of pavement construction in case of Jimma city.

1.4.2 Specific Objective

- ✓ To identify some physical properties of different quarry of crushed stone aggregates.
- ✓ To identify some mechanical properties of different quarry of crushed stone aggregates.
- ✓ To compare quarry site base course crushed aggregate found in Jimma city.

1.5 Scope of the Study

The scope of this research is limited to investigate the suitability of different quarry site of crushed course aggregate in Jimma city for base course of asphalt pavement construction at the laboratory some physical properties (those are Gradation, Specific gravity & Water Absorption, Elongation Index and Flakiness Index) and mechanical properties (those are Los Angeles Abrasion Value, Aggregate Crushing Value and Aggregate Impact Value) of aggregate and Compare to identify the best suitable base course aggregate.

1.6 Significance of the Study

This study could provide helpful information to various stake holders like the city Administration of Jimma will benefit from the study as a source of information and foundation for the road construction industry that can help to improve and control qualities of the base course aggregate regarding to standard and specifications. And also, for Owners, Contractors and Consultants will benefit from the study as a source of information for road construction projects, in case of Jimma city.

The findings of the study could be useful for anyone who has the interest stockholder in the utilization of the engineering properties of base course aggregate found in Jimma city. In addition, it would be helpful to pinpoint the location where different quarry site course aggregate as base course aggregate construction material with suitable physical and mechanical properties located. Concerned body can come up with appropriate measures to address problems resulting from using different types of crushed course aggregate on the strength and other researchers will use the findings as a reference for further research on physical and mechanical performance of crushed base course aggregate.

1.7 Limitation of the Study

The work was limited to the necessary laboratory cannot be available at one place and to be difficult to permit laboratory in different organization that needs to achieve the objectives. The major limitations of the study were lack of the necessary laboratory equipment (those were Specific gravity and water absorption, sieve for gradation and soundness testing materials) in the institution laboratory that enable the researcher to conduct the necessary pavement material tests.

CHAPTER TWO

LITERATURE REVIEW

2.1 Pavement

Roads area unit built up in several layers, consisting of sub-grade, sub-base, base and surface layer. These layers on represent the pavement. Pavements created from wise quality construction materials unfold the forces caused by the traffic so as that the lots exerted on to the road foundation is protected against overloading and deformation (Sisay, 2018).

Pavement is an engineering structure placed on natural soils and designed to face up to the traffic loading and therefore the action of the climate with smallest deterioration and within the most economical approach (Hudson, Monismith, Dougan, & Visser, 2003). Asphalt pavement roads are designed and created to serve the future traffic that reveal during the service lifetime of the road. Various factors taken in to account within the style and construction of versatile pavements embody the characteristics of the traffic, weather conditions, material additionally as structural properties and alternative parts that have important impact on the general performance of the road (Berhanu, 2009).

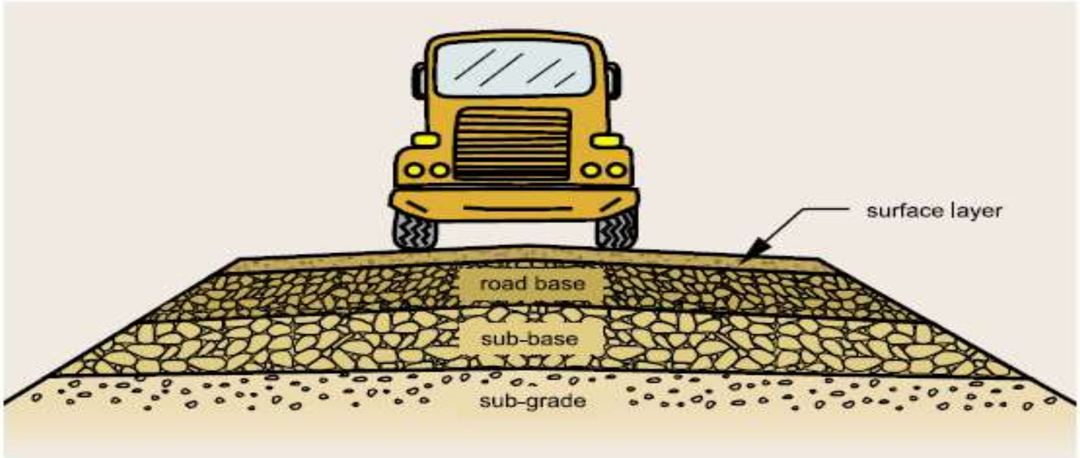


Figure 2.1 Asphalt Pavement layers (Suryakanta, 2019)

Different levels of traffic need specific acceptable designs. The pavement is often made from a large kind of materials and mixtures of materials consisting of gravel, stone, bitumen, concrete or improved soils. The selection of materials and thickness of the pavement layers area unit determined by the expected traffic density. Factors, like accessible budgets, the placement of the road and also the availableness of appropriate local materials are key parameters that additionally need careful consideration throughout the planning stage. Design of Pavement depends on the materials to be used and also the conditions that the pavement should meet.

2.1.1 Type of Payment

Pavements are usually divided into the subsequent two general categories those are flexible pavement and rigid pavement (Bikila, 2018).

2.1.1.1 Flexible (Bituminous) Pavement

A flexible pavement is made of many layers of natural granular material lined with one or a lot of waterproof hydrocarbon surface layers, and as the name imply, is taken into account to be flexible. A flexible pavement can flex (bend) beneath the load of a wheel. The target with the planning of a versatile pavement is to avoid the excessive flexing of any layer, failure to attain this can lead to the over stressing of a layer, that ultimately can cause the pavement to fail. In flexible pavements, the load distribution pattern changes from one layer to another (Yang, 2004), because the strength of every layer is totally different. The strongest material (least flexible) is within the top layer and therefore the weakest material (most flexible) is within the lowest layer. The reason for this can be that at the surface the wheel load is applied to a tiny low space, the result's high stress levels, deeper down within the pavement, the wheel load is applied to larger space, and therefore the result's lower stress levels therefore enabling the employment of weaker materials (Bikila, 2018).

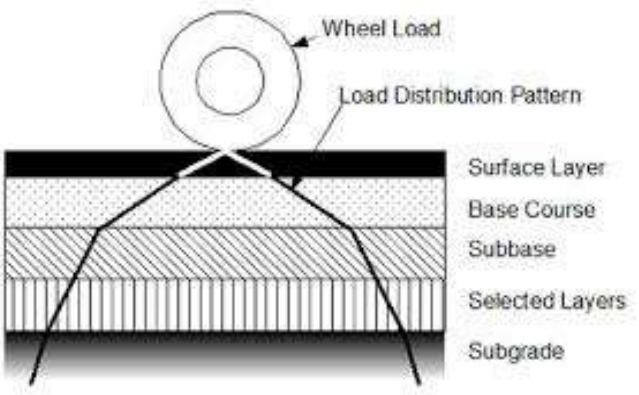


Figure 2.2: Load distribution of flexible pavement (SANRAL, 2019)

Type of Flexible pavement

A. Convention asphalt pavement

Conventional versatile pavements square measure multi-layered structures with higher materials on top wherever the intensity of stress is high and inferior materials at the bottom wherever the intensity is low. This design principle makes attainable to use native materials and usually leads to a most economical design. Starting from the top, a conventional flexible pavement usually consists of surface course, base course, sub base course, compacted subgrade, and natural subgrade. The employment of the assorted courses is based on either necessity or economy and a few of the courses could also be omitted (ASHEBIR, 2016).

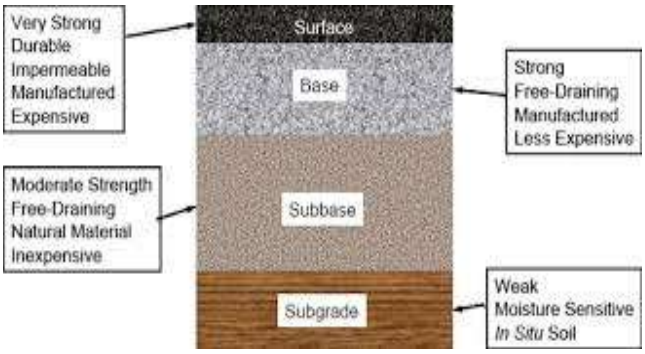


Figure 2.3: Conventional asphalt pavement (FHA, 2019)

In comparison to concrete (rigid) pavement, asphalt pavement usually includes a similar service life before needing rehabilitation and tends to be a lot of liable to wet issues. However, asphalt pavement will offer a quieter and smoother surface and might be a lot of simply repaired as compared with concrete pavement. Standard asphalt pavements will be used for many applications wherever different pavement varieties may be used (Pavement Interactive, 2019).

B. Full depth hot-mix asphalt (HMA)

Full-depth hot-mix asphalt (HMA) pavement has been used on Michigan county roads with low-volume traffic. There are considerations concerning frost protection since it's directly built on subgrade. Additionally, the term full-depth HMA to explain its reconstruction design of three courses of HMA over aggregate base and sand sub base.

Full-depth HMA pavement is “a flexible pavement structure that uses HMA throughout the whole thickness (binder course and surface course layers)” (IDOTBODE, 2016)

Figure 2. 4: Cross section of full-depth HMA pavement (Changjiang, et al., 2017)

Full-depth HMA pavement is implemented on low-volume local roads furthermore as high-volume interstates. The design service life will vary from ten to Twenty-five years. A surface treatment for the wearing surface could also be integrated into the system if required thanks to the traffic loads. (Zhanping, 2018).

2.1.1.2 Rigid (Concrete) Pavement

Rigid pavements are composed of a PCC surface course. Such pavements are considerably "stiffer" than flexible pavements because of the high modulus of elasticity of the PCC material. Further, these pavements will have reinforcing steel, that is mostly accustomed cut back or eliminate joints. The enhanced rigidity of concrete permits the concrete surface layer to bridge small weak areas within the supporting layer through what's called beam action. This permits the location of rigid pavements on comparatively weak supporting layers, as long because the supporting layer material particles won't be carried away by water forced up by the pumping action of wheel loads (Bikila, 2018).

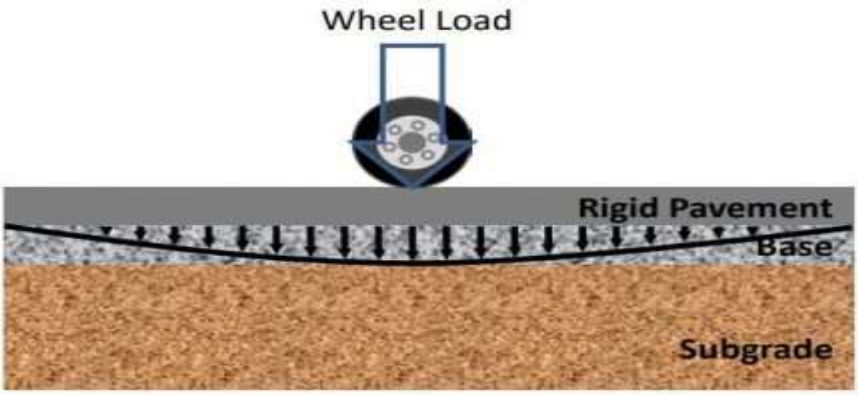


Figure 2. 5: Load distribution of rigid pavement (Sadanandam, 2019)

2.1.2 Pavement Layers

2.1.2.1 Subgrade

Subgrade is that the foundation on that the vehicle load and also the weight of the pavement layers finally rests. It's an in situ or a layer of chosen material compacted to the fascinating density close to the optimum moisture content. it's graded into a correct shape, properly drained, and compacted to receive the pavement layers.

The foundation consists of the native subgrade soil and also the layer of graded stone immediately overlaying it. The function of the sub base and capping is to supply a platform on that to place the road base material additionally on insulate the subgrade below it against the consequences of inclement weather. These layers could form the temporary road surface used throughout the construction phase of the road. (Martin, 2003).

2.1.2.2 Sub base

The sub base course is that the portion of the flexible pavement structure between the roadbed soil and also the base course. It always consists of a compacted layer of granular material, either treated or untreated, or of a layer of soil treated with an acceptable admixture. Additionally, to its position within the pavement, it's usually distinguished from the base course material by less stringent specification requirements for strength, plasticity and gradation. The sub base material ought to be of considerably higher quality than the roadbed soil. For reasons of economy, the sub base is usually omitted if roadbed soils are of high quality (AASHTO, 1993).

Figure 2. 6: Sub Base course layer (Umesh, 2019)

The sub-base is a vital load spreading layer within the completed pavement. It allows traffic stresses to be reduced to acceptable levels within the subgrade, it acts as a working platform for the construction of the upper pavement layers and it acts as a separation layer between subgrade and base course. Underneath special circumstances, it should additionally act as a filter or as a drainage layer. In wet climate, the foremost stringent requirements are set by the necessity to support construction traffic and paving equipment. In these circumstances, the sub-base material needs to be more tightly specified. In dry climate, in areas of good drainage (ERA, 2013).

2.1.2.3 Base course

The base course is that the layer of material directly beneath the surface course. It may be composed of well-graded crushed stone (unbounded), granular material mixed with binder, or stable materials. It the main structural a part of the pavement and provides A level surface for laying the surface layer. If constructed directly over the subgrade, it prevents intrusions of the fine subgrade soils into the pavement structure.

Figure 2. 7: Base course layer (Umesh, 2019)

2.1.2.4 Surface course

The surfacing combines good riding quality with adequate skidding resistance, whereas also minimizing the chance of water infiltrating the pavement with consequent surface cracks. Texture and sturdiness square measure very important requirements of a good pavement surface as are surface regularity and flexibility (Martin, 2003).

The surface course of a flexible structure consists of a mix of mineral aggregates and bituminous materials placed because the upper course and usually constructed on a base course. Additionally, to its major function as a structural portion of the pavement, it should even be designed to resist the abrasive forces of traffic, to cut back the number of surface water penetrating the pavement, to produce a skid resistance surface, and to produce a sleek and uniform riding surface. The success of a surface course depends to a degree on getting a mix with the optimum gradation of aggregate and percent of bituminous binder to be durable and to resist fracture and raveling while not changing into unstable below expected traffic and weather conditions (AASHTO, 1993).

2.2 Base Course Aggregate

The base course is that the portion of the pavement structure straightaway below the surface course. It's constructed on the sub base course, or, if no sub base is employed, directly on the roadbed soil. Its major function within the pavement is load spreading. It always consists of aggregates like crushed stone, crushed slag, crushed gravel and sand, or mixtures of those materials. It should be used untreated or treated with appropriate stabilizing admixtures, like Portland cement, & asphalt, lime, cement-fly ash and lime-fly ash, i.e., pozzolanic stabilized bases. Specifications for base course materials are usually significantly a lot of stringent than for sub base materials in needs for strength, plasticity, and gradation (AASHTO, 1993).

A wide range of materials will be used as unbound base course together with crushed quarried rock, crushed and screened, mechanically stable, modified or naturally occurring "as dug" or "pit run" gravels. Their suitableness to be used depends primarily on the design traffic level of the pavement and climate. However, all base course materials should have a particle size distribution and particle shape which give high mechanical stability and will contain adequate fines (amount of material passing the 0.425 Millimeter sieve) to provide a dense material once compacted. In circumstances wherever many appropriate types of base course materials are available, the final selection should take under consideration the expected level of future maintenance and also the total prices over the expected lifetime of the pavement (ERA, 2013).

Crushed rock consists of rock fragments produced by the crushing and screening of igneous, metamorphic or sedimentary source rock that conforms to specification needs that supply rock for the assembly of stone and aggregates, with or while not additions, produced in a very controlled manner to attain standards for grading, plasticity etc. (Main Roads Western Australia, 2006).

Aggregate refers generally to granular materials like sand and gravel that are employed in pavement construction. Employed by themselves, aggregates are usually used as a base course, sub base, or mound beneath the surface layer. These layers rest directly on the subgrade (the native soil or fill material on that the pavement structure is built) and supply extra support to the structure. Once mixed with asphalt binder or cement concrete (PCC), aggregates are a significant component of pavement surface layers as well. Aggregate base layers are regularly used in both asphalt and PCC pavements and serve a variety of functions. Since subgrade soils may be soft and unstable, an aggregate base often helps ensure the stability of the pavement surface. This includes providing a working platform for paving activity, since equipment operations could lead to rutting and areas of weakness in the subgrade (Yang, 2004).

For asphalt pavements, mixture bases area unit vital structural parts and facilitate distribute load stresses through the total depth of the pavement. In PCC pavements, associate degree mixture base serves primarily to supply the required uniform support conditions for the concrete slabs. Unbound mixture base layers may be used for evacuation functions, since the very fact that they're not certain with asphalt or cement permits water to withstand gaps within the mixture. In colder climates, mixture bases conjointly facilitate to insulate the pavement surface from freeze/thaw cycles (Vinod, 2019).

2.2.1 Function of Base Course Aggregate

Compacted aggregates while not the addition of a cementing material could also be used as a base or sub base for hot mix asphalt and Portland cement concrete pavements. Portland cement concrete pavements are rigid pavements. For these types of pavements, the aim of the base could also be to enhance drainage, to stop pumping, or to cover a material that's extremely at risk of frost. Consequently, gradation and soundness are the first concerns in choosing or evaluating aggregates for bases under rigid pavements. The load-carrying capability could be a primary factor in the choice of aggregates for hot mix asphalt pavements. A hot mix asphalt pavement doesn't carry the load; facilitate from the underlying base course is needed. Additionally, to gradating requirements, the aggregates are required to additionally possess the strength to hold and transmit the applied loads. Aggregates are sometimes used to form up the whole pavement structure. During this kind of pavement, aggregates are placed on the natural soil to serve as a base course and surface course. When a road is constructed, there’s additional to that than simply what you see on the surface. The pavement doesn’t merely get placed with nothing underneath; it must have a robust foundation so as to perform well. A crucial a part of that's having a properly designed and made base layer. Associate degree mixture base is also hidden from sight when the pavement is completed, however it remains an essential a part of the pavement structure. Unbound aggregate base layers need good materials, correct design, and quality construction practices. Building the foundation, the proper method can facilitate the whole pavement perform properly (Pavement Interactive, 2019).

The base course is found next to the surface and provides most of the load carrying capabilities of the pavement. Its principle purpose is to provide sufficient wrap to limit the stresses and strains of wheel loading in order that unacceptable failure and deformation don't come about. It may be composed of one or a lot of kinds of materials, natural gravel, fine crushed rock, broken stone and modified soil. A base course is outlined as the layer of material that lies forthwith below the wearing surface of a pavement, and also the sub base is a layer of material between the base and subgrade (Nikraz, 2004).

2.2.2 Source of Base Course Aggregate

Natural aggregate materials embrace a range of rocks and minerals that may be excavated from quarries or mines. Geologically, these materials may be categorized as one of three types (Pavement Interactive, 2019):

- ✓ *Sedimentary rocks*- rock and other rocks created by sedimentary deposits.
- ✓ *Igneous rocks*- granite and other rocks created by cooling volcanic or liquefied rock material.
- ✓ *Metamorphic rocks*- sedimentary or igneous rocks that are subjected to enough heat and/or pressure to change their mineral structure.

2.2.3 Properties of base course aggregate

Aggregate is a collective term for the mineral materials like sand, gravel, and crushed stone that are used with a binding medium (such as water, bitumen, Portland cement, lime, etc.) to create compound materials (such as bituminous concrete and Portland cement concrete). By volume, aggregate typically accounts for Ninety-two to Ninety six-percent of bituminous concrete and regarding seventy to eighty percent of Portland cement concrete (Ermias, 2014). Aggregate is additionally used for base and subbase courses for each flexible and rigid pavement. Aggregates will either be natural or factory-made. Natural aggregates are typically extracted from larger rock formations through associate open excavation (quarry). Extracted rock is often reduced to usable sizes by mechanical crushing. Factory-made aggregate is commonly a bye product of alternative producing industries (Tom, 2010).

A number of material properties and characteristics have an effect on the performance of an aggregate base layer. Recognition of those properties and characteristics assists the Technician in evaluating the various aggregates employed in road construction. Aggregate particles have bound physical and mechanical properties that create the aggregate acceptable or unacceptable for specific uses and conditions (ASHEBIR, 2016).

2.2.3.1 Physical properties of base course aggregate

The physical properties of aggregates are those that refer to the physical structure of the particles that make up the aggregate.

I. Absorption, porosity and permeability

The internal pore characteristics are important properties of aggregates. The size, the number, and also the continuity of the pores through an aggregate particle might have an effect on the strength of the aggregate, abrasion resistance, and surface texture, relative density, bonding capabilities, and resistance to freeze and thawing action. Absorption relates to the particle's ability to require in a very liquid. Porosity could be a ratio of the volume of the pores to the entire volume of the particle. Permeable refers to the particle's ability to permit liquids to pass through. If the rock pores are not connected, a rock might have high porosity and low permeability.

II. Specific gravity and Density

The specific gravity of an aggregate is to be a measure of strength or quality of the material. The load per unit of volume of a substance makes the density whereas specific gravity is that the ratio of the density of the substance to the density of water. The density additionally the specific gravity of an aggregate particle relies upon the density and specific gravity of the minerals creating up the particle and also on how porous the particle is.

III. Shape of particles

The best aggregates to use for strength are crushed stone or crushed gravel. Crushed aggregate has irregular, angular particles that tend to interlock once compacted or consolidated. The crushed stone or crushed gravel aggregate build the asphalt or concrete mix somewhat troublesome to place. To enhance the workability, several mixes contain each angular and spherical particle. The course aggregate particles are usually crushed stone or crushed gravel, and also the fine aggregate particles are usually natural sand. The quality Specifications detail the wants for crushed materials for numerous uses.

IV. Grain size

The maximum size of an aggregate designates the smallest sieve through that 100% of the material can pass. The nominal maximum size is that the largest size upon that any of the aggregate material is (or is permissible to be) retained. Aggregates are described as their gradation. Some examples are dense-graded or well graded, open-graded, one sized, course graded and gap-graded (AACRA, 2003).

V. Free from deleterious

Specifications for aggregates employed in bituminous mixes usually need the aggregates to be clean, tough and durable in nature and free from excess quantity of flat or elongated pieces, dust, clay balls and other objectionable material. Similarly aggregates employed in Portland cement concrete mixes should be clean and free from deleterious substances like clay lumps, chert, silt and different organic impurities.

2.2.3.2 Mechanical properties of base course aggregate

I. Strength and elasticity

Strength is a measure of the ability of an aggregate particle to face up to pulling or crushing forces. Elasticity measures the "stretch" in a particle. High strength and elasticity are desirable in aggregate base course aggregate and surface courses. These qualities minimize the rate of disintegration and maximize the stability of the compacted material (Ermias, 2014).

II. Hardness of aggregate

Some aggregate is subject to additional crushing and abrasive wear during manufacture, placing, and compaction of asphalt paving mixes. Aggregates are also subject to an abrasion under traffic loads. They must exhibit, to a certain degree, an ability to resist crushing, degradation, and disintegration. Aggregates at or near the pavement surface requires greater toughness than aggregate in the lower layers where loads have dissipated or are not concentrated. The Los Angeles Abrasion test measures wear or abrasion resistance of mineral aggregate. (AASHTO T 96) Relatively high resistance to wear, as indicated by a low percent of abrasion loss, is a desirable characteristic of aggregates to be used in asphalt pavement surface layers. Aggregates having higher abrasion losses, within limits, may generally be used in lower pavement layers where they will not be subject to the high stress caused by traffic (AACRA, 2003).

III. Toughness

Resistance of the aggregates to impact is termed as toughness. Aggregates used in the pavement should be able to resist the effect caused by the jumping of the steel tire wheels from one particle to another at different levels causes' severe impact on the aggregates.

IV. Durability

The property of aggregates to withstand adverse action of weather is called soundness. The aggregates are subjected to the physical and chemical action of rain and bottom water, impurities there-in and that of atmosphere, hence it is desirable that the road aggregates used in the construction should be sound enough to withstand the weathering action.

2.2.4 Tests of Base Course Aggregates

Aggregate constitutes the basic material for road construction and is quarried in the same way as aggregate for concrete. Because it forms the greater part of a road surface, aggregate has to bear the main stresses imposed by traffic, such as slow-crushing loads and rapid-impact loads, and has to resist wear. Therefore, the rock material used should be fresh and have high strength (F.G, 2007).

Aggregates are obtained from different sources and consequently differ considerably in their constitutions; inevitably they differ also with regard to their physical and mechanical properties. The properties of aggregate that are important for road construction include its cleanliness (contamination with dust and other deleterious materials), particle size and shape, gradation, toughness resistance to crushing, absorbability wearing/abrasion resistance, durability or soundness, specific gravity and water absorption, surface texture, tendency to polish, bonding property with bitumen. Aggregate tests are necessary to determine the suitability of the material for a specific use and to make sure that the required properties are consistently within specification limits. The following sub-sections discuss important tests of aggregates and their significance of application (AASHTO, 2001)**.**

Aggregate used as road material must, in addition to having high strength, have high resistance to impact and abrasion, polishing and skidding, and frost action. It must also be impermeable, chemically inert and possess a low coefficient of expansion. The principal tests carried out in order to assess the value of a road stone are the aggregate crushing test, the aggregate impact test, the aggregate abrasion test and the test for the assessment of the polished stone value. Other tests of consequence are those for water absorption, specific gravity and density, and the aggregate shape tests (Anon, 1975).

2.2.4.1 Physical properties of base course crushed aggregate tests

I. Specific Gravity and Water Absorption test

Specific gravity is a measure of a material's density (mass per unit volume) as compared to the density of water at 73.4°F (23°C). Therefore, by definition, water at a temperature of 73.4°F (23°C) has a specific gravity of 1. It is also a measure of the amount of water that an aggregate can absorb into its pore structure. Pores that absorb water are also referred to as "water permeable voids".

Specific gravity can also indicate possible material contamination. For instance, deleterious particles are often lighter than aggregate particles and therefore, a large amount of deleterious material in an aggregate sample may result in an abnormally low specific gravity. Differences in specific gravity can also be used to separate deleterious, or bad, particles from aggregate particles using a heavy media liquid. Water absorption can also be an indicator of asphalt absorption.

Finally, specific gravity differences can be used to indicate a possible material change. A change in aggregate mineral or physical properties can result in a change in specific gravity. For instance, if a quarry operation constantly monitors the specific gravity of its output aggregate, a change in specific gravity beyond that normally expected could indicate the quarrying has moved into a new rock formation with significantly different mineral or physical properties according to AASHTO T 85 and BS EN 1097-6. (AASHTO, 2001).

II. Particle Size

Gradation test: Gradation is the characteristic of aggregates on which perhaps the greatest stress is placed in specifications for highway bases, cement concretes, and asphalt mixes. Hence, gradation test, also called sieve analysis, screen analysis or mechanical analysis, is the most common test performed on aggregates to evaluate the suitability of the aggregate materials with respect to their grain size distribution for a specific use. Gradation is determined by separating the aggregates into portions, which are retained on a number of sieves or screens having specified openings, which are suitably graded from course aggregate to fine.

The combined grading of the material shall be a smooth continuous curve falling within the grading. The particle-size distribution in a sample of aggregate, referred to as the grading, is generally expressed in terms of the cumulative percentage of particles passing (or retained on) a specific series of sieves. These distributions are most commonly shown graphically as grading curves (Tom, 2010).

III. Particle Shapes Tests

Mechanical measures of particle shape which may be included in the specifications for aggregates for road construction, are the flakiness index and elongation index.

Use of the shape tests in specifications is based on the view that the shapes of the particles influence both the strength of aggregate particles and internal friction that can be developed in the aggregate mass.

2.2.4.2 Mechanical properties of base course crashed aggregate tests

I. Los Angeles Abrasion Value Test (LAAV)

Abrasion test is the test used to know how the aggregate is sufficiently hard to resist the abrasive effect of traffic over its service life. The most widely used abrasion test is the Los Angeles Abrasion Test which involves the use of a steel drum, revolving on horizontal axis, into which the test sample of chippings is loaded together with steel balls of 46.8 mm diameter. The Los Angeles Abrasion Value (LAAV) is the percentage of fines passing the 1.7 mm sieve after a specified number of revolutions of the drum at specified speed.

The drum is fitted with internal baffles causing the aggregate and the steel balls to be lifted and then fall as the drum revolves. The test therefore gives an indication of the impact strength in combination with the abrasion resistance of the aggregate. For bituminous surface dressings, chippings with an ACV less than thirty are desirable and the stronger they are the more durable will be the dressings. With premixed bituminous materials and with crushed stone bases, high mechanical strength, though useful, is not always of paramount importance. The repeatability and reproducibility of this test are satisfactory and appropriate for use in contract specifications according to AASHTO T 96-94, ASTM C 131-89 and BS 812-113:1990.

II. Aggregate Crushing Value Test (ACV)

Aggregate crushing test evaluates the resistance of aggregates against the gradually applied load. The test is used to evaluate the crushing strength of available supplies of rock, and in construction, to make sure that minimum specified values are maintained. The test is undertaken using a metal plunger to apply gradually a standard 40 tones load to a sample of the aggregate (10 – 14 mm) contained in a standard test mould. The amount of material passing 2.36 mm sieve in percentage of the total weight of the sample is referred to as the Aggregate Crushing value (ACV). Over the range of normal road making aggregates, ACVs vary from 5 percent for hard aggregates to 30 percent for weaker aggregates. For weaker aggregates than this, the same apparatus is used to evaluate the Ten Percent Fines value i.e. the load which produces 10 percent of fines passing 2.36 mm sieve. The value is obtained by interpolating of the percentage of fines produced over a range of test loads according to BS 812: Part 110:1990.

The strength of course aggregate may be measured by the Aggregate Crushing Value and thus the objective of the test is to determine ACV.

III. Aggregate impact value test (AIV)

This test is a means of evaluating the resistance of aggregates to sudden impact loading. It is carried out by filling a steel test mould with a sample of aggregate (10 – 14 mm) and then the impact load applied is by dropping hammer at a height of 380 mm. The

Aggregate Impact Value (AIV) is the percentage of fines passing 2.36 mm sieve after 15 blows. This test produces results that are normally about 105 per cent of the ACV and it can be used for the same purposes. Both tests give results which re sufficiently repeatable and reproducible for contract specifications according to BS 812: Part 112.

2.3 Standards

2.3.1 National Standard

Ethiopian Road Authority (ERA)

ERA stand for Ethiopia Roads Authority. It is the Standard Technical Specification prepared for the use and technical guidance of design personnel of the Ethiopian Roads Authority and consultants drafting specifications for the Authority. However, it may also be used as a guide by other agencies undertaking relevant work in the road sector.

Specification has particular reference to the prevailing conditions in Ethiopia and reflects ERA’s experience gained through activities within the road sector during the last 50 years.

The Ethiopian Roads Authority (ERA) is responsible for managing, maintaining and developing the national road network across Ethiopia to support economic development, growth and poverty reduction.

2.3.2 International Standards

I. American Association of State Highway and Transportation Officials (AASHTO)

AASHTO means American Association of State Highway and Transportation Officials. It is a standard setting body which publishes specifications, quality control protocols and guidelines which are used in highway design and construction throughout the United States. Despite its name, the association represents not only highways but air, rail, water, and public transportation as well.

Though AASHTO is not a government body, it possesses quasigovernmental powers in the sense that the organizations that supply its members customarily obey most AASHTO decisions. Besides its publications, AASHTO performs or cooperates in research projects (wikipedia, 2019).

AASHTO is an international leader in setting technical standards for all phases of highway system development. Standards are issued for design, construction of highways and bridges, materials, and many other technical areas.

AASHTO serves as a catalyst for excellence in transportation by offering smart solutions and promising practices; critical information, training and data; direct technical assistance to states; and unchallenged expertise.

II. American Society for Testing and Materials (ASTM)

ASTM International, formerly known as American Society for Testing and Materials, is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services.

A test method standard has a short and informative description of a procedure to determine a property or constituent of a material, a collection of materials or a product. To achieve satisfactory precision, the test method should include details about test apparatus, test specimen, test procedure and calculations of data obtained from the test (Media, 2019).

III. British standard

BSI defines a standard as 'something that is generally accepted'. British Standard (BS) publications are technical specifications or practices that can be used as guidance for the production of a product, carrying out a process or providing a service.

The BSI Kite mark, first introduced in 1903, is commonly found on a range of products, including construction products. It indicates that the product has been independently tested by BSI to confirm that it complies with relevant British Standards (Design, 2019).

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 Study Area

The research carried out at Jimma city, situated in south-western Ethiopia, formerly found under Region Oromia administrative zone. It has a latitude and longitude of 7°40′N36°50′E. It features a long annual season from March to October. Temperatures with the daily mean staying between 20°C and 25°C year-round and the average rainfall is 5mm.

The present study was conducted in five quarry site found in Jimma city: namely, Jemila quarry site base course crushed aggregate (JQSBCCA), Frustal quarry site base course crushed aggregate (FQSBCCA), Geruke quarry site base course crushed aggregate (GQSBCCA), Welda Mikrbete quarry site base course crushed aggregate (WMQSBCCA), and Kisho quarry site base course crushed aggregate (KQSBCCA).

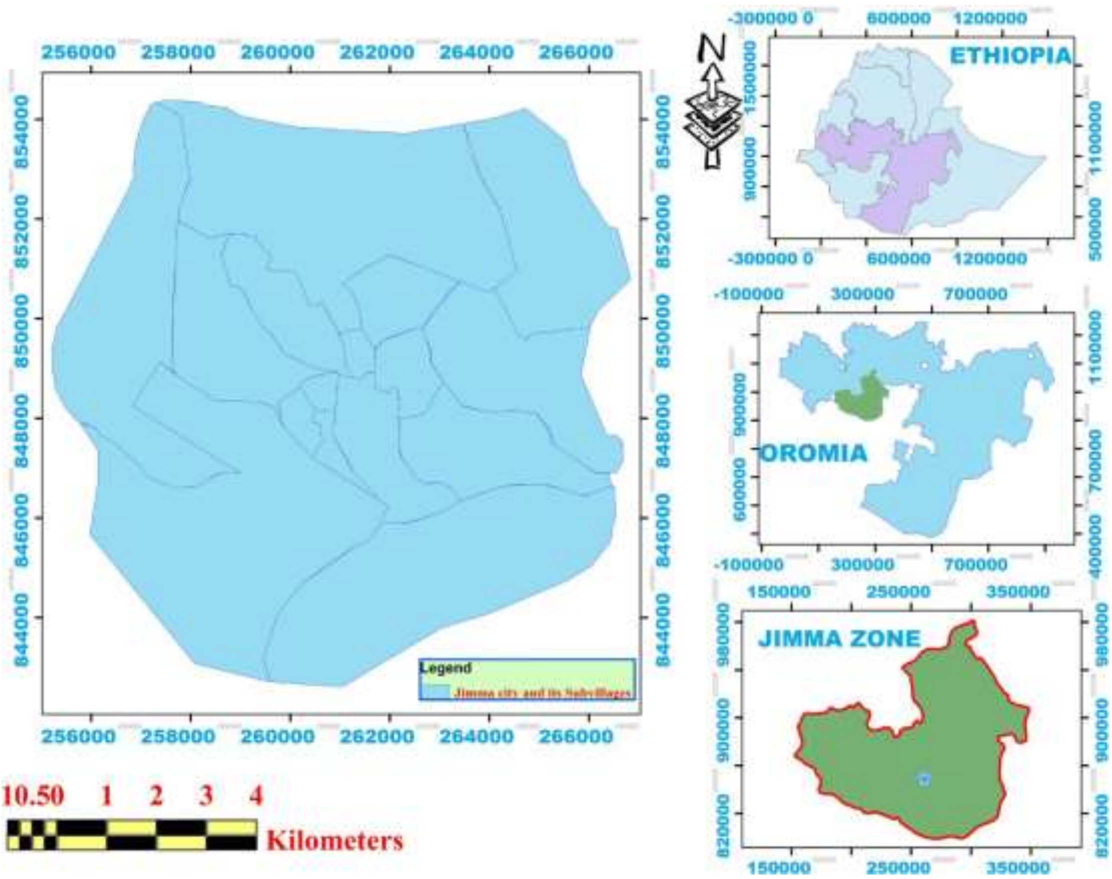


Figure 3. 1: Study area Jimma city, Oromia, Ethiopia (www.googlemap.com)

3.2 Materials

The research was to investigate suitability of different quarry site course aggregate for base course aggregate of asphalt pavement construction in case of Jimma city. For this study five quarries crushed course aggregates were used. Table 3.1, below shows locations of aggregates that were tested for aggregate Physical and Mechanical properties tests.

Table 3-1: location and source of aggregate

No.	Quarry site	Location	Quantity	Sample ID	Date
1	Jemila (Kolbo) aggregate production	Beda Buna	70 Kg	KQSBCCA	1/11/2019
2	Frustale aggregate production	Frustal	70 Kg	FQSBCCA	1/11/2019
3	Geruke aggregate production	Addisu Kera (Gede Lulesa)	70 Kg	GQSBCCA	1/11/2019
4	Welda Mikrbete aggregate crushing quarry	Kito Furdsa	70 Kg	WMQSBCCA	2/11/2019
5	Kisho aggregate production	Kito Furdsa	70 Kg	GQSBCCA	2/11/2019

Figure 3. 2: Quarry site material collecting

3.3 Research Design

To investigate suitability of different quarry site course aggregate for base course aggregate of asphalt pavement construction in case of Jimma city, reviewed related literatures on relevant areas of asphalt pavement layer of base course and their properties, which includes articles, reference books, research papers, class lecture notes, standards specifications like ERA, AASHTO, ASTM and BS. Then test results of base course aggregate samples were collected at Jimma Institute of Technology highway engineering Laboratory and Testing center. Collected data consists, test results of five different quarry site crushed aggregate with total of 3.5 quintals sample.

The Aggregate collected from their source and tested to determine its physical and mechanical properties. The tests were carried out by the appropriate ASTM, AASHTO, BS and ERA were applicable. With this understanding, the requirements of the properties of crushed base course aggregate for specific application and performance of base course layer. This would allow for a performance approach to classification of crushed base course aggregates of different quarries and also used for comparison between crushed aggregate of different quarry Sites with by the appropriate standards. And finally, Compare the result of each quarry site with standards use for base course aggregate in asphalt pavement and recommended based upon outputs.

3.4 Study Variables

3.4.1 Dependent Variable

- ✓ Suitability of different quarry site crushed aggregates for base course aggregate in asphalt pavement construction.

3.4.2 Independent Variables

- ✓ Physical properties of base course crushed aggregates
- ✓ Mechanical properties of base course crushed aggregates

3.5 Sampling Procedure

Sampling for each quarry site of course aggregate according to AASHTO T-2 the filed sample were taken 70 kilo gram per source of aggregate and also reduced to test sample with compliance of AASHTO T-248. All aggregate quality tests result was shown in appendix A.

3.6 Data Collection Process

In order to attain the purpose of this research work ethical considerations was concentrating on the context of quantitative and qualitative research. Before starting any data collection formal letter was obtained from Jimma Institution of Technology department of construction Engineering and Management chairman. Before the collection of the data, the purpose of the data collection was clearly described to the organizations by the data collectors and the principal investigator. The data collection was kept confidential and used only for the research purpose. The total primary research data were collected by conducting laboratory test. The laboratory test result was quantitative and the analysis of the research is both quantitative as well as qualitative data types would have been employed.

3.7 Data Analysis

Quantitative data obtained from test results and were analyzed according to the standard specifications. Microsoft office Excel used for analysis of laboratory data. Among the systematic analysis method, this particular research obtain result was employed percentage, tabulation & graphs as required and discussion format to achieve the objectives of this study. The manuals used were AASHTO, ERA, BS and ASTM.

3.8 Experimental Work Procedures of Aggregate

3.8.1 Physical Properties

The following test methods are used to determine the physical properties of crushed stone aggregate from different quarries.

3.8.1.1 Grading Analysis

Particle gradation was conducted according to AASHTO T-27. Since the objective of this study was to evaluate the suitability of different quarry site aggregate for base course aggregate of asphalt pavement construction, in order to eliminate the effect of gradation on the material properties.

This was done to determine the percentage particle size distribution of a given sample of different quarry crushed aggregate. Dry sieving analysis was performed. This procedure is suitable for base course aggregate. This test aimed at determining the particle size distribution or gradation of the aggregate used. This was presented in form of table and graph plotted on grading chart.

*Graded crushed stone***,** this material is produced by crushing fresh, quarried rock and the material may be separated by screening and recombined to produce a desired particle size distribution, as per the specifications. Alternate gradation limits, depending on the local conditions for a particular project (ERA, 2013).

Table 3-2: Grading limits for graded base course materials (ERA, 2013)

Test sieve (mm)	Percentage by mass of total aggregate passing test sieve		
	Nominal maximum particles size		
	37.5 mm	28 mm	20 mm
50	100	-	-
37.5	95-100	100	-
28	-	-	100
20	60-80	70-85	90-100
10	40-60	50-65	60-75
5	25-40	35-55	40-60
2.26	15-30	25-40	30-45
0.425	7-19	12-24	13-27
0.075	5-12	5-12	5-12

Figure 3. 3: Determination of grading

3.8.1.2 Specific Gravity and Water Absorption

Specific gravity is the ratio of the mass (or weight in air) of a unit volume of material to the mass of the same volume of water at the stated temperature to the weight in air of an equal volume of gas-free distilled water at the same temperature. The specific gravity may be expressed as dry bulk specific gravity, saturated bulk specific gravity SSD or apparent specific gravity. The water Absorption is the increase in the mass of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass. The aggregate is considered dry when it has been maintained at 105°c plus or minus 5°c for sufficient time to remove all. The bulk specific gravity and absorption are based on aggregate after 24 hours soaking in water as described in AASHTO T-85.

Specific Gravity is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. Water, at a temperature of 73.4°F (23°C). Specific Gravity is important for several reasons. Some deleterious particles are lighter than the good aggregates. Tracking specific gravity can sometimes indicate a change of material or possible contamination. A change in aggregate mineral or physical properties can result in a change in specific gravity. Differences in specific gravity may be used during production to separate the deleterious particles from the good.

Absorption: The increase in weight due to water contained in the pores of the material.

Bulk Specific Gravity (Bulk Dry Specific Gravity): The ratio of the weight in air of a unit volume of aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at the stated temperature.

Bulk SSD Specific Gravity: The ratio of the weight in air of a unit volume of aggregate, including the weight of water within the voids filled to the extent achieved by submerging in water for approximately 24 hours, to the weight in air of an equal volume of gas-free distilled water at the stated temperature.

Apparent specific gravity: the ratio of the weight in air of unit volume of the impermeable portion of aggregate at stated temperature to the weight in air of an equal volume of gas free distilled water at stated temperature.

Saturated Surface Dry (SSD): The condition in which the aggregate has been soaked in water and has absorbed water into its pore spaces. The excess, free surface moisture has been removed so that the particles are still saturated, but the surface of the particle is essentially dry.

Specific Gravity is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. Water, at a temperature of 73.4°F (23°C). Specific Gravity is important for several reasons. Some deleterious particles are lighter than the good aggregates. Tracking specific gravity can sometimes indicate a change of material or possible contamination. Differences in specific gravity may be used during production to separate the deleterious particles from the good.

Specific gravity (dry weight of aggregate/weight of equal volume of water)

$$\textbf{Specific gravity (Gsb)} = \frac{\mathbf{A}}{\mathbf{B - C}}$$

Specific gravity on saturated and surface dry

$$\textbf{Specific gravity (SSD)} = \frac{\mathbf{B}}{\mathbf{B - C}}$$

Apparent specific gravity (dry weight of aggregate/weight of equal volume of water excluding air voids in aggregates)

$$\textbf{Apparent Specific gravity} = \frac{\mathbf{A}}{\mathbf{A - C}}$$

Water absorption (%)

$$\textbf{Water Absorption} = \left[\frac{\mathbf{B - A}}{\mathbf{A}}\right] * \mathbf{100\%}$$

Where, A is Oven dry mass of aggregate

B is SSD (surface saturated mass) of aggregate

C is Mass of aggregate in water

Figure 3. 4: Determination of specific gravity and water absorption

3.8.1.3 Shape and Texture

Mechanical measures of particle shape which may be included in the specifications for aggregates for road construction are the Flakiness index & Elongation index.

Use of the shape tests in specifications is based on the view that the shapes of the particles influence both the strength of aggregate particles and internal friction that can be developed in the aggregate mass. Since, other factors being equal, an aggregate composed of smooth rounded particles of a certain gradation will contain less voids than one of the same grading.

3.8.1.3.1 Flakiness Index (FI)

Aggregate particles are classified as flaky when they have a thickness of less than 0.6 of their mean sieve sizes, this size being taken as the mean of the limiting sieve apertures used for determining the size fraction in which the particle occurs. The flakiness index of an aggregate sample is found by separation the flaky particles and expressing their mass as a percentage of the mass of the sample tested. The test is not applicable to material passing a 6.30mm test sieve or retained on a 63.0mm test sieve.

The flakiness index shall not exceed 30% when determined in accordance with BS 812 Part105-1990 but according to ERA not more than 45%. Flakiness Index is one of the tests used to classify aggregates and stones. In Pavement Design there are specific requirements regarding the Flakiness Index of materials.

For base course and wearing course aggregates, the presence of flaky particles is considered undesirable as they may cause inherent weakness with possibilities of breaking down under heavy loads. The Flakiness Index of an aggregate sample is found by separating the flaky particles and expressing their mass as a percentage of the mass of the sample. The value of the Flakiness Index is calculated from the expression:

$$\boldsymbol{FI} = \left[\frac{\boldsymbol{M3}}{\boldsymbol{M2}}\right] * \mathbf{100}\%$$

Where, FI, Flakiness Index

$M_{3,}$ is weight passed after discarding 5% or less (g)

$M_{2,}$ is sum of mass of after discarding 5% or less (g)

Figure 3. 5: Determination of Flakiness index

3.8.1.3.2 Elongation Index (EI)

Aggregate particles are classified as elongated when they have a length of more than 1.8 of their mean sieve sizes. The elongation index of an aggregate sample is found by separating the elongated particles and expressing as their mass as a percentage of the mass of the sample. The test is applicable to material passing a 50 mm sieve and retained on a 6.3 mm sieve.

Elongation index (EI) is calculated as follows:

$$\mathbf{EI} = \left[\frac{\mathbf{M3}}{\mathbf{M2}}\right] * \mathbf{100}\%$$

Where, M_1: - sums of masses of the fractions in the trays

M_2: - mass of remaining fraction from M_1 whose mass is 5% or less

M_3: - mass of all elongated particles

Figure 3. 6: Determination of Elongation index

3.8.2 Mechanical Properties

The following test methods are used to determine the mechanical properties of crushed stone aggregate different quarries.

3.8.2.1 Los Angeles abrasion value (LAAV)

The objective of the test is to assess the durability of base course aggregates used in pavement construction. Resistance to wear or hardness is hence an essential property for road aggregates.

The Los Angeles test is a measure of degradation of aggregates of standard grading resulting from a combination of actions including abrasion and grinding in a rotating steel drum containing a specified number of steel spheres. As the drum rotates, a shelf plate picks up the sample and the steel spheres, carrying them around until they are dropped to the opposite side of the drum, creating an impact/crushing effect.

The contents then roll within the drum with an abrading and grinding action until the shelf plate impacts and the cycle is repeated specification on AASHTO T-96-69 and BS 812-113:1990. Express the loss from the equation.

$$LAAV = \left[\frac{M1 - M2}{M1}\right] * 100\%$$

Where, LAA value, Los Angeles Abrasion Value

M_1: - The mass of the sample recorded to the nearest 1g

M_2: - Oven dry sample retained on 1.7mm sieve to the nearest 1g

Table 3-3: Standard Sieve and Mass of samples for Abrasion Test

Sieve sizes		**Mass of indicated sizes (g)**			
Passing	Retained on	Grading			
		A	B	C	D
37.5 mm	25 mm	1250 ±25			
25 mm	19 mm	1250 ±25			
19 mm	12.5 mm	1250 ±10	2500 ±10		
12.5 mm	9.5 mm	1250 ±10	2500 ±10		
9.5 mm	6.3 mm			2500 ±10	
6.3 mm	4.75 mm			2500 ±10	
4.75 mm	2.36 mm				5000 ±10
Total		5000 ±10	5000 ±10	5000 ±10	5000 ±10
Grading A: Suitable for graded crushed stone and natural gravel for base course Grading B: Suitable for chippings for surface dressing Grading C: Suitable for chippings for surface dressing Grading D: Suitable for chippings for surface dressing					

Figure 3. 7: Determination of LAAV

3.8.2.2 Aggregate Crushing Value (ACV)

Aggregate used in road construction should be strong enough to resist crushing under traffic wheel loads. If the aggregate is weak, the integrity of the pavement structure is likely to be adversely affected. According to BS 812: Part 110:1990, the aggregate crushing value gives a relative measure of the resistance of an aggregate to crushing under a gradually applied load and it determined by measuring the material passing a specified sieve after crushing under a load of 400KN. The test is applicable to a standard fraction aggregates passing a 14 mm sieve and retained on a 10mm sieve.

Aggregate crushing value (ACV) is then expressed as a percentage to the first decimal place for each test specimen from the following equation. If the standard size fraction 14 - 10 mm on BS 812: Part 110:1990.

$$\mathbf{ACV} = \left[\frac{\mathbf{M2}}{\mathbf{M1}}\right] * \mathbf{100}\%$$

Where, M_1: - Weigh the tray and the aggregate

M_2: - Weigh and record the masses of the fraction passing 2.36mm sieve

M_3: - Weigh and record the masses of the fraction retained 2.36mm sieve

If the individual results differ by more than 7 % of the mean value, the test shall be repeated for two further specimens. The median value shall be reported as the ACV.

Figure 3. 8: Determination of ACV

3.8.2.3 Aggregate Impact Value (AIV)

The Aggregate Impact Value (AIV) gives a relative measure of the resistance of an aggregate to sudden shock or impact. The test can be performed in either a dry condition or in a soaked condition. The test is applicable to a standard fraction aggregates passing a 14 mm sieve and retained on a 10 mm sieve in BS 812: Part 112: 1990.

Determine Aggregate Impact Value (AIV) is then expressed as a percentage to the first decimal place for each test specimen from the following equation.

$$\mathbf{AIV} = \left[\frac{\mathbf{M2}}{\mathbf{M1}}\right] * \mathbf{100\%}$$

Where, M_1: - Weigh the tray and the aggregate

M_2: - Weigh and record the masses of the fraction passing 2.36mm sieve

M_3: - Weigh and record the masses of the fraction retained 2.36mm sieve

Figure 3. 9: Determination of AIV

3.9 Summary of Test Carried Out and their Function

Table 3-4: summary of test carried out and their function

No	Test conducted	Standard specifications	Purpose of tests
1	Sieve Analysis	AASHTO T-27	Used to determine the particle size distribution (gradation) of course aggregates.
2	Specific gravity and Water Absorption	AASHTO T-85 and BS 812: Part 2:1975	Used to analysis course aggregate density with relative to water.
3	Shape test	BS 812 Part 105-1990 and BS EN 933-3	Used to determine Elongation Index and Flakiness Index of course aggregate.
4	Aggregate Crushing Value (ACV) Test	BS 812: part 110: 1990	Used to evaluate the crushing resistance of course aggregates under gradually applied load.
5	Aggregate Impact Value (AIV)	BS 812: part 112:1990	Used to determine the Aggregate Impact Value (AIV) of a given aggregate sample.
6	Los Angeles Abrasion Value (LAA) Test	AASHTO T 96-94 and BS 812: part 113:1990	Used to evaluate how the aggregate is sufficiently hard to resist the abrasion effect Or resistance to wearing action.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 General

This chapter presents the result of laboratory investigation and data analysis that conducted to study suitability of different quarry site aggregate for base course aggregate of asphalt pavement. After the completion of laboratory tests, the test results were analyzed to determine Physical and Mechanical properties of different quarry site course aggregate. Therefore, that base course of Asphalt pavement will only become a quality material for base course when the aggregates are properly sourced and selected as well as when it is manufactured under a regulated standard and practice procedure as below table 4.1.

Table 4-1: ERA specification and test methods

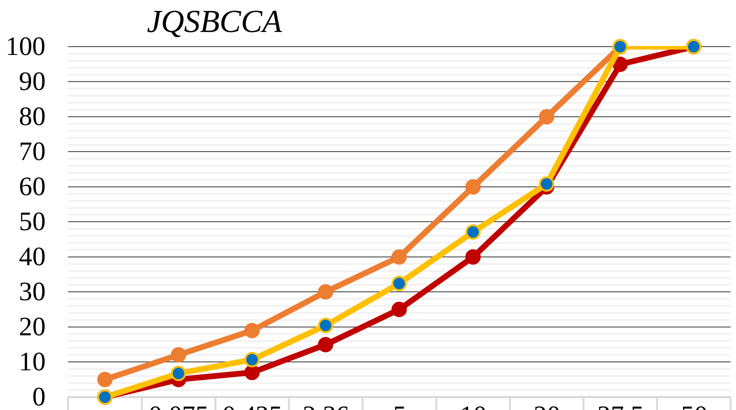
No	Test type	Unit	Test method	Standard	Specification
			Physical Properties		
1	Gradation	%	AASHTO T 27	ERA	On Table 3.2
2	Specific Gravity	Kg/m^3	AASHTO T 85 & BS 812: P2	AASHTO & BS	2.5-2.9
3	Water Absorption	%		ERA	< 2%
4	FI	%	BS 812: P105	ERA	< 45%
5	EI	%	BS 812: P105	ERA	< 45%
			Mechanical Properties		
1	LAAV	%	BS 812: P113 & AASHTO T-96	ERA & BS	< 30%
2	ACV	%	BS 812: P110	ERA & BS	< 25% or
3	AIV	%	BS 812: P112	ERA & BS	< 25%

4.2 Physical Properties of Course Aggregate

4.2.1 Particle Size Distribution

To determine the proportion of course material distribution by use of sieve analysis were under taken on Five different quarry site course aggregate sample which collected and percent by weight were conducted for gradation tests. The result was expressed by a plot of percent finer (% passing) by weight against the size of aggregate particles.

4.2.1.1 Jemila quarry site base course crush aggregate (JQSBCCA)



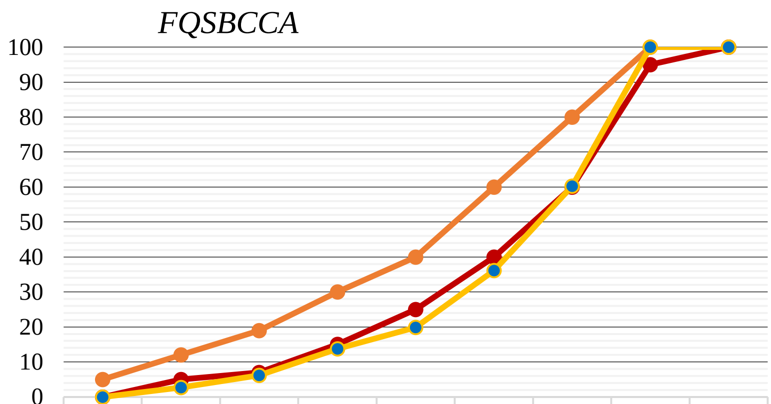
	pan	0.075	0.425	2.36	5	10	20	37.5	50
AASHTO Standared Min.	0	5	7	15	25	40	60	95	100
AASHTO Standard max.	5	12	19	30	40	60	80	100	100
% of pass	0	6.713	10.659	20.422	32.375	47.097	60.794	100	100

Figure 4. 1: Average Gradation Curves of JQSBCCA

Figure 4.1 shows that percent of passing and retaining of each sieve size, as well as their mass of pass and retained with standard specification of ERA and AASHTO T 27. Nominal maximum aggregate particle size was 37.5 mm and the size distribution of aggregate from JQSBCCA was fulfilled within limited specified by standards. It indicated that the JQSBCCA is well graded and distributed at each sieve size.

So, it clearly indicating that the course aggregate was well graded for both lower and higher sieve size were between the range of upper and lower limit.

4.2.1.2 Frustal quarry site base course crush aggregate (FQSBCCA)



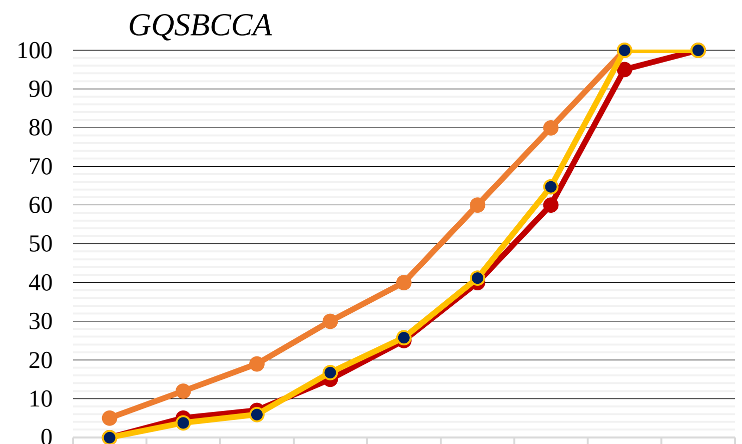
	pan	0.075	0.425	2.36	5	10	20	37.5	50
AASHTO Standared Min.	0	5	7	15	25	40	60	95	100
AASHTO Standard max.	5	12	19	30	40	60	80	100	100
% of pass	0	2.658	6.139	13.734	19.898	36.134	60.298	100	100

Figure 4. 2: Average Gradation Curves of FQSBCCA

Figure 4.2 shows that, size distribution, percent of passing and retaining of each sieve size, as well as their mass of pass and retained of FQSBCCA with standard specification of ERA and AASHTO T-27. It was observed that the FQSBCCA was fulfilled within limits specified except for two sieve No (i.e., 5.90% for 0.425 mm and 3.78% for 0.075 mm). The percentage passing sieve 37.5 mm through 2.36 mm were 100% to 16.77% percentage respectively which was meet the gradating requirement for base course aggregates and Nominal maximum aggregate particle size is 37.5 mm.

So that, this quarry site course aggregate has a deficiency finer aggregate and it is clearly indicating that the gradations requirement especially for lower sieve sizes.

4.2.1.3 Geruke quarry site base course crush aggregate (GQSBCCA)



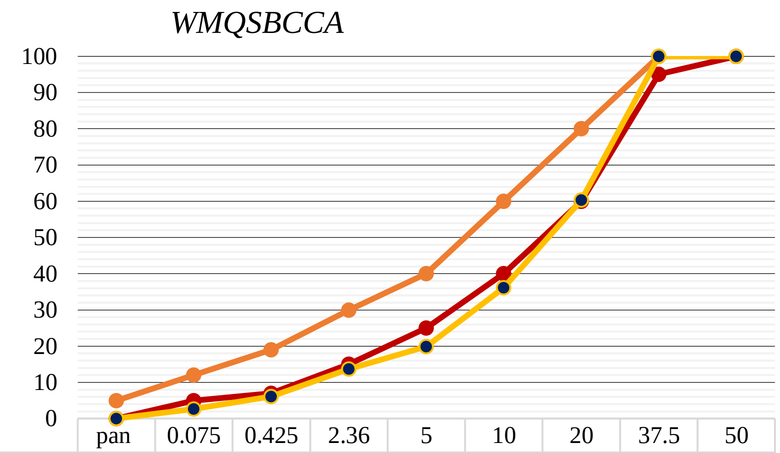
	pan	0.075	0.425	2.36	5	10	20	37.5	50
AASHTO Standard Min.	0	5	7	15	25	40	60	95	100
AASHTO Standard max.	5	12	19	30	40	60	80	100	100
% of pass	0	3.78	5.9	16.77	25.81	41.2	64.72	100	100

Figure 4. 3: Average Gradation Curves of GQSBCCA

Figure 4.3, shows that size distribution, percent of passing and percent of retained of each sieve size, as well as their mass of pass and retained of GQSBCCA with standard specification of ERA and AASHTO T-27. It was observed that the GQSBCCA were not fulfill within limits specified except for sieve size 37.5 mm and 20 mm. The percentage passing sieve 10 mm through 0.075 mm which was not meet the gradating requirement for base course crushed aggregates and Nominal maximum aggregate particle size is 37.5 mm.

So that, this quarry site aggregate result clearly indicating that the gradations requirement special for lower sieve sizes.

4.2.1.4 Welda Mikrbete quarry site base course crush aggregate (MWQSBCCA)



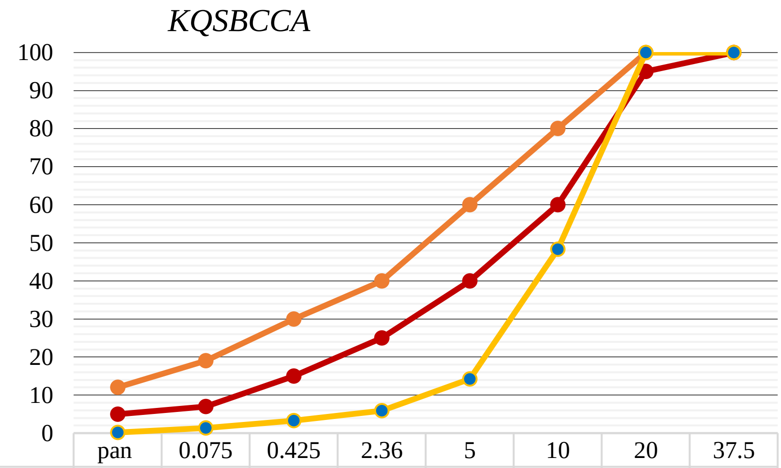
	pan	0.075	0.425	2.36	5	10	20	37.5	50
AASHTO Standard Min.	0	5	7	15	25	40	60	95	100
AASHTO Standard max.	5	12	19	30	40	60	80	100	100
% of pass	0	2.658	6.139	13.734	19.898	36.134	60.298	100	100

Figure 4. 4: Average Gradation Curves of WMQSBCCA

Figure 4.4 show that, size distribution, percent of passing and retaining of each sieve size, as well as their mass of pass and retained of WMQSBCCA with standard specification of ERA and AASHTO T-27. It was observed that the WMQSBCCA fulfill within limits specified sieve and Nominal maximum aggregate particle size is 37.5 mm.

So that, the size distribution was within the specified requirement. It is clearly indicating course aggregate was well graded for both lower and higher sieve size.

4.2.1.4 Kisho quarry site base course crush aggregate (KQSBCCA)



	pan	0.075	0.425	2.36	5	10	20	37.5
AASHTO Standard Min.	5	7	15	25	40	60	95	100
AASHTO Standard max.	12	19	30	40	60	80	100	100
% of pass	0.17	1.35	3.32	5.92	14.26	48.29	100	100

Figure 4. 5: Average Gradation Curves which from KQSBCCA

Figure 4.5 show that, size distribution, percent of passing and retaining of each sieve size, as well as their mass of pass and retained of KQSBCCA with standard specification of ERA and AASHTO T-27. It was observed that the KQSBCCA was not fulfill within limits except for sieve size 37.5 mm. The percentage passing sieve 20 mm through 0.075 mm which was not meet the gradating requirement for base course aggregates.

So that, this quarry site course aggregate has a deficiency finer aggregate or finer aggregates are not sufficient, because it clearly indicating that the gradations requirement special for lower sieve sizes.

4.2.2 Specific Gravity and Water Absorption

Table 4-2: Average specific gravity and water absorption of different quarry site base course aggregate

No	*Quarry site*	*Average Gsb*	*Absorption*	*ERA absorption lim.*
1	JQSBCCA	2.77	1.55%	<2.00%
2	FQSBCCA	2.76	1.48%	<2.00%
3	GQSBCCA	2.78	1.47%	<2.00%
4	WMQSBCCA	2.78	1.30%	<2.00%
5	KQSBCCA	2.81	1.59%	<2.00%

4.2.2.1 Specific gravity

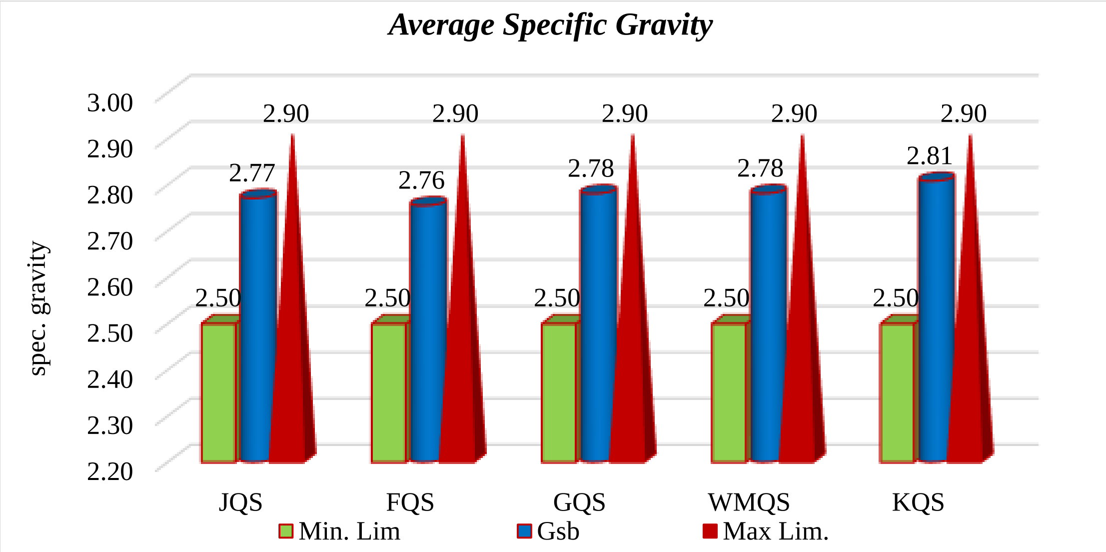


Figure 4. 6: Average Specific gravity graph of different quarry site base course aggregate

4.2.2.2 Water Absorption

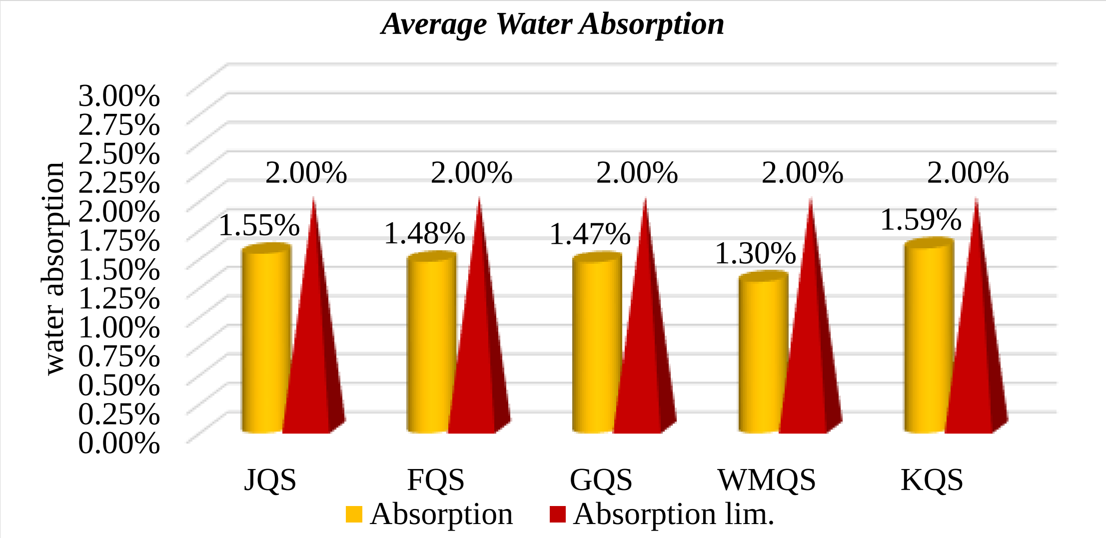


Figure 4. 7: Average water absorption graph of different quarry site base course aggregate

As show in Table 4.2, Figure 4.6 and Figure 4.7, Specific gravity and water absorption of aggregates under investigation were determined using AASHTO T-85 and ERA standard. The values of specific gravity and water absorption of aggregates investigated in this study have been in above Table 4.6 and graphically presented in Figure 4.6 for specific gravity and Figure 4.7 for water absorption. Specific gravity of aggregates was slightly the same range of result obtained which was 2.77, 2.76, 2.78, 2.78 and 2.81 for JQSBCCA, FQSBCCA, GQSBCCA, WMQSBCCA and KQSBCCA respectively. And Water Absorption obtained slightly the same range which was 1.55% for JQSBCCA, 1.48% for FQSBCCA, 1.47% for GQSBCCA, 1.30% for WMQSBCCA and 1.59% for KQSBCCA all are fulfilled requirement which is specified on the standard.

4.2.3 Shape and Texture Test

4.2.3.1 Flakiness Index (FI)

Table 4-3: Average Flakiness Index of different quarry site base course aggregate

No	Quarry site	Average	Sand. Lim.
1	JQSBCCA	17.84%	< 45.00%
2	FQSBCCA	20.90%	< 45.00%
3	GQSBCCA	23.91%	< 45.00%
4	WMQSBCCA	20.15%	< 45.00%
5	KQSBCCA	16.30%	< 45.00%

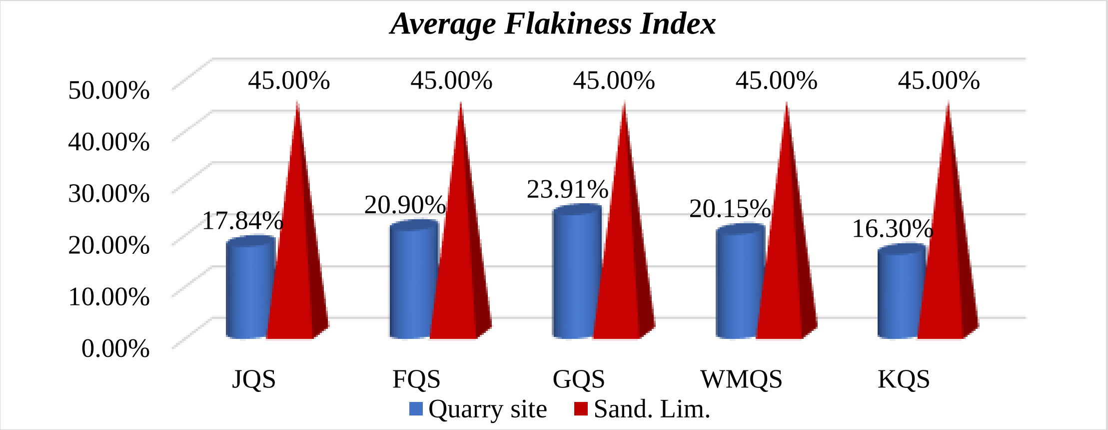


Figure 4. 8: Average Flakiness Index graph of different quarry site base course aggregate

Table 4.3 and Figure 4.8 show that, Flakiness Index values of the Five quarry site crushed course aggregates were determined as per BS 812: P105. The result shows that base course aggregate was obtained 17.84% for JQSBCCA, 20.90% for FQSBCCA, 23.91% for GQSBCCA, 20.15% for WMQSBCCA and 16.30% for KQSBCCA production site and all were fulfilled requirement of ERA and BS. From those Five different quarry site aggregate KQSBCCA was obtained the lowest value of 16.30%.

4.2.3.2 Elongation Index (EI)

Table 4-4: Average Elongation Index of different quarry site base course aggregate

No	Quarry site	Average	Sand. Lim.
1	JQSBCCA	26.88%	< 45.00%
2	FQSBCCA	27.58%	< 45.00%
3	GQSBCCA	29.66%	< 45.00%
4	WMQSBCCA	28.67%	< 45.00%
5	KQSBCCA	25.07%	< 45.00%

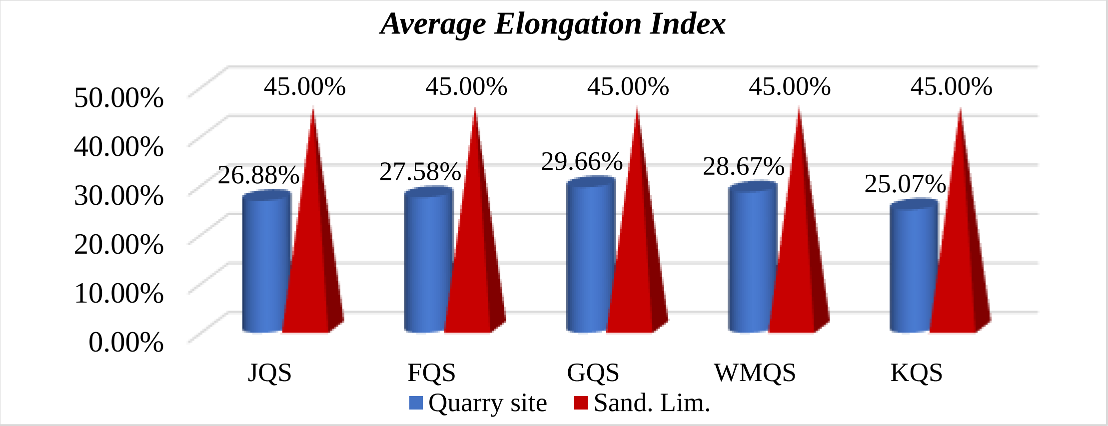


Figure 4. 9: Average Elongation Index graph of different quarry site base course aggregate

Table 4.4 and Figure 4.9 show that, Elongation Index values of the Five quarry site course aggregates were determined as per BS 812: P105. The particle shapes obtained result, for JQSBCCA was 26.88%, FQSBCCA was 27.58%, GQSBCCA was 29.66%, WMQSBCCA was 28.67% and KQSBCCA was 25.07% and all were fulfilled specified requirement of ERA and BS. From all Five different quarry site aggregate, KQSBCCA was the lowest value than the remaining source aggregate which was 25.07%.

4.3 Mechanical Properties of Course Aggregate

4.3.1 Los Angeles Abrasion Value (LAAV)

Table 4-5: Average Los Angeles Abrasion value of different quarry site base course aggregate

No	Quarry site	Average LAAV	Stan. Lim. AASHTO T96
1	JQSBCCA	9.83%	< 30.00%
2	FQSBCCA	8.69%	< 30.00%
3	GQSBCCA	8.41%	< 30.00%
4	WMQSBCCA	10.57%	< 30.00%
5	KQSBCCA	10.31%	< 30.00%

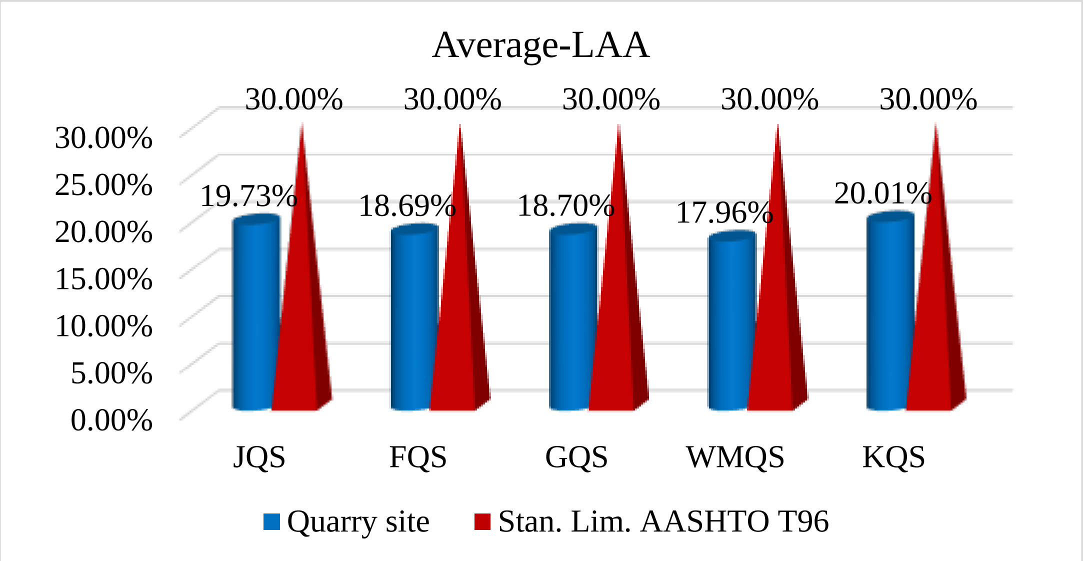


Figure 4. 10: Los Angeles Abrasion graph of different quarry site base course aggregate

As show in Table 4.5 and Figure 4.10, the result of LAAV of five quarry site aggregates with the Standard limitation of AASHTO, ERA and BS specified that base course aggregates LAAV value should be less than 30%. Those quarry site aggregate samples

LAAV laboratory test result show for JQSBCCA yield 19.73%, FQSBCCA yield 18.69%, GQSBCCA yield 18.70%, WMQSBCCA yield 17.69% and KQSBCCA yield 20.01%. From above results, all quarry sites aggregate LAAV are less than 30%.

4.3.2 Aggregate Crushing Test (ACV)

Table 4-6: Average aggregate crushing value Test Result

No	Quarry site	Average ACV (%)	Lim. BS: 812 Part 110
1	JQSBCCA	16.52	< 25
2	FQSBCCA	15.76	< 25
3	GQSBCCA	15.65	< 25
4	WMQSBCCA	15.25	< 25
5	KQSBCCA	16.57	< 25

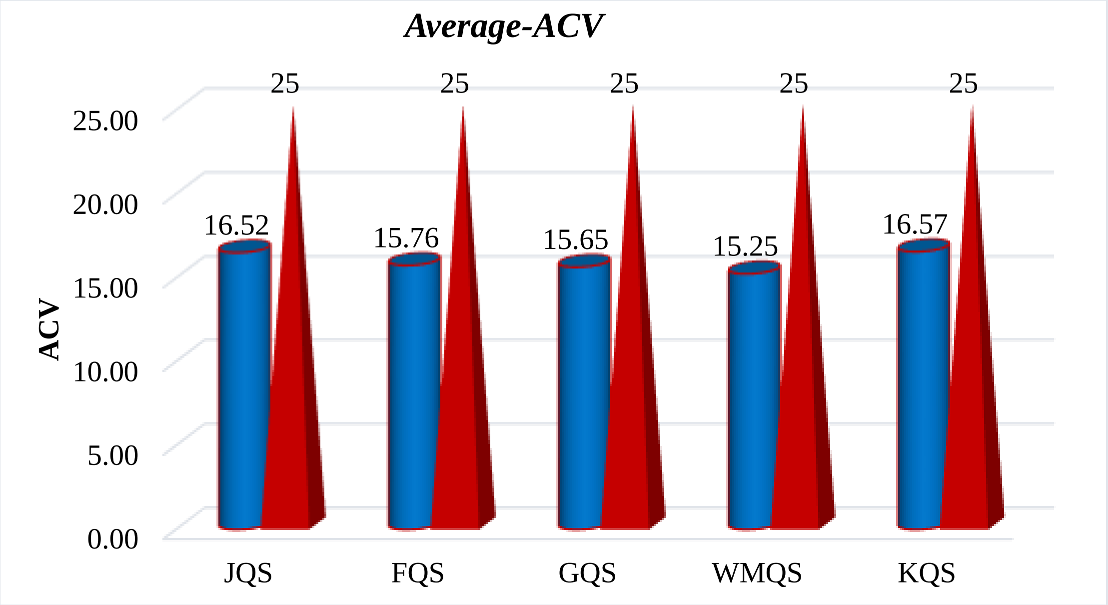


Figure 4. 11: Average aggregate crushing value graph

As show above in Table 4.6 and Figure 4.11, the result of ACV of five quarry site aggregates with the Standard limitation of AASHTO, ERA and BS specified that base course aggregates ACV value should be less than 30%. Those Five quarry site course aggregate samples ACV laboratory result shows that for JQSBCCA was 16.52%, FQSBCCA was 15.76%, GQSBCCA was 15.65%, WMQSBCCA was 15.25% and KQSBCCA was 16.57%. From above results, all the quarry sites crushed aggregate ACV value are less than 30%.

4.3.3 Aggregate Impact Value (AIV)

Table 4-7: Average Aggregate Impact Value (AIV) Test Result

No	Quarry site	Average AIV	standard lim.
1	JQSBCCA	11.94	< 25
2	FQSBCCA	10.47	< 25
3	GQSBCCA	10.22	< 25
4	WMQSBCCA	9.91	< 25
5	KQSBCCA	10.58	< 25

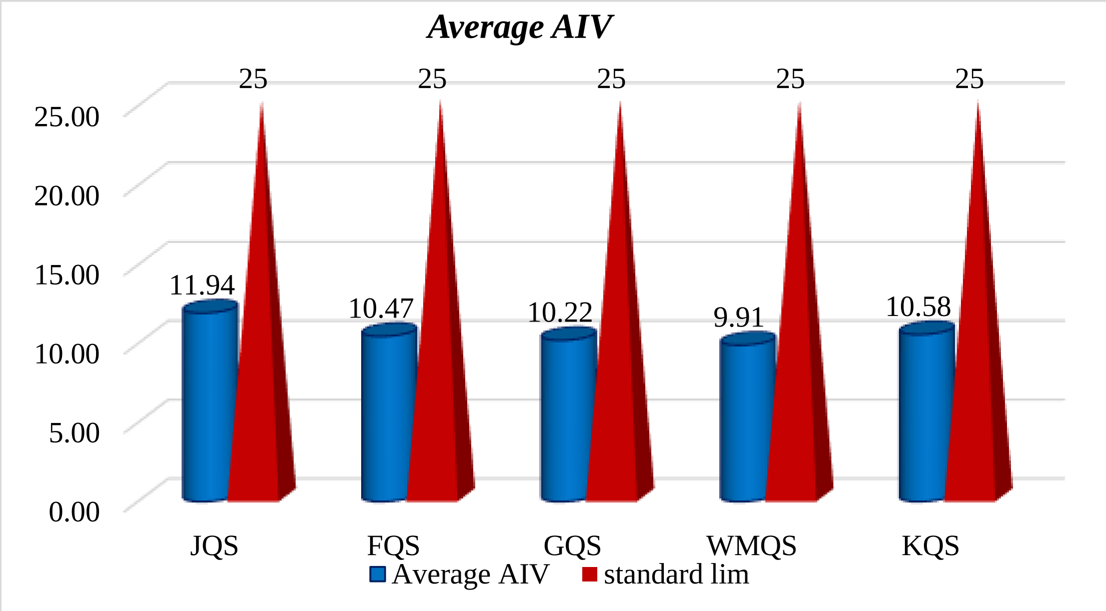


Figure 4. 12: Average Aggregate Impact Value (AIV) graph

The results of this study of AIV of aggregates obtained from the five-quarry site crushed aggregate which were from JQSBCCA, FQSBCCA, GQSBCCA, WMQSBCCA and KQSBCCA. AIV of five quarry site crushed aggregates were found in range from 9.91% and 11.94%.

As show in Table 4.17 and Figure 4.12, the result of AIV of five quarry site crusher aggregates with the Standard limitation of AASHTO, ERA and BS standards specified that base course constituent aggregates AIV value should be less than 30%. The Five quarry site crushed course aggregate samples AIV laboratory result shows that aggregate obtained from JQSBCCA was 11.94%, FQSBCCA was 10.47%, GQSBCCA was 10.22%, WMQSBCCA was 9.91% and KQSBCCA 10.58%. From above results, all the quarry sites crushed aggregate AIV value are less than 30%.

4.4 Compare Test Result of all Quarry Site Base Course Crush Aggregate

Table 4-8: Average result of physical and mechanical properties of different quarry sites

No	physical and chemical properties	Result of course aggregate crush quarry site					standard specification		Remark	Test Method
		JQSBCCA	FQSBCCA	GQSBCCA	WMQSBCCA	KQSBCCA	ERA	AASHTO/BS		
1	Gsb	2.77	2.76	2.78	2.78	2.81	N/A	2.5-2.9	FQSBCCA	AASHTO T-85
2	WA	1.55%	1.48%	1.47%	1.30%	1.59%	<2%	<2%	WMQSBCCA	AASHTO T-85
3	ACV	16.52%	15.76%	15.65%	15.25%	16.57%	<25%	<25%	WMQSBCCA	BS 812: Part 110
4	AIV	11.94%	10.47%	10.22%	9.91%	10.26%	<25%	<25%	WMQSBCCA	BS 812: Part 112
5	LAAV	19.73%	18.69%	18.70%	17.96%	20.01%	<30%	<30%	WMQSBCCA	BS 812: Part 113
6	FI	17.84%	20.90%	23.91%	20.15%	16.30%	<45%	<40%	KQSBCCA	BS 812: Part 105
7	EI	26.88%	27.58%	29.66%	28.67%	25.07%	<45%	<40%	KQSBCCA	BS 812: Part 105

4.4.1 Particle Size Distribution (Gradation)

Gradation of each quarry site aggregate have been done according to AASHTO T-27 WMQSBCCA and JQSBCCA were fulfilled specified requirements. FQSBCCA had deficiency of finer aggregate which were sieve 0.425mm and 0.075mm, GQSBCCA was fulfilled only sieve size 37.8 mm & 20mm and KQSBCCA fulfilled only sieve size 37.5 mm aggregate this indicate that the aggregate was courser aggregate and deficiency of finer aggregate. So according to result WMQSBCCA and JQSBCCA are the suitable aggregate for base course aggregate than the other in term of gradation and fulfilled specified standard requirement.

4.4.2 Specific Gravity and Water Absorption

The specific gravity of an aggregate is to be a measure of strength or quality of the material.

As test result show above in Table 4.8, specific gravity test result of FQSBCCA was 2.76 which has less specific gravity relative to 2.77 of JQSBCCA, 2.78 of GQSBCCA & WMQSBCCA and 2.81 of KQSBCCA. According to the result all quarry site aggregate are satisfy which stated on standards. But, KQSBCCA value was near to the upper limit (i.e. 2.9) compare to the other. So, all were suitable to use as base course aggregate of asphalt pavement construction based on specific gravity result.

Water absorption gives an idea of strength of aggregate having more water absorption are more porous in nature and generally considered unsuitable unless they are found to be acceptable based on strength, impact and hardness tests. According to Table 4.8, water absorption of those five quarries site course aggregate unlikely specific gravity WMQSBCCA had the best one on water absorption 1.30% this show stronger and less porous course aggregate than the other relatively. And the other were fulfilled standards required which below 2% their result were 1.47%, 1.48%, 1.55% and 1.59% for GQSBCCA, FQSBCCA, JQSBCCA and KQSBCCA respectively. According water absorption result all are suitable for base course aggregate of asphalt pavement construction.

4.4.3 Shape and Texture

Use of the shape tests in specifications is based on the view that the shapes of the particles influence both the strength of aggregate particles and internal friction that can be developed in the aggregate mass.

4.4.3.1 Flakiness Index (FI)

Table 4.8 show that, Flakiness Index values of those five crushers site course aggregates was 17.84% for JQSBCCA, 20.90% for FQSBCCA, 23.91% for GQSBCCA, 20.15% for WMQSBCCA and 16.30% for KQSBCCA which implies the aggregates are desirable within base course to resist upcoming load from vehicles wheel, provide better interlock between the aggregate particles which helps prevent plastic deformation and fulfill requirement of ERA and BS standards. From all different five-quarry site course aggregate KQSBCCA was the lowest value than the remaining source crushed aggregate which was 16.30%. And all are suitable for base course aggregate according to FI results show us.

4.4.3.2 Elongation Index (EI)

Table 4.8 show that, EI value of those five crushers site course aggregates was 26.88% for JQSBCCA, 27.58% for FQSBCCA, 29.66% for GQSBCCA, 28.67% for WMQSBCCA and 25.07% for KQSBCCA. As result show that, the EI of the aggregate was within the range of standards which implies the aggregates are desirable within base course to resist upcoming load from vehicles wheel, provide better interlock between the aggregate particles which helps prevent plastic deformation and fulfill requirement of ERA and BS. From all different five-quarry site course aggregate KQSBCCA was the lowest value than the remaining source crushed aggregate which was 25.07%. And all are suitable for base course aggregate based on EI results.

4.4.4 Aggregate Crushing Value (ACV)

Table 4.8 show that, as like to water absorption, WMQSBCCA have better ACV value of 15.25% this show the ability to resist gradually apply load than the other quarry site aggregate which was slightly the same value with GQSBCCA and FQSBCCA had 15.65% and 15.76% respectively. 16.52% for JQSBCCA and 16.57% for KQSBCCA which was KQSBCCA had less to resist against gradual applied load relative to the other these results put KQSBCCA the lower suitable than the other quarry site course aggregate for base course aggregate of asphalt pavement but it fulfilled specified standard requirement.

4.4.5 Aggregate Impact Value (AIV)

Table 4.8 show that, as like to water absorption and ACV, WMQSBCCA had better AIV value of 9.91% this result shows the ability to resist sudden shock or impact than the other quarry site course aggregate slightly the similar value with GQSBCCA, FQSBCCA and KQSBCCA had 10.22%, 10.47% and 10.58% respectively and 11.94% for JQSBCCA. JQSBCCA had less to resist against sudden shock or impact relative to the other these results and put it as the lower suitable than the other quarry site course aggregate for base course aggregate of asphalt pavement but it fulfilled specified standard requirement.

4.4.6 Los Angeles Abrasion Value (LAAV)

Table 4.8 show that, as like to water absorption, ACV and AIV, WMQSBCCA had better LAAV value of 17.96% this show more harder than the other quarry site course aggregate and obtained slightly in the same range with GQSBCCA and FQSBCCA had 18.69%, and 18.70% respectively, 19.73% for JQSBCCA and 20.01% for KQSBCCA. KQSBCCA had less harden than relative to the other and put it as the lower suitable than the other quarry crushes site course aggregate for base course aggregate of asphalt pavement but it fulfilled specified standard requirement.

Generally, as discuss above based on obtained test results WMQSBCCA was the best and more suitable in term of Gradation, 1.30% of WA, 15.25% OF ACV, 9.91% of AIV, 17.96% of LAAV and had very good result 2.78% of specific gravity, 20.15% of FI and 28.67% of EI and it fulfilled specified standard requirement of base course aggregate. The second best suitable relative to other for base course aggregate of asphalt pavement construction was GQSBCCA, which had a better result in term of WA, ACV and AIV which was 1.47%, 15.65% and 10.22% respectively and 18.70% for LAAV, 2.78% for specific gravity, 23.5% for FI & 29.66% for EI value was the lowest but not fulfilled gradation requirement. FQSBCCA had obtained average or medium test results of all of five quarries site, this put it in the third in term of WA, ACV and AIV 1.48%, 15.76% and 10.47% respectively, second in term of LAAV (i.e. 18.69%), first on specific gravity value of 2.76%, 20.90% for FI and 27.58% for EI. JQSBCCA was had second in term of specific gravity, FI and EL 2.77%, 17.81% and 26.88% respectively, fourth in term of WA, ACV and LAAV 1.55%, 16.62% and 19.73% respectively and the least in term of 11.94% of AIV but fulfilled gradation requirements. And KQSBCCA was the least in term of WA, ACV and LAAV 1.59%, 16.57% and 20.01% respectively but meet the requirement of local and international standards and the best on in term of FI 16.30% and EI 25.07%. So, all were fulfilled required specification except gradation of FQSBCCA, GQSBCCA and KQSBCCA according to ERA manual, AASHTO, ASTM and BS.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Aggregate were carefully collected from five quarry site crushed coarse aggregate which found in Jimma city those are Jemila, Frustal, Geruke, Welda Mikrbete and Kisho quarry sites crushed coarse aggregate.

This study investigates suitability of different quarry site crushed coarse aggregate for base course aggregate of asphalt pavement by Using BS, ASTM, AASHTO and ERA aggregate were tested for all the necessary quality tests including from Physical properties; Gradation (Sieve Analysis), Specific Gravity (SG), Water Absorption (WA), Elongation Index (EI), Flakiness Index (FI) and from Mechanical properties; Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV) and Los Angeles Abrasion Value (LAAV).

In term of gradation WMQSBCCA and JQSBCCA are well graded & fulfilled all sieve size requirement and the best suitable aggregate for base course aggregate of asphalt pavement. GQSBCCA and KQSBCCA are coarser aggregate and not fulfill the required finer aggregate, FQSBCCA is fulfill except sieve size 0.425 and 0.075. Generally, most of them were not fulfilled standard requirement of gradation except WMQSBCCA and JQSBCCA.

According to AASHTO T-85 and BS EN 1097-6 specification limits from 2.5 to 2.9 for specific gravity and ERA specification limits less than 2% for water absorption, so from experiment results of those five quarry site base course aggregate obtained from 2.77 to 2.81 of specific gravity, which JQSBCCA yield the lowest 2.77 and KQSBCCA yield the highest 2.81. Water absorption obtained in the range of 1.30% to 1.55% and WMQSBCCA yield the lowest 1.30% and JQSBCCA yield the highest 1.55%. Hence, according to obtained test result of both Specific Gravity and Water absorption of all quarry site crushed coarse aggregates are suitable for base course aggregate of asphalt pavement construction.

According to ERA specification limits FI and EI are less than 45% and BS 812-105.1 less than 45% from the experiment observed Flakiness Index and Elongation index of those Five quarry site course aggregate obtained in the range of 16.30% to 23.91% and 25.07% to 29.66% respectively this result showed that, all quarry site crushed course aggregate fulfilled standard requirement. Hence, all quarry site crushed course aggregate was suitable for base course aggregate of asphalt pavement construction.

Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV) of those five quarry site crushed course aggregate were obtained in the range of 15.25% to 16.52% and 9.91% to 11.94% respectively. The highest yield by JQSBCCA 16.52% & 11.94% and the lowest yield by WMQSBCCA 15.25% & 9.91% value of ACV and AIV respectively. Los Angeles Abrasion Value (LAAV) obtained in the range of 17.96% to 20.01% which the highest yield by WMQSBCCA and the lowest yield by GQSBCCA and all quarry site crushed course aggregate satisfy and fulfilled according to ERA specification which is below than 30% and for ACV and AIV below than 25%. Hence, ACV, AIV and LAAV of all quarry site crushed course aggregates are suitable for base course aggregate in asphalt pavement construction. Welda Mikrbete quarry crushed aggregate are the best suitable than the other in terms of Mechanical properties obtained test results.

The results of overall aggregate Physical and Mechanical properties pointed out that all five quarry site course aggregates are within the standard specification limits and they are suitable to use in base course aggregate of asphalt pavement construction except three quarry site gradation requirements is failed.

5.2 Recommendation

Since road pavement construction is a public property and public have given the responsibility to different organization and professionals, needs caution in designing, material selection, material quality and construction, and am try to recommend as follow:

- ✓ Gradation of aggregate requirement not fulfilled for all quarry site aggregate except JQSBCCA and WMQSBCCA they should be well graded or blended before use.
- ✓ Except gradation of three quarry site aggregates (GQSBCCA, FQSBCCA and KQSBCCA) confident to use for base course aggregate of asphalt pavement construction.

- ✓ Welda Mikrbete quarry site crushed aggregate is the best and recommended suitable aggregate based on obtained overall Physical and Mechanical properties results.
- ✓ JQSBCCA, FQSBCCA, GQSBCCA and KQSBCCA those are alternative for WMQSBCCA for base course aggregate of asphalt pavement construction if they graded according to standard requirement.
- ✓ Aggregate producers should be produced aggregate with in minimum specified requirement of gradation.
- ✓ Client (ERA) should be important if its able review aggregates quality periodical to as per quality specification to protect the public asset from an early deteriorate and maintenance cost.
- ✓ As the one who work for the client, consultants should determine any material quality related activities, in accordance with the intention of client without compromise, in professional way.
- ✓ To contractors, Base course aggregates seem that (not exactly), it meets the requirement specified it supposed to achieve in base course construction but it has a strength problem (due to this not sufficiently durable) in carrying the imposed loads and needed to be checked and select the best suitable aggregate.
- ✓ For future studies, since roads are one of the public asset and needs protection from all nation, with their point of view, therefore, all Highway Engineers, Material Engineers, Construction Engineers and Structural Engineer have the duty to do the research, provide important feedback on the quality of aggregates and its impact on the pavement performance to the officials.

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APPENDIX

Appendix A: Data and Data Analysis of Different Quarry Site

Data and data analysis of the different quarry site base course aggregate of asphalt pavement of the study, which stated under here and data was analyzed.

Appendix A1: Jemila Quarry Site Base Course Crushed Aggregate (JQSBCCA)

Appendix A1.1: sieve analysis (Gradation)

Weight of average sample ***5000 g.***

Table A-1: sieve analysis of JQSBCCA

Sieve (mm)	Retained gm.	% of retained	wt. of pass	% of pass	Specification limit
50	0	0	5000	100	100
37.5	0	0	5000	100	95-100
20	1960.3	39.206	3039.7	60.794	60-80
10	684.85	13.697	2354.85	47.097	40-60
5	736.1	14.722	1618.75	32.375	25-40
2.36	597.65	11.953	1021.1	20.422	15-30
0.425	488.15	9.763	532.95	10.659	7--19
0.075	197.3	3.946	335.65	6.713	5--12
pan	335.65	6.713	0	0	

Appendix A1.2: Specific Gravity and Water Absorption

Weight of sample ***2,000 g***

Table A-2: Sample and calculation of specific gravity and water absorption

Sample	A	B	C	B - C	A - C	B - A
1.00	1979.40	2011.10	1292.20	718.90	687.20	31.70
2.00	1977.10	2006.60	1297.70	708.90	679.40	29.50
Sample	Gsb	Gsb SSD	Gsa	Absorption		
1.00	2.75	2.93	2.88	1.60%		
2.00	2.79	2.95	2.91	1.49%		
	Gsb	Gsb SSD	Gsa	Absorption		
Average	2.77	2.94	2.90	1.55%		

Appendix A1.3: Flakiness Index

Weight of sample ***24,015.11 g***

Table A-3: the weight retained aggregate on each test sieve and % of pass

sieve size (mm)	Mass retained in g (M1)	% retained	Discard retained < 5%
37.5	0	0	None of to be discarded because percent mass of all size is greater than 5%
28	4987.94	20.77%	
20	9255.42	38.54%	
14	6897.14	28.72%	
10	2874.61	11.97%	
M2	24015.11		

Table A-4: calculation Flakiness Index of base course aggregate

Sieve (mm)	Flakiness gauge	Wt. of Retained	Wt. of Passed	FI for each gauge
28	37.5-28	3789.83	1198.11	24.02%
20	28-30	7981.87	1273.55	13.76%
14	20-14	5536.64	1360.5	19.73%
10	14-10	2422.63	451.98	15.72%
	TOTAL	19730.97	4284.14	
	FI	17.84%		

Appendix A1.4: Elongation Index

Weight of sample ***19,470.7 g***

Table A-5: the weight retained aggregate on each test sieve and % of pass

sieve size (mm)	Mass retained in g (M1)	% retained	Discard retained <5%
28	2718.2	13.96%	NO
20	11869.5	60.96%	NO
14	4294.5	22.06%	NO
10	588.5	3.02%	rejected
M1	19470.7		
M2	18882.2		

Table A-6: calculation Elongation Index of base course aggregate

Sieve	Flakiness gauge	Wt. of Retained	Wt. of Passed	FI for each gauge
28	37.5-28	760.5	1957.7	27.98%
20	28-30	3212.5	8657	27.07%
14	20-14	1102.7	3191.8	25.68%
	TOTAL	5075.7	14395	
	EI	26.88%		

Appendix A1.5: Aggregate Crushing Value (ACV)

Weight of sample ***2,500 g***

Table A-7: calculation and sample for ACV

Test No	Mass of sample (A) gm	Mass of Portion Passing 2.36 mm B.S Sieve after Crushing, gm (B)	Aggregate Crushing Value, ACV % individual(B/A*100) %	Average
	M1	M2	Individual ACV	16.52
1	2500	415.6	16.624	
2	2500	410.2	16.41	

Appendix A1.6: Aggregate Impact Value (AIV)

Weight of sample ***650 and 654.5 g***

Table A-8: calculation and sample for AIV

No	**Details**	**Trial Number**		
			T1	**T2**
1	Total Weight of aggregate sample filling the cylindrical measure=W1	W1	650	654.5
2	Weight of aggregate passing 2.36mm sieve after the test=W2	W2	74.5	81.3
3	Aggregate Impact Value= W2/W1*100	AIV	11.46	12.42
		Average	11.94	

Appendix A1.7: Los Angeles Abrasion Value (LAAV)

Weight of sample ***5000 g***

Table A-9: Calculation and sample for LAAV

Trial	Grading of Test Sample	Fraction and Mass		Steel Balls no	Mass of Sample Retained on 1.70 mm Sieve after washing & oven dried (B)	Loss through 1.70mm Sieve	**LAAV= C/A*100**
		Fraction (mm)	Mass A (g)			A - B = C	
1	B	19 to 12.5	2500	11	4081.6	918.4	18.37%
		12.5 to 9.5	2500				
Trial	Grading of Test Sample	Fraction and Mass		Steel Balls No.	Mass of Sample Retained on 1.70 mm Sieve after washing & oven dried (B)	Loss through 1.70mm Sieve	**LAAV= C/A*100**
		Fraction (mm)	Mass A (g)			A - B = C	
2	A	37.5 to 25	1250	12	3945.9	1054.1	21.08%
		25 to 19	1250				
		19 to 12.5	1250				
		12.5 to 9.5	1250				
						Average	19.73%

Appendix A2: Frustal Quarry Site Base Course Crushed Aggregate (FQSBCCA)

Appendix A2.1 Sieve analysis

Weight of sample ***5,000 g***

Table A-10: Sieve Analysis Sample and calculation

Sieve (mm)	Retained gm.	% of retained	wt. of pass	% of pass	Specification limit
50	0	0	5000	100	100
37.5	0	0	5000	100	95-100
20	1763.8	35.276	3236.2	64.72	60-80
10	1176	23.52	2060.2	41.20	40-60
5	769.75	15.395	1290.45	25.81	25-40
2.36	451.85	9.037	838.6	16.77	15-30
0.425	543.75	10.875	294.85	5.90	7--19
0.075	105.65	2.113	189.2	3.78	5--12
pan	189.2	3.784	0		

Appendix A2.2 Specific gravity and Water Absorption

Weight of sample ***2,000 g***

Table A-11: Sample and calculation of Specific gravity and Water Absorption

Sample	A	B	C	B - C	A - C	B - A
1.00	1,976.60	2,005.90	1,291.90	714.00	684.70	29.30
2.00	1,979.70	2,008.80	1,286.80	722.00	692.90	29.10
Sample	Gsb	Gsb SSD	Gsa	Absorption		
1.00	2.77	2.93	2.89	1.48%		
2.00	2.74	2.90	2.86	1.47%		
	Gsb	Gsb SSD	Gsa	Absorption		
Average	2.76	2.91	2.87	1.48%		

Appendix A2.3 Flakiness Index (FI)

Weight of sample ***13,651.48 g***

Table A-12: the weight retained aggregate on each test sieve and % of pass

sieve size (mm)	Mass retained in g (M1)	% retained	Discard retained <5%
28	3204.75	23.48%	None of to be discarded because percent mass of all size is greater than 5%
20	4983	36.50%	
14	3501.1	25.65%	
10	1962.63	14.38%	
M2	13651.48		

Table A-13: calculation Flakiness Index of base course aggregate

Sieve (mm)	Flakiness gauge	Wt. of Retained	Wt. of Passed	FI for each gauge
28	37.5-28	2821.97	382.78	11.94%
20	28-30	4138.9	844.1	16.94%
14	20-14	2512.2	988.9	28.25%
10	14-10	1325.25	637.38	32.48%
	TOTAL	10798.32	2853.16	
	FI	20.90%		

Appendix A2.4 Elongation Index (EI)

Weight of sample ***19,586.7 g***

Table A-14: the weight retained aggregate on each test sieve and % of pass

sieve size (mm)	Mass retained in g (M1)	% retained	Discard retained <5%
28	498.3	2.48%	Rejected
20	5108.7	25.44%	NO
14	11769.3	58.60%	NO
10	2708.7	13.49%	NO
M1	20085		
M2	19586.7		

Table A-15: calculation Elongation Index of base course aggregate

Sieve (mm)	Flakiness gauge	Wt. of Retained	Wt. of Passed	FI for each gauge
20	28-30	1011.9	4096.8	80.19%
14	20-14	3329.9	8439.4	71.71%
10	14-10	1060.9	1647.8	60.83%
	TOTAL	5402.7	14682.3	
	EI	27.58%		

Appendix A2.5 Aggregate Crushing Value (ACV)

Weight of sample ***2,500 g***

Table A-16: Sample and calculation of ACV

Test No	Mass of sample (A) gm	Mass of Portion Passing 2.36 mm B.S Sieve after Crushing, gm (B)	Aggregate Crushing Value, ACV % individual (B/A*100) %	Average
	M1	M2	Individual ACV	
1	2500	377.7	15.108	15.76
2	2500	410.2	16.41	

Appendix A2.6 Aggregate Impact Value (AIV)

Weight of sample ***666.5 and 650.2 g***

Table A-17: Sample and calculation of AIV

No	Details	Trial Number		
			T1	**T2**
1	Total Weight of aggregate sample filling the cylindrical measure=W1	W1	666.5	650.2
2	Weight of aggregate passing 2.36mm sieve after the test=W2	W2	64.5	73.2
3	Aggregate Impact Value= W2/W1*100	AIV	9.68	11.26
		Average	10.47	

Appendix A2.7 Los Angeles Abrasion Value (LAAV)

Weight of sample ***5,000 g***

Table A-18: Sample and calculation of LAAV

Trial	Grading of Test Sample	Fraction and Mass		Steel Balls No.	Mass of Sample Retained on 1.70 mm Sieve after washing & oven dried (B)	Loss through 1.70 mm Sieve (g)	**LAAV= C/A*100**
		Fraction (mm)	Mass A (g)			A - B = C	
1	B	19 - 12.5	2500	11	4089.1	910.9	18.22%
		12.5 - 9.5	2500				
Trial	Grading of Test Sample	Fraction and Mass		Steel Balls No.	Mass of Sample Retained on 1.70mm Sieve after washing & oven dried (B)	Loss through 1.70 mm Sieve (g)	**LAAV= C/A*100**
		Fraction (mm)	Mass A (g)			A - B = C	
1	A	37.5 - 25	1250	12	4042.3	957.7	19.15%
		25 - 19	1250				
		19 - 12.5	1250				
		12.5 - 9.5	1250				
						Average	18.69%

Appendix A3: Geruke Quarry Site Base Course Crushed Aggregate (GQSBCCA)

Appendix A3.1 Sieve Analysis (Gradation)

Weight of sample ***5,000 g***

Table A-19: Sieve analysis sample and calculation

Sieve (mm)	Retained gm.	% of retained	wt. of pass	% of pass	Specification limit
50	0	0	5000	100	100
37.5	0	0	5000	100	95-100
20	1985.1	39.702	3014.9	60.298	60-80
10	1208.2	24.164	1806.7	36.134	40-60
5	811.8	16.236	994.9	19.898	25-40
2.36	308.2	6.164	686.7	13.734	15-30
0.425	379.75	7.595	306.95	6.139	7--19
0.075	174.05	3.481	132.9	2.658	5--12
pan	132.9	2.658		0	

Appendix A3.2 Specific Gravity and Water Absorption

Table A-20: Sample and calculation of Specific Gravity and Water Absorption

Sample	A	B	C	B - C	A - C	B - A
1.00	1,975.50	2,007.50	1,295.90	711.60	679.60	32.00
2.00	1,984.40	2,010.60	1,298.30	712.30	686.10	26.20
Sample	Gsb	Gsb SSD	Gsa	Absorption		
1.00	2.78	2.95	2.91	0.02		
2.00	2.79	2.93	2.89	0.01		
	Gsb	Gsb SSD	Gsa	Absorption		
average	2.78	2.94	2.90	1.47%		

Appendix A3.3 Flakiness Index (FI)

Weight of sample ***17,901.89 g***

Table A-21: the weight retained aggregate on each test sieve and % of pass

sieve size (mm)	Mass retained in g (M1)	% retained	Discard retained <5%
37.5	0	0	None of to be discarded because percent mass of all size is greater than 5%
28	3745.95	20.92%	
20	6957.5	38.86%	
14	5242.5	29.28%	
10	1955.94	10.93%	
M2	17901.89		

Table A-22: calculation Flakiness Index of base course aggregate

Sieve (mm)	Flakiness gauge	Wt. of Retained	Wt. of Passed	FI for each gauge
28	37.5-28	2841.97	903.98	24.13%
20	28-30	5548.9	1408.6	20.25%
14	20-14	3874.2	1368.3	26.10%
10	14-10	1625.25	330.69	16.91%
	TOTAL	13890.32	4011.57	
	FI	22.41%		

Appendix A3.4 Elongation Index (EI)

Weight of sample ***17,602.5 g***

Table A-23: the weight retained aggregate on each test sieve and % of pass

sieve size (mm)	Mass retained in g (M1)	% retained	Discard retained < 5%
28	647.5	3.55%	Rejected
20	5617.5	30.78%	NO
14	10207.5	55.93%	NO
10	1777.5	9.74%	NO
M1	18250		
M2	17602.5		

Table A-24: calculation Elongation Index of base course aggregate

Sieve (mm)	Flakiness gauge	Wt. of Retained	Wt. of Passed	FI for each gauge
20	28-30	582.3	5035.2	89.63%
14	20-14	3677.5	6530	63.97%
10	14-10	961	816.5	45.94%
	TOTAL	5220.8	13029.2	
	EI	29.66%		

Appendix A3.5 Aggregate Crushing Value (ACV)

Weight of sample ***2,500 g***

Table A-25: Sample and Calculation of ACV

Test No	Mass of sample (A) gm	Mass of Portion Passing 2.36 mm B.S Sieve after Crushing, gm (B)	Aggregate Crushing Value, ACV % individual(B/A*100) %	Average
	M1	M2	Individual ACV	
1	2500	379.5	15.18	15.65
2	2500	403.2	16.13	

Appendix A3.6 Aggregate Impact Value (AIV)

Weight of sample ***695.7 and 650 g***

Table A-26: Sample and Calculation of AIV

No	**Details**	**Trial Number**		
			T1	**T2**
1	Total Weight of aggregate sample filling the cylindrical measure=W1	W1	695.7	650
2	Weight of aggregate passing 2.36mm sieve after the test=W2	W2	74.5	63.2
3	Aggregate Impact Value= W2/W1*100	AIV	10.71	9.72
		Average	10.22	

Appendix A3.7 Los Angeles Abrasion Value (LAAV)

Weight of sample ***5,000 g***

Table A-27: Sample and Calculation of LAAV

Trial	Grading of Test Sample	Fraction and Mass		Steel Balls No.	Mass of Sample Retained on 1.70 mm Sieve after washing & oven dried (B)	Loss through 1.70mm Sieve	**LAAV= C/A*100**
		Fraction (mm)	Mass A (g)			A - B = C	
1	B	19 to 12.5	2500	11	4078.5	921.5	18.43%
		12.5 to 9.5	2500				
Trial	Grading of Test Sample	Fraction and Mass		Steel Balls No.	Mass of Sample Retained on 1.70 mm Sieve after washing & oven dried (B)	Loss through 1.70mm Sieve	**LAAV= C/A*100**
		Fraction (mm)	Mass A (g)			A - B = C	
1	A	37.5 to 25	1250	12	4051.5	948.5	18.97%
		25 to 19	1250				
		19 to 12.5	1250				
		12.5 to 9.5	1250				
						Average	18.70%

Appendix A4: Welda Mikrbete Quarry Site Base Course Crushed Aggregate (WMQSBCCA)

Appendix A4.1 Sieve Analysis (Gradation)

Weight of sample ***5,000 g***

Table A-28: Sieve analysis sample and calculation

Sieve (mm)	Retained gm.	% of retained	wt. of pass	% of pass	Specification limit
50	0	0	5000	100	100
37.5	0	0	5000	100	95-100
20	1946.7	38.93	3053.3	61.07	60-80
10	986.7	19.73	2066.6	41.33	40-60
5	753.8	15.08	1312.8	26.26	25-40
2.36	555.05	11.10	757.75	15.16	15-30
0.425	346.7	6.93	411.05	8.22	7--19
0.075	155.85	3.12	255.2	5.10	5--12
pan	255.2	5.10			

Appendix A4.2 Specific Gravity and Water Absorption

*Weight of sample **2000 g***

Table A-29: Sample and calculation of Specific Gravity and Water Absorption

Sample	A	B	C	B - C	A - C	B - A
1.00	1,981.20	2,010.20	1,294.50	715.70	686.70	29.00
2.00	1,987.00	2,009.70	1,298.70	711.00	688.30	22.70
Sample	Gsb	Gsb SSD	Gsa	Absorption		
1.00	2.77	2.93	2.89	1.46%		
2.00	2.79	2.92	2.89	1.14%		
	Gsb	Gsb SSD	Gsa	Absorption		
Average	2.78	2.92	2.89	1.30%		

Appendix A4.3 Flakiness Index (FI)

Weight of sample ***15,240.3 g***

Table A-30: the weight retained aggregate on each test sieve and % of pass

sieve size (mm)	Mass retained in g (M1)	% retained	Discard retained <5%
37.5	0	0	None of to be discarded because percent mass of all size is greater than 5%
28	2129.2	13.97%	
20	5048.5	33.13%	
14	4681.3	30.72%	
10	3381.3	22.19%	
M2	15240.3		

Table A-31: calculation Flakiness Index of base course aggregate

Sieve (mm)	Flakiness gauge	Wt. of Retained	Wt. of Passed	FI for each gauge
28	37.5-28	1556.3	572.9	26.91%
20	28-30	4102.9	945.6	18.73%
14	20-14	3149.2	1532.1	32.73%
10	14-10	2788.2	593.1	17.54%
	TOTAL	11596.6	3643.7	
	FI	23.91%		

Appendix A4.4 Elongation Index (EI)

Weight of sample 16,465.3

Table A-32:the weight retained aggregate on each test sieve and % of pass

sieve size (mm)	Mass retained in g (M1)	% retained	Discard retained <5%
28	2375.4	14.43%	None of to be discarded because percent mass of all size is greater than 5%
20	6477.1	39.34%	
14	5110.2	31.04%	
10	2502.6	15.20%	
M1	16465.3		
M2	16465.3		

Table A-33: calculation Elongation Index of base course aggregate

Sieve (mm)	Flakiness gauge	Wt. of Retained	Wt. of Passed	FI for each gauge
28	37.5-28	556.3	1819.1	76.58%
20	28-30	1022.9	5454.2	84.21%
14	20-14	2158.2	2952	57.77%
10	14-10	982.5	1520.1	60.74%
	TOTAL	4719.9	11745.4	
	FI	28.67%		

Appendix A4.5 Aggregate Crushing Value (ACV)

Weight of sample 2,500 g

Table A-34: Sample and Calculation of ACV

Test No	Mass of sample (A) gm	Mass of Portion Passing 2.36 mm B.S Sieve after Crushing, gm (B)	Aggregate Crushing Value, ACV % individual (B/A*100) %	Average
	M1	M2	Individual ACV	
1	2500	379.5	15.18	15.25
2	2500	383.2	15.33	

Appendix A4.6 Aggregate Impact Value (AIV)

Weight of sample ***724.43 g and 691.8 g***

Table A-35: Sample and Calculation of AIV

S.NO	**Details**	**Trial Number**		
			T1	**T2**
1	Total Weight of aggregate sample filling the cylindrical measure=W1	W1	724.43	691.8
2	Weight of aggregate passing 2.36mm sieve after the test=W2	W2	78.1	62.5
3	Aggregate Impact Value= W2/W1*100	AIV	10.78	9.03
		Average	9.91	

Appendix A4.7 Los Angeles Abrasion Value (LAAV)

Weight of sample ***5,000 g***

Table A-36: Sample and Calculation of LAAV

Trial	Grading of Test Sample	Fraction and Mass		Steel Balls No.	Mass of Sample Retained on 1.70 mm Sieve after washing & oven dried (B)	Loss through 1.70 mm Sieve	**LAAV= C/A*100**
		Fraction	Mass A				
		(mm)	(g)			A - B = C	
1	B	19 to 12.5	2500	11	4118.5	881.5	17.63%
		12.5 to 9.5	2500				
Trial	Grading of Test Sample	Fraction and Mass		Steel Balls No.	Mass of Sample Retained on 1.70 mm Sieve after washing & oven dried (B)	Loss through 1.70 mm Sieve	**LAAV= C/A*100**
		Fraction	Mass A				
		(mm)	(g)			A - B = C	
2	A	37.5 to 25	1250	12	4085.5	914.5	18.29%
		25 to 19	1250				
		19 to 12.5	1250				
		12.5 to 9.5	1250				
						Average	17.96%

Appendix A5: Kisho Quarry Site Base Course Crushed Aggregate (KQSBCCA)

Appendix A5.1 Sieve Analysis (Gradation)

Weight of sample ***5,000 g***

Table A-37: Sieve analysis sample and calculation

Sieve (mm)	Retained gm.	% of retained	wt. of pass	% of pass	Specification limit
50	0	0	5000	100	100
37.5	0	0	5000	100	95-100
20	2585.7	51.71	2414.3	48.29	60-80
10	1701.3	34.03	713	14.26	40-60
5	417.1	8.34	295.9	5.92	25-40
2.36	129.9	2.60	166	3.32	15-30
0.425	98.75	1.98	67.25	1.35	7--19
0.075	58.65	1.17	8.6	0.17	5--12
pan	8.6	0.172			

Appendix A5.2 Specific Gravity and Water Absorption

Table A-38: Sample and calculation of Specific Gravity and Water Absorption

Sample	A	B	C	B - C	A - C	B - A
1.00	1,980.50	2,012.40	1,308.80	703.60	671.70	31.90
2.00	1,982.20	2,013.50	1,306.05	707.45	676.15	31.30
Sample	Gsb	Gsb SSD	Gsa	Absorption		
1.00	2.81	3.00	2.95	1.61%		
2.00	2.80	2.98	2.93	1.58%		
	Gsb	Gsb SSD	Gsa	Absorption		
Average	2.81	2.99	2.94	1.59%		

Appendix A5.3 Flakiness Index (FI)

Weight of sample ***16,972.6 g***

Table A-39: the weight retained aggregate on each test sieve and % of pass

sieve size (mm)	Mass retained in g (M1)	% retained	Discard retained <5%
28	2541.2	14.97%	None of to be discarded because percent mass of all size is greater than 5%
20	7260.8	42.78%	
14	4546.2	26.79%	
10	2624.4	15.46%	
M2	16972.6		

Table A-40: calculation Flakiness Index of base course aggregate

Sieve (mm)	Flakiness gauge	Wt. of Retained	Wt. of Passed	FI for each gauge
28	37.5-28	2221.9	319.3	12.56%
20	28-30	6500.2	760.6	10.48%
14	20-14	3858.9	687.3	15.12%
10	14-10	1625.4	999	38.07%
	TOTAL	14206.4	2766.2	
	FI	16.30%		

Appendix A5.4 Elongation Index (EI)

Weight of sample ***20,367.12 g***

Table A-41: the weight retained aggregate on each test sieve and % of pass

sieve size (mm)	Mass retained in g (M1)	% retained	Discard retained <5%
28	3049.44	14.97%	None of to be discarded because percent mass of all size is greater than 5%
20	8712.96	42.78%	
14	5455.44	26.79%	
10	3149.28	15.46%	
M2	20367.12		

Table A-42: calculation Elongation Index of base course aggregate

Sieve (mm)	Flakiness gauge	Wt. of Retained	Wt. of Passed	FI for each gauge
28	37.5-28	921.9	2127.54	69.77%
20	28-30	2200.2	6512.76	74.75%
14	20-14	1258.9	4196.54	76.92%
10	14-10	725.4	2423.88	76.97%
	TOTAL	5106.4	15260.72	
	FI	25.07%		

Appendix A5.5 Aggregate Crushing Value (ACV)

Weight of sample 2,500 g

Table A-43: Sample and Calculation of ACV

Test No	Mass of sample (A) gm	Mass of Portion Passing 2.36 mm B.S Sieve after Crushing, gm (B)	Aggregate Crushing Value, ACV % individual (B/A*100) %	Average
	M1	M2	Individual ACV	
1	2500	416.5	16.66	16.57
2	2500	412.2	16.49	

Appendix A5.6 Aggregate Impact Value (AIV)

Weight of sample 613.5 and 58.23 g

Table A-44: Sample and Calculation of AIV

No	Details	Trial Number		
			T1	T2
1	Total Weight of aggregate sample filling the cylindrical measure=W1	W1	613.5	587.23
2	Weight of aggregate passing 2.36mm sieve after the test=W2	W2	68.12	59.1
3	Aggregate Impact Value= W2/W1*100	AIV	11.10	10.06
		Average	10.58	

Appendix A5.7 Los Angeles Abrasion Value (LAAV)

Weight of sample 5,000 g

Table A-45: Sample and Calculation of LAAV

Trial	Grading of Test Sample	Fraction and Mass		Steel Balls No.	Mass of Sample Retained on 1.70 mm Sieve after washing & oven dried (B)	Loss through 1.70 mm Sieve	**LAAV= C/A*100**
		Fraction	Mass A			A - B = C	
		(mm)	(g)			(g)	
1	B	19 to 12.5	2500	11	3978.5	1021.5	20.43%
		12.5 to 9.5	2500				
Trial	Grading of Test Sample	Fraction and Mass		Steel Balls No.	Mass of Sample Retained on 1.70 mm Sieve after washing & oven dried (B)	Loss through 1.70 mm Sieve	**LAAV= C/A*100**
		Fraction	Mass A			A - B = C	
		(mm)	(g)			(g)	
2	A	37.5 to 25	1250	12	4020.5	979.5	19.59%
		25 to 19	1250				
		19 to 12.5	1250				
		12.5 to 9.5	1250				
						Average	20.01%

Appendix B: Different Photos during Laboratory Work