JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

Evaluation of Cinder Gravel for Gravel Road Surfacing Construction: A Case of Gadab Asasa Woreda

A thesis is submitted to School of Graduate Studies, Jimma University, Jimma Institute of Technology, Faculty of Civil and Environmental Engineering in a Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Highway Engineering)

By: Getachew Asefa Aboye

(November, 2021)

Jimma, Ethiopia

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Getachew Asefa Aboye

Main Advisor: Dr. JEMAL JIBIRIL MUHAMMED (PhD)
Co-Advisor: Engr. BASHA FAYISSA (MSc)

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Approved by Board of Examiners

Dr. Ing Alemayehu Gabisa		24/01/22
External Examiner	Signature	Date
Eng. Gutema Wakijira	____________	________________
Internal Advisor	Signature	Date
Eng. Oluma Gudina	____________	_____________
Chairman	Signature	Date
Dr. Jemal Jibril	___________	____________
Main Advisor	Signature	Date
Eng. Basha Fayissa	______________	______________
Co- Advisor	Signature	Date

DECLAREATION

I, the undersigned, declare that the thesis entitled: *"*Evaluation of Cinder Gravel for Gravel Road Surfacing Construction A Case Of Gadab Asasa Woreda*."* is my original work, and has not been presented by other person for an award of any degree in this or any other University, and all sources of material used for this thesis proposal have to be duly acknowledged.

Mr. Getachew Asefa Aboye ________________ ________________

Candidate: Signature Date

As a master's research advisor, I hereby certify that I have read and evaluated the thesis entitled "Evaluation of Cinder Gravel for Gravel Road Surfacing Construction" which has been done under my guidance and supervision by Getachew Asefa Aboye.

Dr. Jemal Jibril (PhD) _______________ _____________________

Main Advisor Signature Date

Engr. Basha Fayissa (MSc) _______________ ____________________

Co- Advisor Signature Date

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ABSTRACT

Ethiopia has one of the lowest road densities and lowest Rural Accessibility Indexes in Sub- Saharan Africa (World Bank, 2016). *The second Growth and Transportation Plan Of the country involves the construction of 100,000 km of road between 2015 and 2020, and it is likely that this planned expansion of the road network will continue in later years and decades. Cinder gravel offers significant potential as a low-cost, naturally occurring material in low-volume rural road construction and rehabilitation. However, the variability in its engineering parameters, particularly its grading, density, porosity and strength, have meant that the material often fails to meet standard specifications for road construction.*

From previous related studies, the sub-base and base courses such as cement, lime, calcium, fly ash were stabilized by so many researchers with mixing, but less attention was given to naturaly available Cinder gravel with fine materials for surfacing gravel road. The objective of this study is to investigate the strength characteristics of mechanically stabilized and to evaluate the potential use of cindergravel to be used as a surfacing gravel road material. when blended with fine grained soil.

The samples of material were taken from Sigalo and Dabara Quarry sites.by using Experimental trial through processes of mixed, to achieve the ERA manual specification, the cinder gravel was blended with 0, 5, 10, 15, 20, and 25% of fine-grained soil by total mass. In this study the conducted tests includes gradation, compaction test, atterberg limits, specific gravity, AIV, ACV, LAA, and California Bearing Ratio test.

Results indicated that the CBR, SG, AIV, ACV, LAA, water absorption and Atterberg's limits of neat Cinder gravel are: 64%, 2.55, 39.87%, 41.63%, 43.36%, 13.3% No Value, respectively. The optimum amount of fine grained soil is 20 % by weight proportion at a density of 1.683 g/cc, the range of soaked CBR of the blended mix increases from 64 % to 85.9 % and PI value changed from zero % to 12.1%. Analysis of the results shows the addition of fine increase the plasticity index, CBR.MDD and reduce water absorption with an increase in MDD and CBR with steeped locally fine contents up to 20%.

Therefore, it is concluded that, from both MDD and CBR-percent of fine-grained soil curve, the optimum amount of fine- soil treatment by 20%, as exhibited in improvement of its gradation and plasticity. From this study it was found out that locally fine soil stabilized with cinder gravel do meet the minimum requirement of ERA pavement manual specification for use as a wearing course material in gravel road construction.

Key words: Wearing course, cinder Gravel, Blending, Optimum, Amount

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ABBREIVATION AND ACCRONNYMS

AASHTO	American Association of Highway and Transportation Officials
ASTM	American Society for Testing and Material
CM	Centimeter
CBR	California bearing ratio
CESAL	cumulative equivalent standard axle loads
Dr.	Doctor
ERA	Ethiopian Roads Authority
GPS	Global Position System
ITCZ	Inter Tropical Convergence Zone
TRRL	Transport and Road Research Laboratory
LS	Linear Shrinkage
LVRs	Low volume roads
MDD	Maximum dry density
NO	Number
NP	Non-Plastic
ORA	Oromia Road Authority
PI	Plastic Index
PL	Plastic Limit
UK	United Kingdom
URRAP	Universal Rural Road Access Program
VPD	Vehicles Per Day
WAZRA	West Arsi Zone Road Authority

CHAPTER ONE

1 INTRODUCTION

1.1 Background of the study

Ethiopia has one of the lowest road densities and lowest Rural Accessibility Indexes in Sub-Saharan Africa (World Bank, 2016). The second Growth and Transportation Plan of the country involves the construction of 100,000 km of road between 2015 and 2020, and it is likely that this planned expansion of the road network will continue in later years and decades.

Low volume roads (LVRs) are the roads which are designed and constructed to serve 50 – 300 vehicles a day (VPD) with pavement layers and materials capable to resist vehicle axle loads up to 1.0 mil CESAL (cumulative equivalent standard axle loads) during its design life (Gareth, G. J.,, 2018). Cinder gravels are volcanic materials with physical properties different from other natural gravels that are normally used for construction of LVRs.

They have high void contents which absorbs high amount of water, low specific gravity, relatively soft grains and have no binding properties (Subash G. C, S. R., Suresh K. B, Mipe Sora, Gowtham B., 2017). However, the variability in its engineering parameters, particularly its grading, density, porosity, light weight, their rough vesicular surface and strength, have meant that the material often fails to meet standard specifications for road construction. Usually they are weak enough to be crushed under the heel.

Cinder gravel has been used in a number of engineering applications in Ethiopia. Among the first to be documented was its use as sub-base and base course in low-volume roads by (Newill D, Aklilu K, 1980)and (Newill D, Robinson R, Aklilu K, 1987). The general conclusion was that cinder gravels blended with volcanic ash or quarry fines can be used as sub-base and base course on sealed roads with up to 440,000 ESAs and a pavement design based on Overseas Road Note 31 (TRL, 1993).

Observations by the present authors have confirmed that these trial sections of road continue to perform satisfactorily with increased traffic loads, of up to three million ESAs. Other investigations have examined the suitability of cinder gravel as base course material when blended with fine-grained soils and volcanic ash and with lime stabilization (e.g. (Ayele, 2002); (Birhanu.G, 2009); (Eshete, 2011); (Hadera, 2015).

This paper describes an investigation of two type of material, volcanic cinder gravel and fine clay which, although widespread in Ethiopia has been used for road construction only to a limited extent. One reason for the limited use of volcanic cinder gravels up to the present is that they are generally deficient of fine material and do not conform to the grading specifications for conventional crushed rock bases. Another reason is that they have a reputation for being difficult to compact.

This thesis will be conducted taking the case of Asasa Woreda cinder gravel material which is stock piled in sigalo village 15 km from Asasa town.

1.2 Statement of the problem

In many parts of Ethiopia, there is widely distributed cinder gravel. Cinder gravels are pyroclastic materials associated with recent volcanic activity. However, this material has the problem of compaction due to its light weight, its rough circular surface and its high porosity. Another Problems associated with cinder gravels are lack of finer materials in comparison to standard specification and having weak particles that can be broken easily which make them unsuitable for gravel wearing course construction. (Birhanu.G, 2009). Largest cinder cones extending up to a height of 100m can be a source of about one million metric tons of cinder gravel. Particles size of this material may reach up to 0.5m in diameter. In those areas where cinder gravels are available, they are used by mixing with fine-grained soils without having any research based output and guideline regarding their proportion using these materials everywhere incurs transportation cost and time is consuming.

As a result, soil stabilization is one of the most suitable alternatives which are widely used in pavement construction; specifically, mechanical stabilization (Catherine, 2010). Since most cinder gravel soil which is found in Asasa woreda have non plastic index and high CBR value; this property of this cinder gravel soil has high dust nuisance and slippery when dry and wet weather condition are occurred and the surface of the pavement makes it deteriorated. So far, from previous related studies, it give consideration only for the sub-base and base courses, such as cement, lime, calcium, fly ash were stabilized by so many researchers both individually and with mixing through experimental processes, but less attention was given to locally available natural Cinder gravel materials for surfacing gravel road in woreda and kebele level.

Therefore due to the above problems the researcher looking the mechanism to improve the plasticity grading and strength of bearing capacity of the cinder gravel soil by means of mechanical stabilization the soil by natural fine grained material around Dabara kebele in order to increase engineering properties of the soil. The primary objective of the study was to determine the Physical and Chemical Characteristics of mechanically stabilize Cinder gravel road material for surfacing Gravel road construction using natural Cinder gravel and locally available fine grained material directly or through the processing of blended which is stock piled in sigalo query site 15 km from Asasa town.

The tasks carried out:

a) To identify sources of materials from the quarry site suitable for surfacing gravel road material;

b) To investigate the engineering properties of natural Cinder gravel material by mechanical stabilization from the sources; and,

c) To determine mix proportion of the natural Cinder gravel material from quarry sites for use as surfacing gravel road material on the Gravel road project. And

To compare the laboratory results with ERA standard specification.

1.3 Research question

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

1. What are the physical and chemical characteristics of cinder Gravel?
2. How the cinder gravel is potentially used in the construction of gravel road surfacing?
3. What is the optimum amount of cinder gravel needed in the construction gravel road?

1.4 Objective of the study

1.4.1 General objective

The general objective of this study is to evaluate the potential use of cinder gravel as gravel road Surfacing material “A case of Gadab Asasa Woreda’’

1.4.2 Specific objectives

To evaluate the physical characteristics and the chemical of cinder gravel

To determine the potential use of cinder gravel in the construction of gravel road surfacing.

To estimate the optimal percentage amount of cinder gravel in the construction of gravel road surfacing.

1.5 Scope of the study

The findings of the research are limited to sample considered in this research and also specific to the type of locally cinder gravel material most of them that used for road gravel surfacing material in low volume road around the project site. Then test procedures were adopted in the experimental work. The laboratory investigation starts with examining the physical and mechanical properties of Cinder Gravel and Fine grained soil samples in as usual condition which were Sieve analysis, particle size distribution, California bearing ratio (CBR), Plasticity Index (PI), Los Angeles Abrasion (LAA), Grain size distribution, Compaction, Water content, Optimum moisture content (OMC), Water absorption & Specific gravity (SG), Aggregate Impact value(AIV), Flakiness index(FI) and Aggregate crushing value (ACV) tests

Therefore, this research work can correspondingly be reserved as a symbolic and unusual way of improvement of cinder gravel in the research area to be used as road surfacing material.

1.6 Significance of the study

The evolving use of locally Excavating Cinder gravel material could be used for many purposes.

- ❖ Application of locally producer cinder gravel material as rod gravel surface material could benefits road agencies in determining maintenance and rehabilitation for low volume road requirement of the surfacing material.
- ❖ In order to update predicting the outstanding life of surface gravel road and evaluating the trade-offs between different maintenance and construction policies cycle and determining re-gravelling frequency and cinder gravel materials characteristics also specification.
- ❖ It encourage the use of locally available cinder material for gravel road construction having low plasticity index and higher CBR vale for effective utilization of material without wasting the original material.
- ❖ In order to reduce transporting cost of material from quarry site to road project.
- ❖ When stabilized with natural fine soil it minimize initial cost of the project and avoid the deficiency of fine cinder material.
- ❖ Material of cinder and locally available fine grained soil to improve all the physical and chemical characteristics of surfacing coarse material. This will help all the participants of (Contractor, client and consultant) to decide the selecting the quarry Site.

CHAPTER TWO

2 RELATED LITERATURE REVIEW OF PREVIOUS RESEARCH

2.1 Experimental use of cinder gravels for roads in Ethiopia

As part of the joint research project between ERA and TRRL, a full scale experiment has been carried out in Ethiopia to examine the performance of volcanic cinder gravels as surfacing material for unpaved roads and as road base under bituminous surfaced roads (Aklillu, 1987) Compaction trials were carried out to determine the type of equipment to be used and an experimental road stretch comprising 20 different sections were constructed. Six sections were left UN surfaced and were monitored for 28 months during which they carried approximately 140,000 vehicles. A bitumen surface was provided for the remaining 14 sections and these carried 150-200 vehicles per day for 7 1/2 years giving a total of 440,000 equivalent single axles in one direction. Monitoring was carried out by taking quantitative measurements of the performance of the road pavement throughout this period. As a result of the study, recommendations were made for the use of cinders in both paved and unpaved roads. For unpaved roads, recommendations are made for a particle size distribution which provides a road surface that is resistant to corrugations. Improved performance can be obtained by mechanically stabilizing cinders with plastic fines. For paved roads, it is concluded that the types of materials used in this experiment are all capable of carrying in excess of 400,000 equivalent single axles when sealed with a surface dressing and designed. Road mixed asphalt is not a suitable surfacing for cinder gravels. In addition to the cinders, other materials also performed satisfactorily including dry bound macadam, agglomerate and tuff. Besides it was recommended that cinders are easier to compact when they are mechanically stabilized with 10 per cent of volcanic ash soil ((Newill D, Robinson R, Aklilu K)., 1987).

Studied blending of cinder gravels with fine grained soil to be used as sub base material (yitayou Eshete, 2011).In road construction, the use of locally available materials should be made as much as possible. However, when appropriate material cannot be found in areas close to the construction site, very high prices have to be paid with significant time delays and cost increases. In many parts of Ethiopia, there is widely distributed cinder gravel. However, this material has the problem of compaction due to its light weight, its rough circular surface and its high porosity. An investigation has been made on the performance of mechanically stabilized natural cinder gravels of different area to be used as road sub-base material. To achieve the Ethiopia Road Authority manual specification, the cinder gravel was blended with some trail proportion of 0, 10, 15, 20, and 25 % of fine-grained soil by weight and different tests including grain size distribution, Atterberg Limit, compaction, CBR, LAA, absorption and linear shrinkage are conducted in the laboratory. Based on the laboratory test results it is shown that, from both MDD and CBR percent of fine grained soil curve, the optimum amount of fine-grained soil required in order to improve its properties is 19% by weight proportion.

Studied The Use of Natural Pozzolana (Volcanic Ash) to Stabilize Cinder Gravel for a Road Base (Along Modjo-Ziway Route).Based on the study the cinder gravel is blended with 0, 4, 8, 12, 16, 20, and 24% by mass of volcanic ash (Pumicite). Compaction, CBR, Gradation, Atterberg limit, Los Angeles Abrasion, Aggregate Crushing Value, Ten Percent Fines Value, Absorption and Specific gravity tests were conducted in the laboratory (Teshome.T, 2015).

From the laboratory test results of moisture content vs. density relationship, it has been observed that the optimum amount of natural pozzolana (volcanic ash) is 20% by mass proportion at a density of 1.76g/cc. Air curing technique was used for the soaked and un soaked condition where the stabilized samples were covered with a polyethylene sheet and kept in a normal air temperature and out of water intrusion during the a curing period of zero, three, seven, fourteen and twenty eight days. For the optimum blending proportion; the range of soaked CBR increases from 98% to 245% whereas for the un soaked condition the CBR increases from 118% to 307%, for 0 to 28 days curing (Teshome.T, 2015) Studied stabilizing cinder gravel for heavily trafficked base course. Based on this study Mechanical and cement stabilization were investigated in two subsequent phases. In the first phase, optimum amount of fine soils that makes up the deficiency of the fine particles of natural cinder gravels was found to be 12%. In the second phase, natural cinder gravel sample without, and with 12% fine soils were stabilized with 3, 5, 7, and 10% of cement by weight. The result of investigation indicated that the optimum amount of cement required to achieve the minimum UCS of 3.0 MPa as specified in ERA and AACRA pavement design standard for heavily trafficked base course without adding fine soil is found to be 7% cement. However, this high cement requirement was reduced to 5% cement which is practical value by mechanically stabilizing cinder gravel with 12% of fine soils before cement stabilization. Nevertheless, it was recommends that the performance of cement stabilized cinder gravel should be investigated in a full-scale road experiment against cracking due to stresses induced by thermal, shrinkage and traffic. (Hadera, 2015) An Experimental Investigation on stabilization of fine grained soil using cinder and coir pith. Based on this study The CBR ratio at 15% replacement of cinder was found to be 13.31%. The CBR increased 1.8 times than untreated soil sample. The CBR at 1% replacement of coir pith was obtained as 12.06%. The CBR value increased 1.7 times than the pure soil. At 15% replacement of cinder, compressive strength was obtained as 0.14kg/cm² for 0 days curing. The strength increased 1.19 times compared to pure soil specimen. At 1% replacement of coir pith, the Compressive strength was obtained as 0.132kg/cm² for 0 days curing. The strength increased 1.12 times compared to pure soil specimen. The optimum amount of cinder is obtained as 15% and that of coir pith is obtained as 1%. The CBR value is obtained as 15% which is 2.12 times the untreated soil sample. From these observations it can be concluded as cinder and coir pith can be used as the stabilizers for the improvement of strength properties of the soil ((Clarke BG, 2017)).

2.1.1 Engineering properties of cinder gravels in Ethiopia

They concentrated on the occurrence and use of cinders. In this study they define cinder gravels in the context of our country and conduct mapping after location survey using aerial photographs, they also study the physical and chemical characteristics of this materials. In order to assure their performance as road construction materials a full –scale experiment was designed and conducted on selected sections of road (Akaki, Bishoftu, mojo, Lake Ziway, Lake Chamo,Woliso, Butajira, Bekoji,Debrezeit - Bekoji).. (ERA, 2017)

Properties of Cinder Gravels vary in size and color and their color can be black, red, gray or brown usually with in the same cone. The black color is mostly due to its high iron content while the red color is caused by oxidation of iron in the scoria, which might have happened because of rainfall during the eruption. Color of cinder doesn't have significance effect on their properties. a) The difference in their properties is attributed to: an Initial deposition of the cone and, b). the way they have been modified since their depositions. Cinder gravels have weak particles which can be easily broken down and they are coarser materials in their natural state. Compaction produces finer particles although this may lead to reducing the required amount of coarser particles. This property makes them difficult to be compacted to a stable layer. The material has moderate durability, high porosity and CBR value well less than that is required to be used as base course material for heavily trafficked roads. Besides their availability they have the advantages of being easily dug out using simple hand tools like mechanical shovel after opening up a working surface using bulldozer.

2.1.2 Performance of cinder gravels in constructed roads

The 110 km Alemgena-Butajira road is the oldest road in Ethiopia known to possess a cinder gravel sub-base. Approximately half of the road length was constructed with a blended cinder gravel sub-base and the other half with conventional weathered basalt, i.e. very different materials. The entire road has a crushed basalt base course. The road was constructed 15 years ago as a low-volume road, but traffic volumes have increased substantially since then. Two sections were selected for performance measurement and sampling. Rutting was measured, a traffic classification count made, and sub-base samples were taken for laboratory testing. The rut depth for both sections was regarded as fair (i.e. 5–15 mm) by Ethiopian Roads Authority standards. Moreover, the road carries an estimated 2.7 million ESAs of traffic in the heaviest loaded direction and has, therefore, become a relatively high-volume road. The blended cinder gravel has, therefore, performed very well as a low-cost subbase material, despite it having a liquid limit of 50% and a PI of 26%, both of which are higher than the maximum recommended in the (ERA, 2017) Low Volume Roads Design Manual (45 and 12%, respectively). Instead of using the PI as the defining parameter for cinder gravel sub-base suitability, it is recommended that the plasticity modulus (PM) be used instead. PM is a measure of the quantity of plastic fines in a material, it is expressed as plasticity index multiplied by the percentage of particles passing the 425 μm sieve, whereas plasticity index (PI) is only a measure of the magnitude of the plasticity, i.e. material stickiness.

2.1.3 Engineering use

Cinder gravel has been used in a number of engineering applications in Ethiopia. Among the first to be documented was its use as sub-base and base course in low-volume roads1 by ((Newill D, Robinson R, Aklilu K)., 1987). These studies involved sampling, laboratory testing, field compaction trials and ultimately full-scale application trials. The general conclusion was that cinder gravels blended with volcanic ash or quarry fines can be used as sub-base and base course on sealed roads with up to 440,000 ESAs and a pavement design based on Overseas Road Note. Observations by the present authors have confirmed that these trial sections of road continue to perform satisfactorily with increased traffic loads, of up to three million ESAs (TRL, 1993). Other investigations have examined the suitability of cinder gravel as base course material when blended with fine-grained soils and volcanic ash and with lime stabilization. (Birhanu.G, 2009). Despite the success of these various investigations, the wider use of cinder gravel as a road construction material in Ethiopia has been constrained due to a lack of material specification and clear guidelines on prospecting, sampling, preparation and application. The current use of cinder gravel is dominated by the hollow block construction industry and many cinder cones and related landforms have been exploited for this purpose.

2.1.4 Guideline for the Use of Cinder Gravel in the Road Sector

The guideline developed as an output of this study included recommendations for prospecting, investigation, sampling and engineering use. Outline procedures for the use of remote sensing and field observation, ground investigation, sampling and testing are included in the guideline to ensure that borrow pits are properly selected for future exploitation. Quite often cinder gravel material can be observed within the exposed soil on natural hillsides and an examination of this material can indicate potentially the worst-case (weathered) condition of the material likely to be present at depth. Recommendations for the use of trial pitting, sampling and field-based AIV testing are made in order to provide an initial assessment of material quality prior to deciding which sources offer the greatest potential. Close liaison with the Environmental Protection Agency and the Geological Survey of Ethiopia, and other regulatory and statutory authorities, is also mandatory to avoid disturbing areas where there might be environmental concerns or where volcanic landforms are of special scientific or landscape interest. (ERA, 2018)

The laboratory testing, combined with the performance assessment of existing cinder gravel road pavements, has demonstrated that most cinder gravel materials can be used in the construction of low-volume roads, either in their natural state or as blended materials, for capping layer, sub-base and base course. The guideline contains recommendations for material testing, subgrade preparation, blending mix design, pavement layer design, and construction method. The design of cinder gravel base courses with lime or cement stabilization for use in heavily trafficked roads is also covered in the guideline, as are the operational limitations on the use of cinder gravels in bituminous surface seals and the techniques that can be applied to optimize their use

2.1.5 Preliminary Investigation of Cinder Gravels by TRRL

The main conclusion from the preliminary investigation of cinder gravels by TRRL which

Covered a field survey, a laboratory study and an examination of a cinder gravel road, are given below

i. Cinder gravels are more widespread in Ethiopia than was originally believed; this showed the value of using aerial photographs in survey work and enabled a preliminary map to be prepared giving the distribution of cinder cones.

ii. In order to obtain representative material from a cinder cone, it is important that samples are taken from below the weathered zone, which can extend to a depth of two meters.

iii. Although 'as dug' cinder gravels do not meet the recommended grading requirements for road base materials, the laboratory investigation revealed that, because of the weak nature of the aggregate particles, breakdown under compaction occurred with an improvement in both grading and strength properties

iv. In the laboratory investigation, the cinder gravels were not affected by changes in moisture and even complete immersion in water only reduced their strength slightly.

v. The addition of locally available plastic volcanic ash soil, to make up for the deficiency of fine material in the grading, improved the mechanical stability of cinder gravels and indicated that this could be a valuable construction practice. However, unlike the natural cinders the mixed materials lost some of their strength when they were saturated with water

vi. The gravel road study confirmed that an improvement in the grading and the strength of cinder gravels occurred under normal road conditions even when trafficking was used as the means of compaction.

Construction materials especially for gravel roads. However, it was necessary to carry out further work under known conditions of traffic and climate in bituminous surfaced roads, as well as in gravel roads, before limits could be recommended for their various uses. It was therefore decided to construct pilot scale compaction trials and then a full-scale road experiment to examine these aspects further.

2.1.6 Gravel road surfacing materials in general

Surfacing is a layer of aggregate materials laid on sub grade on which the base coarse layer is located and it is often the main load bearing layer of the pavement. It protects the sub grade against significant deformation due to traffic loading. In addition it is also serve to protect sub grade against frost and environmental damage. The major requirements of for surfacing material usually are given in terms of gradation, plastic characteristics, and strength of materials Surface gravel road with thickness typically between 200 and 300 mm is a layer of selected material above the sub grade. Gravel road surfacing course provides uniform load and adds to the required structural capacity of the pavement section (ERA, 2002)

Cinder gravels are pyroclastic materials associated with recent volcanic activity which occur in characteristically straight sided cone shaped hills. Cinder cones frequently have large concave depressions on their tops or sides where mixtures of solid and gasses were released during the formation of the cones. Cones are commonly found in group sand can extend to a height of 100 meters and generate about 1million metric ton of cinder gravel.

Particles size of this material may reach up to 0.5m in diameter. Volcanic cinder generally has a rough surface and high porous nature, with its pores chiefly in the form of vesicles instead of the more tube like, interconnected pores of the pumice Scoria aggregate (cinder gravels) is found extensively in Ethiopia especially in the great rift valley, which crosses the northeastern part of the country The study conducted in joint venture by Ethiopian road authority and transport and research laboratory (UK) indicated that volcanic cinder gravels are extensively found in Ethiopia especially in rift valley areas including Akaki, Bishoftu,mojo,LakeZiway, Lake Chamo,Woliso, Butajira, Bekoji, loggia and Nazareth ((Newill D, Robinson R, Aklilu K)., 1987).

2.1.7 Engineering properties of cinder gravel

Natural cinders gravels are pyroclastic natural materials associated with recent volcanic activity. They vary in color, often within the same quarry and may be red, brown, grey, or black. The particle sizes also vary from irregularly shaped lumps of 0.5 m in diameter to sand and silt sizes. Other characteristics features of cinder are their light weight, their rough vesicular surface, and their high porosity. An advantage of cinders as a road construction material is the relative ease with which they can be dug from the quarry; a mechanical shovel or hand tools are usually adequate for their extraction although occasionally a bulldozer may be required to open up a working face ((Newill D, Robinson R, Aklilu K)., 1987).

Modification of properties of existing materials Exiting materials may require modifications so as to improve their engineering properties. Also, locally available materials, which are otherwise not satisfying general specification requirement, can be suitably modified to become acceptable. This also serves the purpose of economy in terms of saving of haulage of costly materials from elsewhere. Sometimes, design may require special purpose material having specific properties which can be achieved through material modification Economic adaptation of a road to special needs and its technical adaptation to local conditions are two complementary aspects which greatly influence planning decisions. The excavation, haulage, and lying of satisfactory pavement materials must be accomplished as economical as possible for all highway projects. However, in developing countries, where a high percentage of the roads to be built and maintained are primarily un surfaced and involve a gravel placement, investment in materials is normally higher. Therefore, in order to obtain the most cost-effective construction, it is necessary for haulage distances, which form the major item of expense, to be minimized by making the best use of locally available materials. ((Newill D, Robinson R, Aklilu K)., 1987).

2.1.8 Marginal Materials

The gap-graded materials are difficult to compact, increased risk of deformation under traffic, increased moisture susceptibility and pumping of fines. The aggregate bases with high fines content are susceptible to loss of strength and load supporting capability upon wetting (Jean Chorowicz, 2005). Base aggregate may be considered marginal in terms of shape if it is not only too flaky or elongated but also if its particles are over-rounded with no angular faces. Rounded with smooth surface texture have poor inter-particle friction and loss of stability, compaction difficulty, low density and high air voids content and low stability. Marginal base materials often lead to distress and can lead to premature failure in the form of severe shrinkage cracking followed by accelerated fatigue cracking and a general loss of stability (Donatas C, 2008). In Ethiopia marginal materials have been successfully used in for pavement layers even though their use is restricted to low volume roads (T1 - T2). Some of these materials are lateritic soils, calcareous, and volcanic rocks. ((Newill D, Robinson R, Aklilu K)., 1987), (ERA, 2013)). Soft aggregates having very poor crushing resistance can be used as pavement construction material by improving them through mechanical or chemical stabilization.((Martin R, 2003), (ERA, 2011)). Cinder gravels having weak particles are one of these and proved to be used as construction of base course layer in roads having low volume of traffic and gravel roads. Both ERA and AACRA recommend the use of locally available materials to reduce cost and environmental effect provided that the suitability of the material has been checked by local experimental investigation. ERA suggest that they can be used for highly trafficked roads given that their performance have been tested locally. ((ERA, 2011), (Birhanu.G, 2009)).

2.1.9 Requirements of wearing courses for unpaved roads and compliance of sections

An ideal wearing course for unpaved roads should have the following attributes:

- An ability to provide an acceptably smooth and safe ride without excessive maintenance;
- Stability, in terms of resistance to deformation under both wet and dry conditions;
- An ability to shed water without excessive erosion or scouring;
- Resistance to the abrasive action of traffic;
- Freedom from excessive dust in dry weather;
- Freedom from excessive slipperiness in wet weather without excessive tire wear; and
- Low cost and ease of maintenance (Netterberg., 1985).

2.2 Methods of stabilization

Stabilization refers to improving the physical and engineering properties of certain material so as to make it suitable for our desired purpose to be an alternative standard material. Soils that do not possess the desired characteristics for a particular construction reduce pavement life and can be improved by adding stabilizers. Aggregate stabilization is approving pavement construction technique which utilizes local aggregates to enable pavement construction at often significantly reduced costs and without adversely affecting the pavement's performance (Maniyazawal, 2020) .The general goal is to reduce the volume of interstitial voids, fill empty voids, and improve bonding between the soil grains .In this way better mechanical properties, reduced porosity, limited dimensional changes, and enhanced resistance to normal and severe exposure conditions can be achieved. The Principal factors to be considered when selecting the most suitable method of treatment are as follows as indicated by (Maniyazawal, 2020)

- Type of material to be treated
- Climatic conditions
- Type and availability of stabilizers
- Proposed use of the stabilize material
- The capabilities and experience of the construction personnel
- The availability of specialist construction plant
- The availability of testing facilities for investigation and subsequent quality control relative costs.

There are three most common categories of stabilization techniques. These are physical, mechanical and chemical stabilization.

2.2.1 Mechanical stabilization

Mechanical stabilization involves compressing the soil particles together to increase density and reduce porosity. Compaction is best achieved when the grain size distribution of a soil is continuous, not uniform or gap graded. The presence of grains of different sizes facilitates the occupation of voids left by other soil particles. Unfortunately, the effect of mechanical stabilization when used alone is easily reversed, especially when the soil comes into contact with water. (AASHTO, 2000) Water causes the lubrication the soil grains, forcing them to move about within the otherwise dandified but still unbound fabric when the material becomes saturated. It therefore follows that in addition to densification, the use of a binder will normally be required mainly to overcome the reversible effect of contact with water (Birhanu.G, 2009).

2.2.1.1 Mechanical Stabilization of Cinder Gravel

Table 5 shows the compaction and CBR test results conducted on mechanically stabilized cinder gravel with 10 to 15% fine soils by mass to determine the optimum amount of fines. Figure 3 shows the plots of these results. In both cases, the results consistently indicate that MDD and CBR increase with increase in fine soils up to 12%. However, beyond 12%, these values decreased. This result indicates that the optimum amount of fine soil that makes up for the deficiency of fines in cinder gravel samples from both Alemgena and Lake Chamo areas is 12%. This optimum amount, 12% fine soils by mass, was mixed with the cinder gravel samples in order to investigate the improvement in strength that can be obtained when mechanically stabilized cinder is stabilized with cement (Birhanu.G, 2009)

2.2.2 Physical stabilization

To involve modification of soil properties by introducing the missing size fractions, The texture of a soil can be altered by calculated and controlled mixing of the different fractions together. When this is done, most of the voids that existed prior to physical stabilization are closed due to closer packing of the grains. An anisotropic network is created limiting the movement of the grains in a soil.. Unfortunately, as was the case with mechanical stabilization, the effect of physical stabilization alone is not permanent. On saturation with water, soil grains are easily dispersed, or washed away. For better results, physical stabilization of soil should therefore be combined with the other two methods (Newill D, Robinson R, Aklilu K, 1987).

2.2.3 Chemical stabilization

Chemical stabilization involves the addition of a binder or bonding agent to a soil (aggregates). The binder modifies the soil properties through cementation or linkage of its particles. Both cementation and linkage are a result of chemical reactions involving the binder and water. Cementation creates strong and inert matrix that can appreciably limit movement in a soil. The voids in the soil are also filled with insoluble by-products of the hydration reaction while some soil particles are coated and firmly held together by the binder The effect of chemical stabilizations more permanent, and may take several years or even decades to partially reverse. For this reason, chemical stabilization of soil is so far considered to be the superior method of choice

2.3 Particle-size distribution

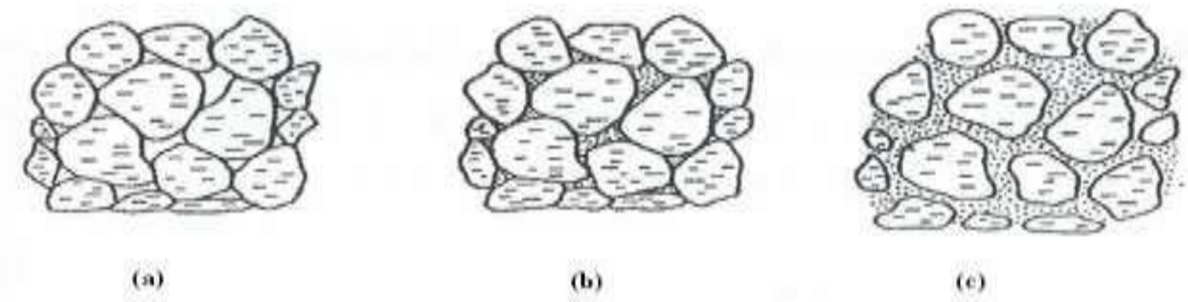
a) Particle size and gradation

The particular packing arrangement for material is normally represented by the particle size distribution (gradation) curve based on proportions (by mass) passing successive sieves.

A lack of coarse or finer particles would produce an unbalanced gradation or distorted gradation curve resulting in poor mechanical stability and unsatisfactory compaction. Therefore, an improvement in gradation and in the reduction of oversized material will result in more uniform strength development, uniform mixing, and compaction. It is preferable to have a gradation with a continuously smooth curve from the maximum particle size to the smallest particle size with no excess or lack in certain particle fractions. The Gradation depends on the amount of weathering of the material. This means that material close to the surface will most probably be finer graded than material that is retrieved at a greater depth (Yoder, 1991)

An aggregate, with little or no fines content as shown in figure 2.2a, gains stability from grain-to grain

Contact. An aggregate that contains no fines usually has a relatively low density but is pervious and not frost susceptible. This material is, however, difficult to handle during construction because of its non-cohesive nature



Aggregate with No fines | Aggregate with sufficient fines | Aggregate with great amount of fines

Figure 2-1 Physical States of Soil Aggregates Mixture

An aggregate that contains sufficient fines to fill all voids between the aggregate grains will still gain its strength from grain-to-grain contact but has increased shear resistance as shown in figure 2.2b. Its density is high and its permeability is low. This material is moderately difficult to compact but is ideal from the standpoint of stability. As shown in figure 2.2c, material that contains a great number of fines has no grain-to-grain contact and the aggregate merely 'float' in the soil. Its density is low; it is practically impervious and it is frost susceptible. In addition, the stability of this type of material is greatly affected by adverse water conditions. Paradoxically, the material at times is quite easy to handle during construction and compacts quite readily (Yoder, 1991) .Mixtures are difficult to design and build satisfactorily without laboratory control. A rough estimate of the proper proportions of available soils in the field is possible and depends on manual and visual Inspection. Several trial mixtures should be made until this consistency is obtained. The proportion of each of the two soils should be carefully noted

The Arithmetical Proportioning is method, the actual gradation of soils X and Y in their respective columns are recorded, average the gradation limits and record in the column

Labeled "S". Next, determine the absolute values of S-X and S-Y for each sieve size and record in the column labeled "(S-X)" and "(S-Y)", respectively. Finally, the summation of columns (S- X) and (S-Y) to determine $\sum A$ and $\sum B$, to determine the percent of soil A in the final mix, use the formula (Birhanu.G, 2009).

$\%A = (\sum B) / (\sum A + \sum B)) * 100$ ---equation 2.1

$\%B = (\sum A / (\sum A + \sum B)) * 100$-- equation 2.2

Asphalt concrete requires the combining of two or more aggregates, having different gradations, to produce an aggregate blend that meets gradation specifications for a particular asphalt mix.

Aggregate blending is a process that blends available aggregates to create a blend that meets gradation specifications while minimizing the unit cost of the blend (Fuzzy, 2012)

2.3.1 Method for Combining Aggregates

Mathematical procedures are available to determine an optimum combination of aggregates, but the "Trial and Error Method" guided by a certain amount of reasoning is the most practical procedure to determine a satisfactory combination and the one we will demonstrate.

a) Trial and Error Method (Source (Yoder, 1991)

The following steps are used to blending the aggregate through trial and error methods: -

Step 1 Obtain the required data, by recording the actual measuring for each material.

a. The gradation of each material must be determined. In this study, the gradation of each natural Cinder gravel and locally fine grained collected from Sigalo and Debara town has been determined in their own columns, let X and Y columns.

b. The design limits for the type of mix must be obtained. The desirable limits of the study of blending Fine with Cinder Gravel will obtained from the ERA manual Specification of Sub-base materials.

Step 2 - Select a target value for a trial blend.

The target value for the combined gradation must be within the design limits of the specifications. This value now becomes the target for the combined gradation.

Step 3 - Estimate the proportions

Estimate the correct percentage of each aggregate needed to get a combined gradation near the target value. The study has been based on the ERA manual of standard Specifications

Step 4 - Calculate the combined gradation.

This calculation will show the results of the estimate from Step3 estimate proportions.

Step 5 - Compare the result with the target value.

If the calculated gradation is close to the target value, no further adjustments need to be made; if not, an adjustment in the proportions must be made and the calculations repeated. The second trial should be closed due to the "education" received from the first. The trials are continued until the proportions of each aggregate are found that will come close to the target value. If the aggregates will not combine within the design range, it may be necessary to use or add different materials.

The gradation curve has shown that the cinder gravel is deficient in fines. However, compaction has been observed to improve its deficiency to a certain extent (Birhanu.G, 2009)

The present study was representative sample was collected from a different area of Debara and Sigalo Vilage. In order to investigate the gradation of the representative sample of the study, the following representative samples were carried out in JIT laboratory tests. Those materials were; neat Cinder gravel, neat locally available Fine and Cinder gravel replaced by Fine at a different ratio based on mass (0, 5,10,15,20, and25%).before the laboratory of gradation performed, the representative sample of Fine sample was kept in an oven for 24 hours, and Cinder gravel were dried under the sun to allow moisture to evaporate until below the target values and the tests of those samples were carried out according to AASHTO T -27.

2.4 Economical aspects of blending of material

Economic necessity and the diversity of physical and climatic conditions require highway engineers to make the best use of available natural resources in developing countries, where the economic adaptation of a road to special needs and its technical adaptation to local conditions are two complementary aspects which greatly influence planning decisions. The excavation, haulage, and laying of satisfactory pavement materials must be accomplished as economically as possible for all highway projects. However, in developing countries, where a high percentage of the roads to be built and maintained are primarily unsurfaced and involve a gravel placement, investment in materials is normally higher. Therefore, in order to achieve the most cost-effective construction and lower subsequent maintenance costs, it is necessary for haulage distances, which form the major item of expense, to be minimized by making the best use of locally available material (Sinha, 1983).Throughout many countries in the developing world locally occurring materials are often not used as extensively as would be possible due to the adaptation of specifications for road building materials that have been derived in industrialized countries with temperate climates and different geology.

When climatic conditions are favorable, more heavily trafficked roads may also be constructed if the type of material is carefully selected and controlled. Recent increases in the costs of road construction have further emphasized the need to make optimum use of these locally occurring resources, not only to reduce expenditure, but also to conserve those better quality materials which are frequently in short supply and of value for special projects that require construction to high specifications (e.g. airfields). (Sinha, 1983)

There are very large potential savings indeed to be made from the implementation of research findings from work done by TRRL and others on design standards for low volume secondary and feeder roads. For example, in Malawi, the provision of a crushed stone base, which is often the preferred design option, is generally around 15% of the total project costs. The difference between the cost of 1km of crushed stone base and 1km of locally available lateritic gravel is at least 4: 1 (BOSSTON, 2006). Substantial savings on the cost of construction of low volume roads can be achieved if these locally abundant gravels can be utilized for the base construction. Where sources of crushed stone are not readily available, which is the case in many areas in southern Africa the difference in costs between crushed stone and the natural gravel base is much higher than the 4:1 quoted (BOSSTON, 2006).

The use of recycled concrete materials for capping and road sub-base can be economically advantageous when compared with the use of primary materials for the same purposes. Cost comparisons with primary aggregates suggest that savings of 20 - 30% are possible (Digest , 1999). These savings vary depending upon the geographical location and transport requirements. In some countries, crushed concrete in defined circumstances can be used as a substitute material to primary material often with economic advantage. Such material is available from demolition operations and can be suitably prepared by appropriate processes such as screening, crushing, grading and testing. The use of crushed concrete can offer benefits cost savings, primary resource conservation and transport impact reduction. With correct selection and processing the material can have a performance that can match or even exceed the properties of conventional primary materials to strengthen foundation soils.

There has been a limited use of the material in the construction of roads and paved areas over many years (Digest , 1999). If the appropriate sub-base material cannot be found in areas close to the construction site, then very high prices have to be paid in this type of road construction process, which causes significant delays or cost increases. In such cases, sometimes low-quality materials are used which affects the road quality and durability over time and results in very significant losses. Therefore, improving the quality of materials is very important for road construction works, in order to ensure that projects meet the necessary cost and quality criteria.

2.5 Summary

As seen in the literature review, this method is used primarily to determine the grading of materials proposed for use as Cinder or being used as fine grained soils. Then we determine grain size analysis is used to determine the relative proportions of various particle sizes in cinder gravels. To do this analysis, a wet preparation method is performed which is given in AASHTO T-146 and weighed sample of dried aggregate is shaken over a nest of sieves having selected sizes of square openings. Then the weight of material retained on each sieve is determined and expressed as a percentage of the original sample the results are used to determine compliance of particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various natural cinder gravel products and mixtures containing fine grained material.

The source of suitable materials for road construction may become increasingly, difficult as conventional high-quality resources depleted and the costs of hauling or transporting materials for long distance may also increase in many areas. However, to minimize the problem associated with the pavement life, an affordable stabilization method for natural Cinder gravel, as surfacing gravel road material for the unpaved road had been undertaken for locally available material. So far, from previous related studies, there were different mechanisms by which stabilization of soil had achieved, such as cement, lime, calcium, fly ash both individually and mixing but less attention was given to locally available natural cinder gravel materials as a gravel road construction. The researcher was conduct the study of the two areas of natural cinder gravel materials and locally available fine grained that constitute for a low volume of gravel road surfacing layer with blending in several proportions.

CHAPTER THREE

3 RESEARCH METHODOLOGY

3.1 Study area

The study was conducted at Asasa town, southeastern Ethiopia, which is located in the West Arsi Zone of the Oromia region 385 km away from Addis Ababa. Its geographical coordinates are between 07° 06' N latitude and 39°12"E longitude with an estimated area of 1,139.38 km^2 and with an elevation of 2367 meters above mean sea level. It lies in the climatic zone locally known as woyna-dega. It is the administrative center of Gedeb Asasa woreda. The selected materials for this research was taken from quarry sites in Asasa Woreda area, namely; Debara , and Sigalo which are located at 5 km, & 15km away from Asasa Town, respectively.

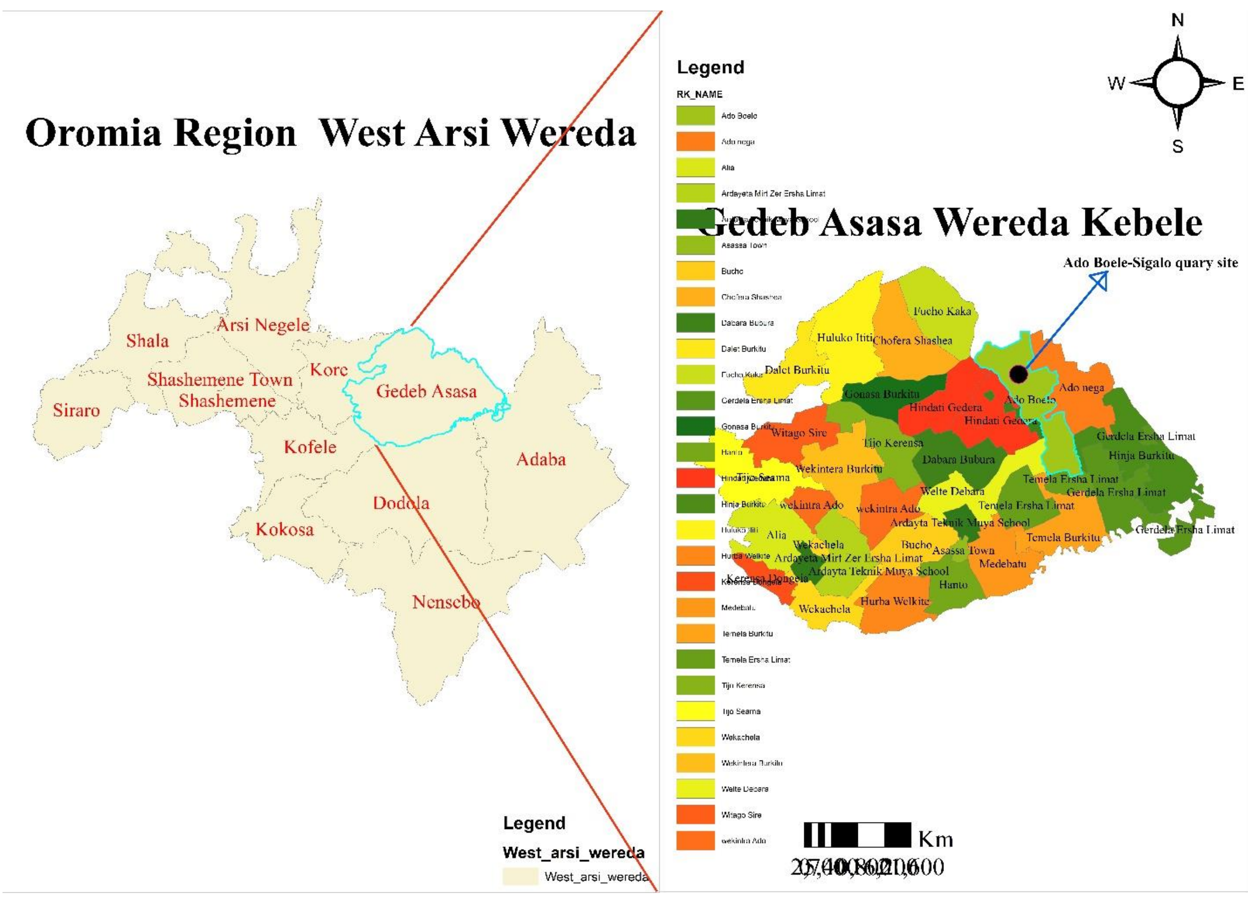


Figure 3-1 location of the quarry site

The samples in this study was collected around Asasa area. The available cinder gravels are located 15 km (07º 6'21´´.N, 39º 11'40´´.E) far from the project and the fine grained soil of the blending materials are located 10 km (07º 14´.2191'N, 39º 51.2904'E) far from Asasa town. The fines borrow materials are also used in the gravel road surfacing construction of the road. Cinder is collected from quarry. The same in color, often within the different space the same quarry and may be red. The particle sizes also vary from irregularly shaped lumps of 0.5 m diameter to sand clay and silt sizes. Other characteristics features of cinder are their light weight, their rough vesicular surface, and their high porosity. The surface of cinder aggregate is usually rough and highly porous due to its mineral structure. The status of the project for this study was conducted under the construction of the surface layer. After

Mixing/blending of the natural gravel soils with cinder material the engineering properties of soils was computed to know how much improvement of the quality of gravel road surfacing observed.

3.1.1 Climate

The major factors influencing the rainfall in Ethiopia are the Inter Tropical Convergence Zone (ITCZ) and wings blowing from the Atlantic and Indian Ocean. The traditional classification of climatic zones in Ethiopia is based on altitude and temperature. It divides the country into five climatic zones as shown in the table(Berhanu, 2009). According to the rainfall statistics Gadab Hasasa woreda the climate zone is Weindega and its Average Annual rain fall is 1200 ml.

Table 3-1 C1imate Zone of Ethiopia

Climate zone	Elevation(m)	Average Temperature(°C)	Average Annual RF
Wurch (cold)	>3200	<10	<800
Woyina Dega (Cool-Cold)	2300-3200	10-16	1000_2000
Wein Dga(Warm-Cool)	1500-2300	16-20	1200
Kola(hoot-Warm)	500-1500	20-28	600 (1000 in places)
Berha(hot)	<500	28-34	<400

3.1.2 Population of the study

The study population for this research was the material to be used in order to make the wearing course materials for Construction based on the Standard specifications of ERA, BS, AASHTO, and ASTM. Those material were the Fine material from Dabara kebele which is collected from quarry sites and the locally available materials of Natural Cinder gravel from Sigalo kebele which is collected from the quarry sites.

3.1.3 Research Materials

Surfacing materials improves the structural support and reduces road surface erosion. The selection of surfacing type depends upon the traffic volume, local soils; Materials used for surfacing layer construction shall consist of hard, durable, tough and strong particles or fragments of stone which must be resistant to carry load imposed on them during construction and design life. They must have mechanical interlocking stability, must be resistance to mineralogical change and physical break down due to any cyclic environmental change. Materials acquiring Suitable for surfacing construction have been labeled by ERA as standard materials designated as Cinder gravel, locally fine grained material, and Water with certain specification of grading, shape and minimum strength. The Fine Samples and Cinder gravel were purposively collected from Gadab Hasasa town from the stockpile and Debara and sigalo quarry site for wearing course Construction respectively according to AASHTO T-2

Figure 3-2: Photo shows Cinder Graveling Road surfacing (July 06, 2021, Captured by Getachew)

3.1.4 Study variables

There were two types of variables that were taken into consideration

- Dependent variable
- Independent variable

3.1.4.1 Dependent Variable

In this study, Evaluation on the potential use of Fine grained soil with Natural Cinder gravel has been considered as the dependent variable which is the suitability of blended Fine grained soil with Cinder Gravel road for wearing course material, which is determined the Effect of natural fine grained soil on cinder gravel for gravel road surfacing.

- Cinder gravel
- Fine grained soil

3.1.4.2 Independent Variable

Variables while independent variable are the laboratory tests as shown in table3.2 has been carried out such as the:-

- Particle size distribution,
- California Bearing Ratio
- Plasticity Index (PI),
- Los Angeles Abrasion (LAA),
- Grain size distribution,
- Compaction,
- Water content,
- Optimum moisture content (OMC),
- Specific gravity (SG),
- Aggregate Impact value (AIV), and
- Aggregate crushing value (ACV)

Which is the values of laboratory tests that has been described the engineering property of Cinder gravel and Fine gained soil mixture. They can represent the appropriateness of the material for use as a Wearing course.

3.1.5 Study design

The research follows experimental type of study which begins by collecting samples. The stages involved in the study include:

• Taking samples

• Preparation of samples for each laboratory tests

• Laboratory tests to characterize natural untreated cinder gravel materials and Fine samples.

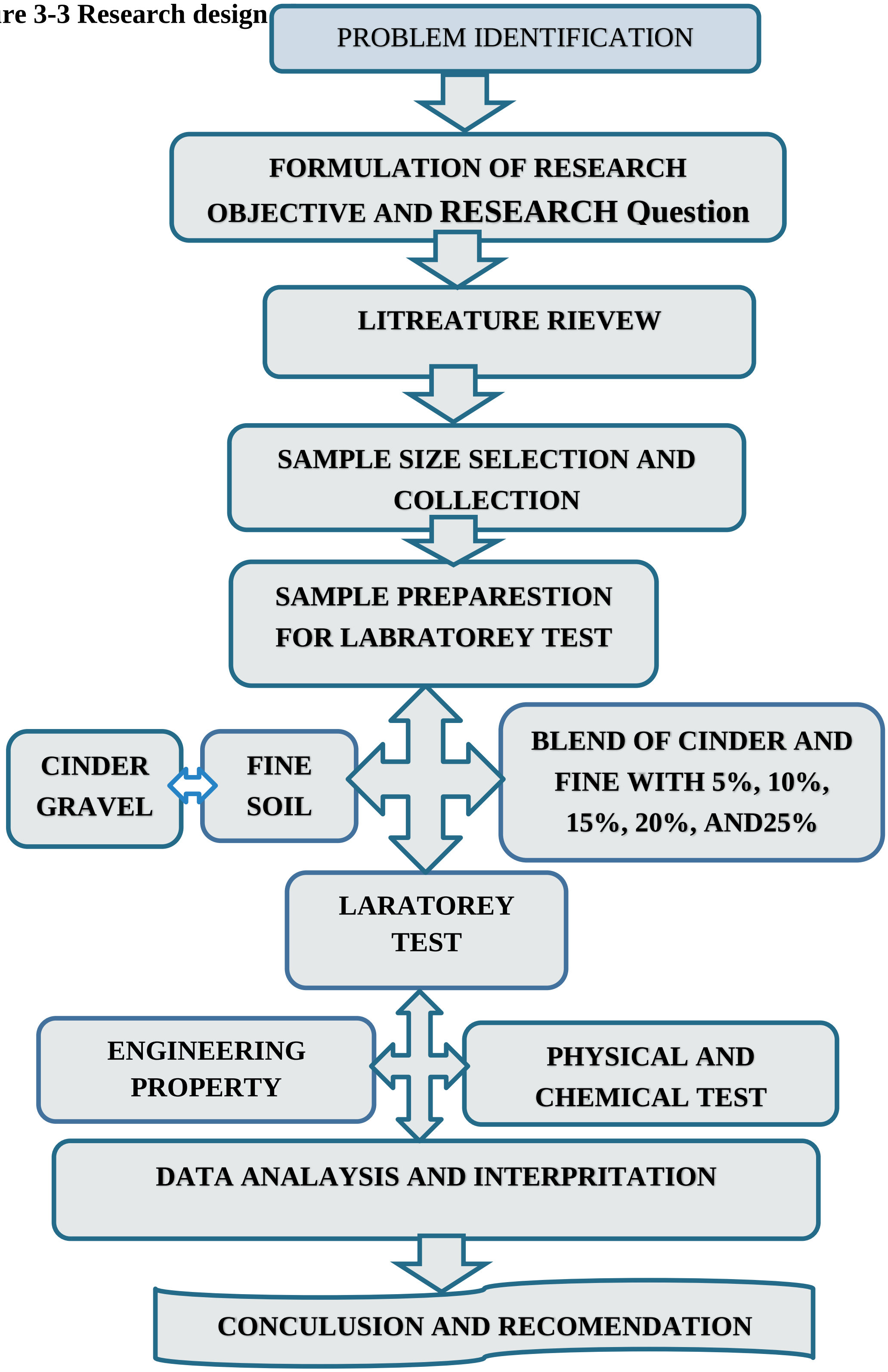
• Process of blending cinder gravel with FINE soil to find out maximum replacement amount that satisfy requirements of standard specification

The laboratory investigation starts with examining the physical and mechanical properties of Cinder Gravel and Fine grained soil samples in as usual condition which were Sieve analysis, particle size distribution, California bearing ratio (CBR), Plasticity Index (PI), Los Angeles Abrasion (LAA), Grain size distribution, Compaction, Water content, Optimum moisture content (OMC), Water absorption & Specific gravity (SG), Aggregate Impact value(AIV), Flakiness index(FI), , Aggregate crushing value (ACV) and modified compaction tests

All above mentioned test was conducted on Cinder gravel - Fine grained soil and Cinder gravel separately and their blending with varying proportions (Cinder gravel replaced by 0, 5, 10, 15, 20, and 25% of Fine grained soil because to improve the deficiency of fine material, to increase the durability, stability and strength of the road.

All Laboratory tests performed were as per AASHTO, ASTM, ERA, and BS manuals and for the investigation of this research, seven samples of materials are studied.

Figure 3-3 Research design



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3.2 Source of data

3.2.1 Primary data sources and collection techniques`

Field visits in connection with the survey would be all carried out within a distance of 15 km from west Gadab Asasa town. They would been concentrated in areas near to Negele village approximately cinder cones soil was visited and taken two samples were collected for laboratory examination. Samples was obtained from sigalo cone either from existing borrows pits from which material had previously been extracted or by digging pits where cinder cones had not been disturbed

3.2.2 Secondary data sources and collection techniques

The secondary data was collected through review document, reading and note taking; scanning and photocopying books, journals, reports and maps; browsing and extracting through trusted websites; like Academia, science direct, research gate and other relevant websites that are need to get evidence on the study topic.

3.3 Sampling sample size and techniques

Sampling procedures for materials was Purposive-sampling techniques and quartering sampling techniques is used for sample preparation.so cinder gravel and fine samples was collected from two different areas namely Sigallo, and Debara which would remain from now on through the paper as their designation in this research for result analysis. Representative Samples was collected in accordance with AASHTO T-2 methodology for sampling from stock piles. Samples of cinder gravel would be taken in increments taking care weathered material not to be include. .before commencing to testing samples of cinder gravel and locally fine grained soil will prepared using mechanical splitter to obtain uniform samples for all tests. Details of this procedure can be referred in AASHTO T – 248 reducing samples of aggregate to testing size.

These sampling techniques were proposed based on the intention to perform laboratory test on the required materials to design mixed such as Cinder and fine grained soil, and to investigate the effect of fine grained soil material on cinder gravel by finding the result according to specification of ERA manual .. The study was performed to achieve and improve the characteristics of cinder gravel material either directly or through processes of blending with fine grained by proportion of its percentage through laboratory tests for both types. It was requires a minimum of 2 samples and 3 specimens for each laboratory test.

3.4 Data collection method

Field visits in connection with the survey were all carried out within a distance 15 km of west Arsi Zone Asasa town. They were concentrated in areas near to Negele village approximately cones is visit and more than two samples were collect for laboratory examination. The samples are obtained from sigalo cone existing borrows pits from which material had previously been extracted or by digging pits where cinder cones had been disturbed. Existing borrow pits provided the opportunity to obtain deeper profile Samples which would more representative of the cone as a whole. The survey data sheets is used to make a comprehensive record of all the relevant information that related to each site. This included descriptions of soil profiles and samples which was collected, the geology, topography, vegetation and climate of the area. The data together with the subsequent test information was obtained is used as an input to a data storage system for engineering materials.

3.5 Data processing and analysis

Prior to data collection, an official letter would be written by Jimma University and send to concerned local authorities and other respective agencies for taking samples and perform the relevant tests then the research will be conducted in performing physical properties and characteristics of cinder gravel, and locally available fine grained soil material through laboratory tests. Then test result was taken with a standard specification of surface, the potential use of cinder gravel as the gravel road surfacing course and the optimum of material on ERA pavement design manual would be an important aspect of the analysis.

3.5.1 Plan for dissemination

The findings of the research will be presented for the civil engineering department and Research, Publications, and Post Graduate Studies office as part of the evaluation and it will be publicly defended in the presence of examiner

3.6 Laboratory test

In this section a description of the testing procedures followed as a part of this research will be discussed. Standard procedures of AASHTO and ASTM have been used wherever possible. The concept of mechanical stabilization was to blend available natural gravel so that, when properly compacted, it will give the desired stability in subject road sections areas. For example, the natural gravel at a selected location material may have low load-bearing strength because of the presence of clay, silt, or fine sand. Soil stabilization aims at improving soil strength and increasing resistance to softening by water through binding the soil particles together, waterproofing the particles or combination of the two. Fine-grained gravel materials are the easiest to stabilize due to their large surface area about their particle diameter while blending fine materials with naturally available natural gravel trial combinations will be followed based on the mechanical analysis of the concerned soil. In other words, the researcher could do the calculations to determine the gradation of the combined materials and the proportion of each component, so that the gradation of the combination could lie within the specified limit

. The laboratory tests in this study were undertaken to evaluate the mechanical and physical properties of locally available Fine grained soil, Cinder gravel and the blending of them in detail procedure

The physical properties of Fine grained soil, are largely dependent on the properties of the Fundamental materials. 100% neat Cinder gravel does not meet the Mechanical properties of the

Requirements of the standard specification for wearing course as per ERA.

To achieve the Ethiopia Road Authority manual specification, the fine grained soil has been mixed, with some trail proportion of (0, 5, 10, 15, 20, and 25%) of Cinder gravel by mass and different tests shown in table 3.1 are conducted in JiT Laboratory Tests

In general, this experimental study was performed in two phases to meet the objective of the research: The first part of this study focuses on the mechanical characterization and determining of the physical properties of neat Fine grained soil and neat Cinder gravel separately. Secondly to determine the optimum percentage of Blending of Fine grained soil replaced with Cinder gravel for Wearing course materials. For the two phases, there were seven different tests as shown in table 3.1 carried out. From these tests, the average value was taken as the input parameter for the analysis and to be compared with the ERA, AASHTO, BS, and ASTM standard specifications manuals

The necessary laboratory tests were conducted for representative samples, and the summary of the laboratory test results is presented in a tabulated form to achieve the objectives of this study.The Samples of different compositions were prepared by adding the different percentages of Fine grained materials of (0, 5, 10, 15, 20, and 25%) by mass with Natural Cinder gravel as shown in table 3.6 below. The trial proportions of this study begun with a minimum of 0%, by weight of Fine grained soil and continued increasing by 5%, to avoid complicated ratios, until the blend fails to satisfy the requirements for wearing course materials as per national and international standards.

Table 3-2: Samples of Fine soil and Cinder gravel at different mix ratio

Sample	Material Descriptions	Specifics arrangement
1	Neat Fine grained soil	100% Fine grained soil +0% Cinder gravel
2	Neat Cinder gravel	0% Fine grained soil +100% Cinder gravel
3	Fine grained soil+ cinder gravel blend	5% Fine grained soil +95% Cinder gravel
4	Fine grained soil +cinder gravel blend	10% Fine grained soil +90% Cinder gravel
5	Fine grained soil+ cinder gravel blend	15% Fine grained soil +85% Cinder gravel
6	Fine grained soil+ cinder gravel blend	20% Fine grained soil +80% Cinder gravel
7	Fine grained soil+ cinder gravel blend	25% Fine grained soil +75% Cinder gravel

3.6.1 Particle size distribution (AASHTO t-88)

This method is used primarily to determine the grading of materials proposed for use as aggregates or being used as aggregates. The aim of this study was to determine the particle size distribution of all the seven sample materials that have been studied as shown in table 3.6. The data obtained were presented in the form of a graph plotted on the grading chart. The tests of particle size distribution procedures were as:

- The specimen to be used for the test is obtained from the original sample by riffling box, or by subdivision using the quarter method.
- The specimen is placed on a tray and is allowed to dry.
- After drying to constant weight, the whole specimen was weighted to the accuracy within 0.1% or less of its total mass.

According to the ERA grading limit, the material shall have a smooth continuous grading within the limits for grading Type 4 gravel wearing course shall be used in the new construction of roads having Annual Average Daily Traffic design less than 50.

3.6.2 Atterberg's Limits (ASTM D424 or AASHTO T90)

Atterberg Limits are defined as water contents at certain limiting or critical stages in soil behavior. These tests help in examining the consistency of the soil and also used for classifying the soil type either using AASHTO or USCS soil classification systems because they correlate with the engineering properties and engineering behavior of soils (AASHTO, 2004).

The liquid limit may be defined as the minimum moisture content at which the soil will flow under the application of a very small shear force. At this moisture content, the soil is:-

General terms, as the minimum moisture content at which the soil remains in plastic condition. The plastic limit is further described as the lowest moisture content at which the soils can be rolled into the thread of 3.2mm diameter without crumbling. The “Plasticity index” (PI) of a soil is defined as the numerical difference between the liquid and plastic limits. It thus indicates the range of moisture content over which the soil is in a plastic condition.

According to ERA specification, all sub-base materials shall have a maximum plasticity index of 12 when determined in accordance with AASHTO T-90. The plasticity product (PP = PI x percentage passing the 0.075mm sieve) shall not be greater than 75% (ERA, 2002).

The laboratory tests were conducted based on procedures outlined in AASHTO T-89 for Liquid limit and AASHTO-90 standard test methods for Plastic Limit.

3.6.3 Moisture – density relations by proctor test (AASHTO T-180)

Practically most soils exhibit a similar relationship between moisture content and density (dry unit weight) when subjected to dynamic compaction. That is, practically the cohesive soils have an optimum moisture content at which the soil attains maximum density under a given compacting effort but the granular soils difficult to define. This fact, which was first stated by R.R. Proctor in a series of articles published in Engineering News-Record in 1933, forms the basis for modern construction process commonly used in the formation of highway sub-grades, bases, embankments, and earthen dams. In the laboratory, dynamic compaction is achieved by the use of a freely falling weight on confined soil mass; in the field, similar compaction is secured through the use of rollers or vibratory compactors applied to relatively thin layers of soil during the construction process. Compaction is a process by means of which the soil can be densified. In soils, there is some amount of air and water besides solid grains. Theoretically, the density of soil can be increased by:

- By reducing the space occupied by the air.
- By elastic compression of soil grains.

During the design of engineered fill, shear, consolidation, permeability, or other tests require preparation of test specimens by compacting at some water content to some unit weight. It is common practice to first determine the optimum water content and maximum dry unit weight by means of a compaction test. Test specimens are compacted at selected water content, either wet or dry of optimum or at optimum, and at a selected dry unit weight related to a percentage of maximum dry unit weight. The selection of water content, either wet or dry of optimum or at optimum and the dry unit weight may be based on past experience, or a range of values may be investigated to determine the necessary percent of compaction.

The determination of the relationship between water content and density of soils is used in determining the compaction of the material. The purpose of compaction is to arrange the particles in such a way as to achieve the highest possible density for the layer with minimum voids. By achieving high densities, not only is the shear strength and elastic modules improved but also the entry of water is reduced or eliminated.

The compaction test was performed by the modified proctor testing procedure stated in AASHTO T-180, standard specification for moisture-density relations of soils using a 4.54 kg rammer and a 457 mm drop, method C (AASHTO, 2004). In this test, a specimen is prepared by compacting aggregate in 152.4 mm mold in five approximately equal layers to give a total compacted depth of about 127 mm, each layer being compacted by 56 uniformly distributed blows from the rammer.

This study of Laboratory test was done to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the material. It was done on neat of Fine grained soil and the natural Cinder gravel, as well as various percentages of Fine grained soil blending with the natural Cinder gravel and MDD and OMC, were determined.

Figure 3-4 Photo during the Determination of Compaction test (June 12, 2021, Captured by Biniyam

3.6.4 California bearing ratio (AASHTO T-193 and T-180)

CBR test conducted to determine the strength of a given material, and how it was behaving under loading. This had been determined by measuring the relationship between force and penetration when a cylindrical plunger of cross-sectional area 1935mm^2 is made to penetrate the soil at a given Standard piston is used to penetrate the soil at a standard rate.

The pressure up to penetration of 10mm and its ratio to the bearing value of a standard crushed rock is termed as the CBR. The principle is to determine the relationship between force and penetration when a cylindrical plunger with a standard cross-section area is made to penetrate the soil at a given rate. It pushed with a constant 1.27 mm/min displacement rate into a sample contained in a steel cylinder with a diameter of 152.4 mm. Although vast experience is built up with this specific test, it is actually at best a strength test that gives some information on the shear resistance of the material about its degree of compaction and moisture content.

The CBR value is determined by force needed to penetrate the plunger 2.54 mm, and 5.08 mm into the compacted specimens (ERA, 2002) . The greater the CBR value in these penetrations is accepted as the CBR value of the sample at any penetration value, the ratio of the force to a standard force is defined as the California Bearing Ratio. This test method covers the determination of the CBR of pavement subgrade, sub-base, base course and gravel wearing course materials from laboratory compacted specimens. The method uses soil particles that pass 19 mm size and provides the CBR value of material at optimum water content. The specimen shall be soaked prior to penetration. This test simulates the prospective actual condition at the surface of the gravel wearing course. A surcharge is placed on the surface to represent the mass of pavement material above the wearing gravel road. The sample is soaked to simulate its weakest condition in the field.

The expansion of the sample is measured during soaking to check for potential swelling. To determine the strength and swelling potential of the samples, a test has been carried out by 4-days soaking- 3-point CBR and loaded Swell testing procedure. The material strength has been used for design purposes by interpolating the CBR values at different compaction levels, with 10, 30 and 65 blows and compacting in 5 layers by heavy compaction. This procedure is necessary to obtain 95% of dry density as determined by the laboratory compaction test. Water to be added was calculated from the compaction test result which is the OMC obtained at MDD and by considering the natural moisture content of the material at the test.

Amount of water to be added for CBR can be calculated as (OMC-NMC)/ (100-NMC)) *Msoil(gm)

Where OMC = Optimum Moisture Content at Compaction (%)

NMC= Natural Moisture Content, dry soil after oven-dried (%)

Msoil= Mass of soil required to be mixed (gm)

According to the (ERA, 2017). ERA manual, for the wearing course material, the minimum soaked California Bearing Ratio (CBR) shall be 20% when determined in accordance with the requirements of AASHTO T- 193. The Californian Bearing Ratio (CBR) shall be determined at a density of 95% of the maximum dry density when determined in accordance with the requirements of AASHTO T-180 method D

Figure 3-5 Photo during the Determination of California bearing ratio test (June 16 2021Captured by Euel)

3.6.5 Specific gravity water absorption (AASHTO T-84/ T-85)

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 % of the dry mass.

The aggregate is considered dry when it has been maintained at 105^0C plus or minus 5^0 C for sufficient time to remove all. The bulk specific gravity and absorption are based on aggregate after 24 +4 hour soaking in water. This method is not intended to be used with lightweight coarse aggregate as they may not become saturated after soaking for 15 hours as described in AASHTO T- 85 Therefore, AASHTO T-84 method which is used for the determination of absorption and specific gravity of grain size less than 4.75mm was followed instead of AASHTO T-85 (AASHTO, 2004).

Bulk specific gravity is the characteristic generally used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate including Portland cement concrete and other mixtures that are proportioned or analyzed on an absolute volume basis. The bulk specific gravity determined on the saturated surface-dry basis is used if the aggregates are wet, that is, if its absorption has been satisfied.

The present study was carried out as the following procedures:

- The representative sample of 2kg passing 19mm IS sieve and retained on 4.75mm IS Sieve was taken
- The two-trial representative sample taken filled in wire Basket and then the basket which filled with sample kept in water which filled inside of cylinder
- The representative sample measured inside the water-filled inside the cylinder after 24 hours
- The representative sample measurement was taken which submerged in water
- The weight of the wire basket in water was measured

- Wipe the surface of aggregates using a cotton cloth to make the surface dry and saturated surface of representative sample was measured
- The representative sample kept in oven dry for 24 hours
- Then the specific gravity and water absorption of the representative sample calculated

Saturated Specific gravity = (W2)/ ((W4+W2)-W3))) Where

W1: Weight of oven-dry aggregate

W2: Weight of surface dry aggregate

W3: Weight of saturated aggregate suspended in water + Wire basket

W4: weight of Empty Wire Basket

Water absorption = (W2-W1) / (W1)

In this study, both Laboratory Test of Absorption and Bulk (saturated specific gravity of the Coarse aggregate material <4.75mm) were performed for each different proportion of Fine with Cinder gravel as well as the neat of Fine and Cinder gravel according to AASHTO T- 84 and AASHTO85

3.6.6 Aggregate crushing value (BS 812-111)

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. The aggregate crushing value gives a relative measure of the resistance of an aggregate to crushing under a gradually applied load and is determined by measuring the material passing a specified sieve after crushing under a load of 400KN. The test is applicable to standard fraction aggregates passing a 12.5mm sieve and retained on a 10mm sieve.

The method is not suitable for testing aggregates with an aggregate crushing value higher than 30, and in such cases, the method for ten percent fines value described in BS 812-111 is applicable.

Then the ACV is defined as the ratio of a weight of fines passing the specified IS sieve to the total weight of the sample expressed as the percentage.

ACV= (M2/M1) *100

Where: - M1, Total weight of dry sample taken (in g)

M2, the weight of the portion of crushed material passing 2.36mm IS sieve (in g)

3.6.7 Aggregate impact value (BS 812: Part 112: 1990)

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 aggregate passing a 12.5 mm sieve and retained on a 10 mm sieve in BS 812: Part 112: 1990. The counter fitted to the machine automatically records the number of blows delivered to the sample. Supplied complete with a 75 mm internal diameter measuring detachable metal cylinder cup, and a steel tamping rod 16 mm diameter, 600 mm length and 13.5 to 14 Kg weight. Arrangement for raising the hammer and allow it to fall freely between vertical guides from a height of 38cm on the test sample in the cup. The test sample is subjected to a total of 15 such blows each being delivered at an interval of not less than one second (Harold N Atkins, 1997). The crushed aggregate is then removed from the cup and the whole of it is sieved on 2.36mm BS sieve until no significant amount passes and the fraction passing the sieve is weighed accurately to 0.1g. Calculate the aggregate impact value (AIV) expressed as a percentage to the first decimal place for each test specimen from the following expression. AIV = (M2 / M1) *100

Where,

M1 is the mass of the test specimen (in g).

M2 is the mass of the material passing the 2.36mm test sieve after test (in gm)

3.6.8 Los Angeles Abrasion value (ASTM C 131 – 89)

The Los Angeles test is a measure of degradation of mineral aggregates of standard grading resulting from a combination of actions, including abrasion or attrition, impact and grinding in a rotating drum containing a specified number of steel spheres, the number depending upon the grading of the test sample (AASHTO, 2002)

The objective of the test is to assess the durability of coarse aggregates used in pavement construction. Due to the movement of traffic, the road stones used in the surface course are subjected to wearing action at the top. Resistance to wear or hardness is hence an essential Property for road aggregates, especially when used in wearing course.. 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 of ASTM C 131 – 89. Los Angeles machine and sieves were utilized for the test. The clean oven-dried sample was sieved through 1.8 mm sieve and weighed. The specimen was placed in the cylinder machine and then a rotation of 500 revolutions at a speed of 30 to 33 revolutions per minute had been done. After the desired number of revolutions, the material discharged and graded through 1.8 mm size sieve. The material that was coarser than 1.7 mm size had been washed and dried in an oven and weighed. The difference between the original and final weights of the sample was expressed as a percentage of the total weight of the sample and recorded as the percentage wear.

Express the Los Angeles Abrasion from the equation. LAA value (%) = (M1-M2)/M1*100

Where M1 is the total mass of the test specimen (in g)

M2 is the mass of the material retained on 1.7 mm sieve (in g)

3.6.9 Flakiness index (BS 812 Part105-1990)

The shape test for aggregate materials includes flakiness index, angularity number, and elongation index when used in the construction of pavement, which may cause the pavement to fail due to the preferred orientation that the aggregates take under repeated loading and vibration. Elongation Index is the percentage by weight of particles in it, whose largest dimension (i.e., length) is greater than one and four-fifths times its mean dimension. For base course and wearing coarse aggregates, the presence of flaky particles is considered undesirable as they may cause inherent weakness with a possibility of breaking down under heavy loads. They are not conducive to good interlocking, and hence the mixes with an excess of such particles are difficult to compact to the required degree. 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 (A.k.AH, 2010)

The flakiness index of the wearing course shall not exceed 35% when determined in accordance with BS 812 Part105-1990. 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. 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 tested. The test is not applicable to materials passing 6.3mm BS test sieve or retained on a 63.0mm BS test sieve. The test is performed using a measuring gauge that has standard-sized slots through which the sample pieces are either passed through or retained.

The result is based on a combined Calculation of that which passes through the slots divided by those retained on the gauge. The test is conducted by trying to pass materials prepared by sieving through standard gauges for each fraction of aggregates (63mm, 50.0mm, 37.5 mm, 28.0 mm, 20.0

mm, 14.0 mm, 10.0 mm, and 6.3 mm) and recording the weights of particles passing and retained. 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:

Flakiness Index, FI = (M3/M2) *100

Where M3 is weight passed after discarding 5% or less (g)

M2 is the sum of the mass of after discarding 5% or less (g)

3.6.10 Linear shrinkage

The linear shrinkage test offers a convenient method to confirm that the test results for the plasticity index are reasonable. Most types of soil exhibit a relationship between the plasticity index and the linear shrinkage of the material. The linear shrinkage is considered a more reliable indicator than the plasticity index for materials with very low plasticity.

Shrinkage due to drying is significant in clays, but less so in silts and sands. If the drying process is prolonged after the plastic limit has been reached, the soil will continue to decrease in volume, which is also relevant to the converse condition of expansion due to wetting.

Linear shrinkage is found by determining the change in length of semi-cylindrical bar sample of soil when it dries out, starting from near the liquid limit. The linear shrinkage value is a way of quantifying the amount of shrinkage likely to be experienced by clayey material.

The method covers the determination of the total linear shrinkage from linear measurements on a bar of soil of the fraction of a soil sample passing a 425 µm test sieve, originally having the moisture content of the liquid limit. For highly plastic material even 3 days of air drying may be deemed necessary. The sample should not be placed too early in the oven. Therefore, due to the long time required for air drying, linear shrinkage is a time consuming test. However, it is important to take the time required in order to produce reliable results. Finally, the linear shrinkage of the soil is calculated as a percentage from the equation given below.

If the original length when made up at about the L.L is denoted by L_o, & the dried length by L_D, the change length is equal to $L0 - LD$, the linear shrinkage, LS, is given by:

LS = (1-LD/Lo (*100)…………………1

Where: L_D is the length of the oven-dry specimen (in mm).

L_o is the original length of the specimen (in mm).

Figure 3-6 Photo during the Determination of Shrinkage limit (July 01 2021, Captured by Haile)

CHAPTER FOUR

4 RESULTS AND DISCUSSIONS

4.1 Physical and mechanical properties of materials

4.1.1 Particle-size distribution. Of cinder gravel

Particle-size analyses were carried out on the samples that were collected during the field survey. Although the zone of weathering varied in different profiles it was clear that this did not extend beyond depths of two meters as, below this level, there was little fine material present. The samples from below two meters that were tested from sigalo, from a cone near to km 3 on the Asasa to Assela road, had more than 3.14 per cent passing the 0.075mm sieve before the material compacted as the Figure 4.1 show. The samples tested after compaction as shown in Figure 4.2 had 5.0 percent a far wider range in the finer fraction with as much as 4 per cent passing the 75mm sieve observed in (table 4.1).

From this study, the gradation of cinder obtained from Sigalo is generally coarser cinder as table 4.1shows. However, in both cases the gradation is almost within the specification limits except that the samples are deficient in fines before compaction and coarse particles are finer than the desirable limits after compaction due to cinder particles break down during compaction due to their weak strength. The cinder gravel is a weak material and has a high water absorption capacity because of high porosity as the particle size increased then generally the strength increased. due to the above reason mentioned compaction is improved the physical property of cinder gravel but still it needs addition of fine material to get the optimum strength.

Table 4-1 Particle size distributions of cinder gravel

SIEVE size (mm)	Before Compaction Passing (%)	After Compaction Passing (%)	ERA Specification	
			Upper limit	Lower limit
50	100.00	100.00	100	100
37.5	94.71	97.00	100	80
20	65.59	88.00	80	60
10	41.47	50.00	65	45
5	25.33	32.00	50	30
2.36	15.21	22.00	40	20
0.425	6.83	14.00	25	10
0.075	3.14	5.00	15	5

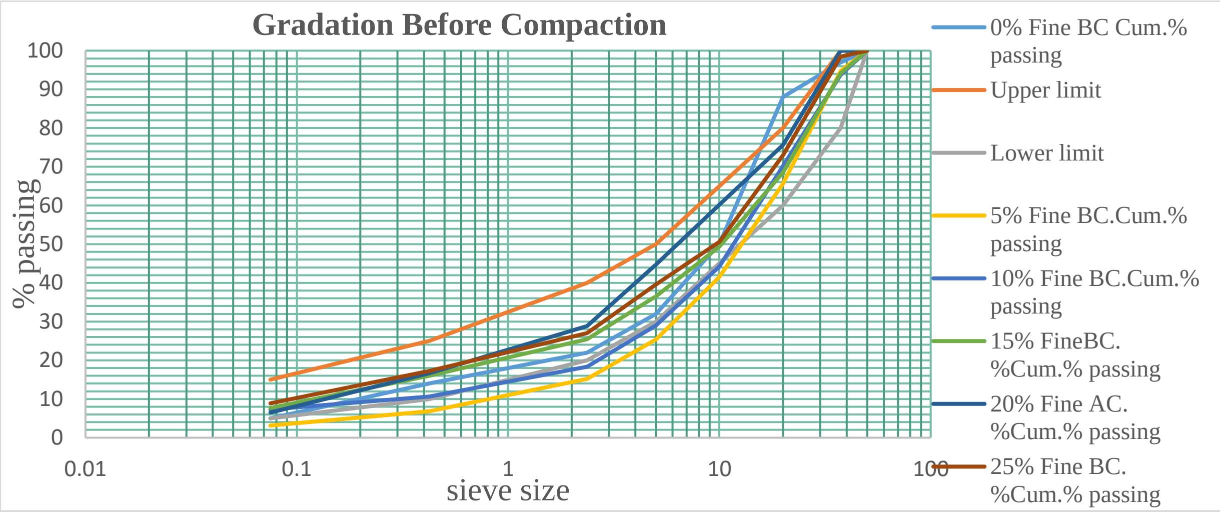

Figure 4-1Particle size distribution before compaction

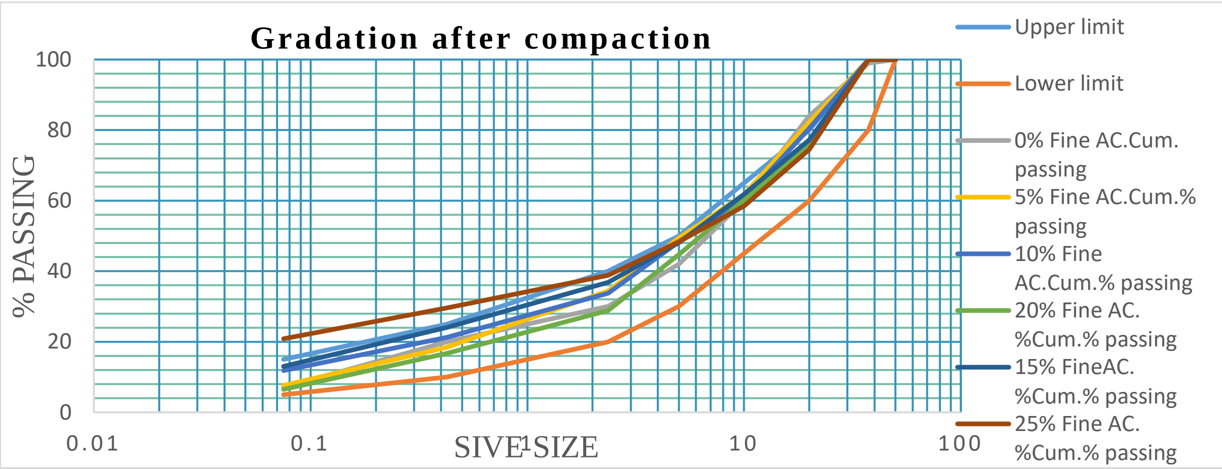

Figure 4-2 Particle size distribution after compaction

4.2 Physical properties of cinder gravel and the addition of fines to cinder gravel

4.2.1 The Effect of Fine material on Maximum Moisture – Density relations

The Standard Proctor's test for cinder gravel with natural fine soil mixes are performed and presented in Table 4.2 and Figure 4.3 The values for the maximum dry densities were noted to significantly increase with the addition of natural fine soil from a neat value of 1.67 g/cm3 to a maximum value of 1.77g/cm3 attained in the blend 20% natural fine soil. Thus the materials used to improve the fine soils were found to facilitate the closer packing of the cinder gravel particles and thus an increase in the maximum dry density. The OMC was found to increase from 8.45 to 13.02 this may be attributed to the addition of natural fine soil as stabilizer.

The effect of natural fine soil on the optimum moisture content for the cinder gravel is shown in figure 4.3 the optimum moisture content for different percentage of fine grained soil increased as the percentage of natural fine grained soil increase from 5% to 25%. The OMC for the natural fine grained soil is 19.9, in the process of stabilizing the cinder gravel soil the addition of 5%, 10%, 15%, 20% and 25% natural fine soil increased the OMC as 5.59, 9.81, 11.28, 12.23 and 13.02 respectively.

The observed values after blending of natural gravel from the two quarry sites indicated a significantly improved condition of 12.23% Optimum Moisture Content (OMC) and MDD of 1.77 g/cc as compared with the values when it was not blended. Good compact ion produces tightly bound gravel with optimum particle interlock. Minimum Permeability and porosity have significantly increased the soil strength, while a high degree of moist compaction results in a road with a lower roughness than similar materials which are poorly compacted in a dry condition. The roughness deterioration can be much slower, and gravel loss and dust emission can be significantly reduced.

For this study, the cinder gravel has little fine-grained soil content and gains its stability from grain-to-grain contact; consequently it usually has relatively low density. Adding fine-grained soil to the cinder gravel still gains its strength from grain-to-grain contact and leads to the increment of density up to an optimum point. The cinder gravel that contains optimum amount of fine-grained soil fills all the voids. It has been seen that the dry density California bearing ratio increases up to 20% then decreases beyond 25% and the optimum moisture content increases as the proportion of different fines increases. The decrease in maximum dry density and CBR may be due to the addition of fines with lower specific gravity than the cinder gravel soil.

Figure 4-3 Effect of different percentage of Natural Fine soil on compaction.

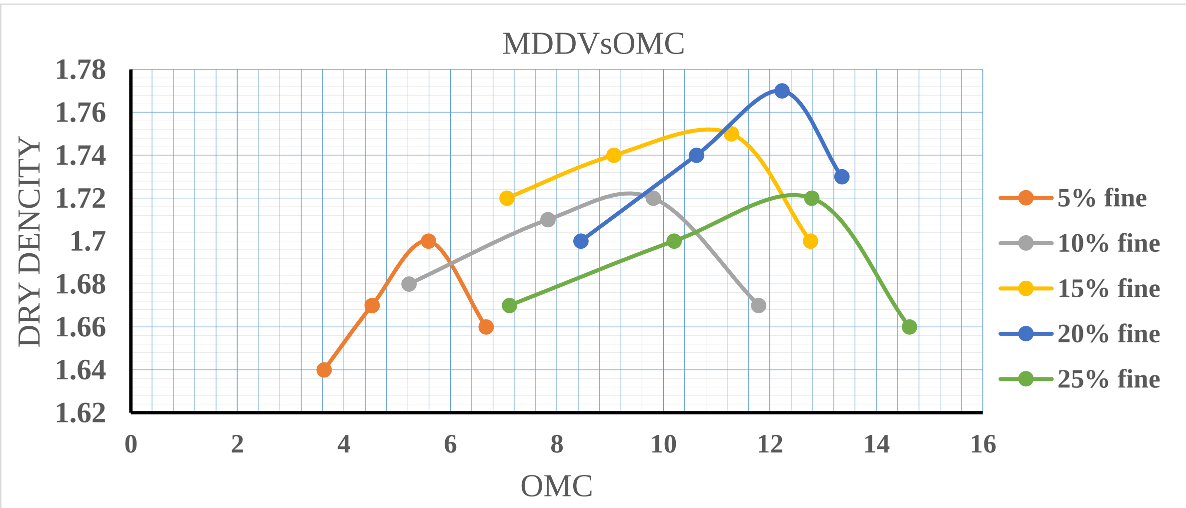

Table 4-2 Effect of Different percentage of Fine soil on Maximum dry density.

% SAMPLE	OMC (%) MDD	MDD (g/cm3)
0%Fine + 100%Cinder	2.51	1.67
5%Fine + 95%Cinder	5.59	1.70
10%Fine + 90%Cinder	9.81	1.72
15%Fine + 85%Cinder	11.28	1.75
20%Fine + 80%Cinder	12’23	1.77
25%Fine + 75%Cinder	13.02	1.72

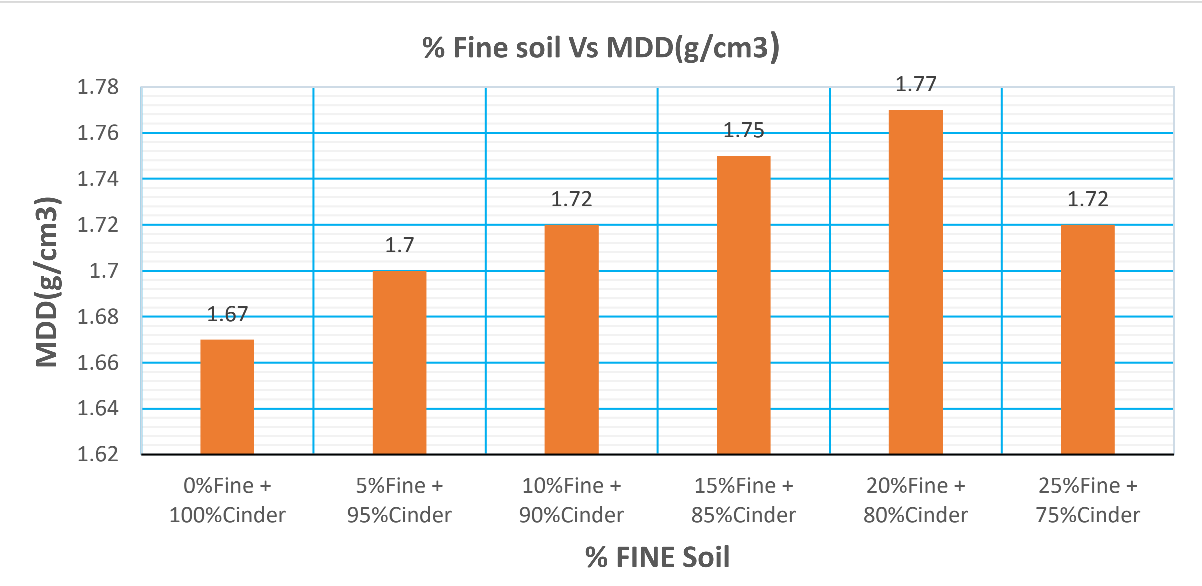

Figure 4-4 Effect of different percentage of Fine soil on Maximum dry density.

The effect of natural Fine soil on the optimum moisture content for the cinder gravel soil is shown in figure 4.5 .The optimum moisture content for different percentage of natural fine soil increased as the percentage of natural fine soil increase from 5% to 25%. The OMC for the natural fine soil is 19.9%, in the process of stabilizing the cinder gravel soil the addition of 5%, 10%, 15%, 20% and 25% natural fine grained soil increased the OMC as 2.51, 5.59, 9.81, 11.28, 12.23 and 13.02 respectively. Where the cohesion increased to the highest value with the increment of the moisture content, then when the moisture content became higher than 12.23%, the density tends to decrease with the increment of the moisture content

From previous researcher, (Belkhatir, 2010) expressed the decrement in the shear strength with the increment of the fine content as the followings; when the fine content increase the voids were filled by the fine materials which caused increment the inter-granular void ratio then decrement in the friction surface between the coarse particle thus the shear strength decreased. However, the reduction percentage of the shear strength was subjected to change when all the voids were totally filled

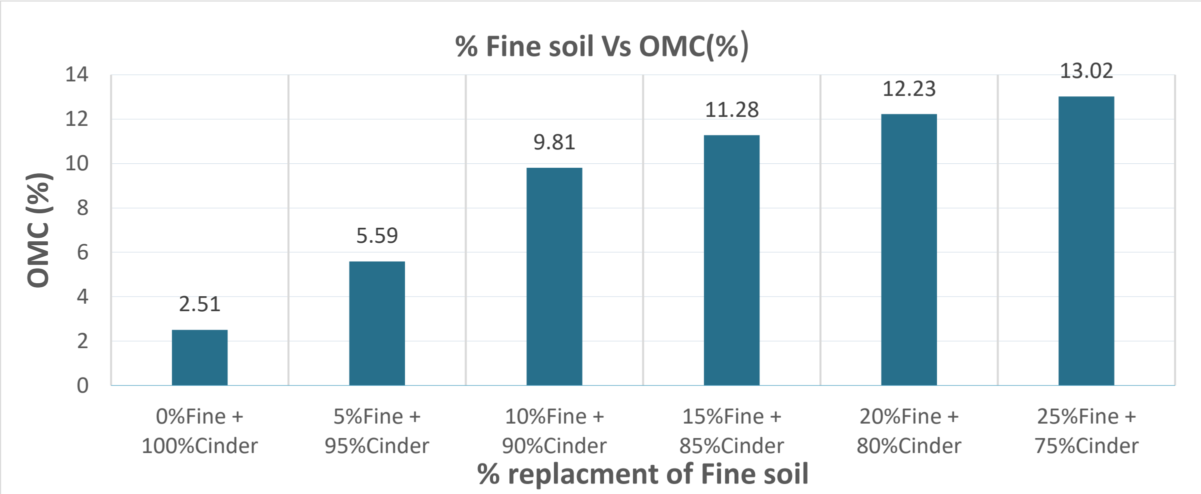

Figure 4-5 Effect of different percentage of Fine soil on moisture content.

4.2.2 California Bearing Ratio

From the Figure 4.3 we can see that as percentage of Fine grained soil replacement for volume of cinder gravel increases the California Bearing Ratio (CBR) also increase by almost 14% From the result of the laboratory test, the CBR value of mixed samples from the sigalo sites was greater than the minimum required by 20%. The Fine quarry sample composed 16.9 % of CBR value while Cinder quarry sample revealed above the standard specification 64%. However, after blending the two samples from the quarry sites considering the mix proportion the CBR value 85.9% had increased due to the improved gradation of the materials while the fine material. Fill the voids between coarser particles.

The reason for this could be increase due to the complete workability to compact the material because of change in gradation due to stabilization and rounded particles of cinder which decrease the shear strength

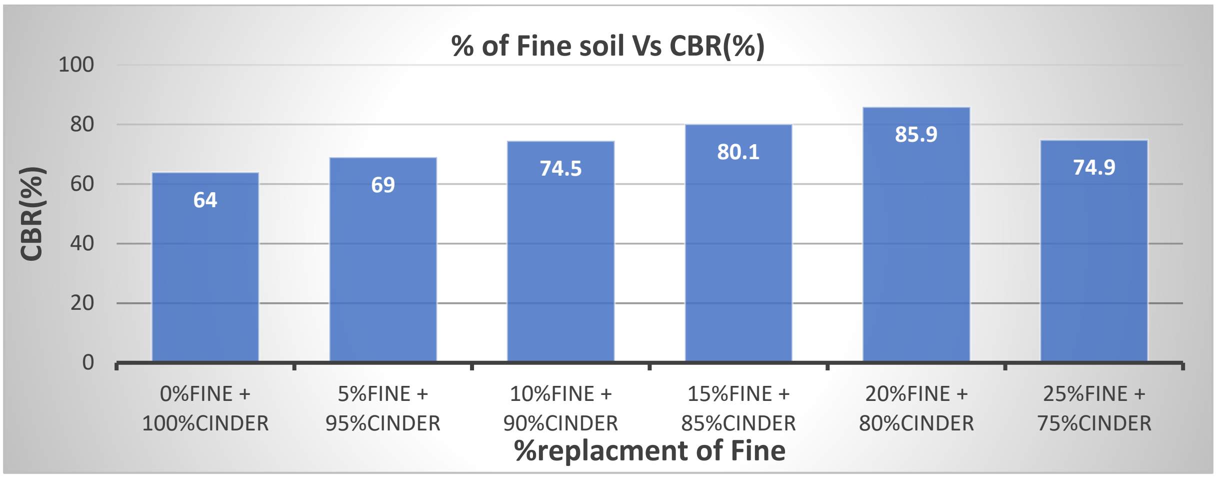

Figure 4-6 Effect of different percentage of Fine soil on CBR value.

The CBR for the cinder gravel soil was 64 %, indicating good quality. The addition of 5%, 10%, 15%, to 20% natural Fine soil increased the CBR by 7.8%, 16.4%, 25.2%, and 34.2% and beyond 20% the CBR decreases by 17.03% respectively. This shows that the strength of the cinder gravel soil increased with an increase of percentage of up to 20% of natural fine soil The decrease in the soaked CBR after 20 % fines content may be due to excess fines that was not mobilized in the reaction, which consequently occupies spaces within the sample and therefore reducing bond in the cinder gravel soil-fine mixtures. Maximum soaked CBR with blending is 85.9 % at 20 % of fine content. And without blending for cinder gravel and fine soil 64 % and 16.9 % respectively.

According to (ERA, 2002). ERA 2002 site investigation manual, a material with CBR value greater than 20% are good quality to work and for gravel wearing course would be recommended, Therefore, due to the cinder gravel soil have a deficiency of clay material, it requires initial modification and/or stabilization to improve its workability and engineering property. Therefore, the addition of 20% of natural fine soil modifies the cinder gravel soil to a suitable for gravel wearing course material for pavement construction.

The improvement of CBR values of the blended sample is because of enhanced interlocking and friction properties of the mixtures and addition of fine which act as binder to the coarse grain particles. It is important to develop suitable envelopes for surfacing layer materials of LVRs since interlocking and friction resistance are enhanced by gradation characteristics of material grain particles.

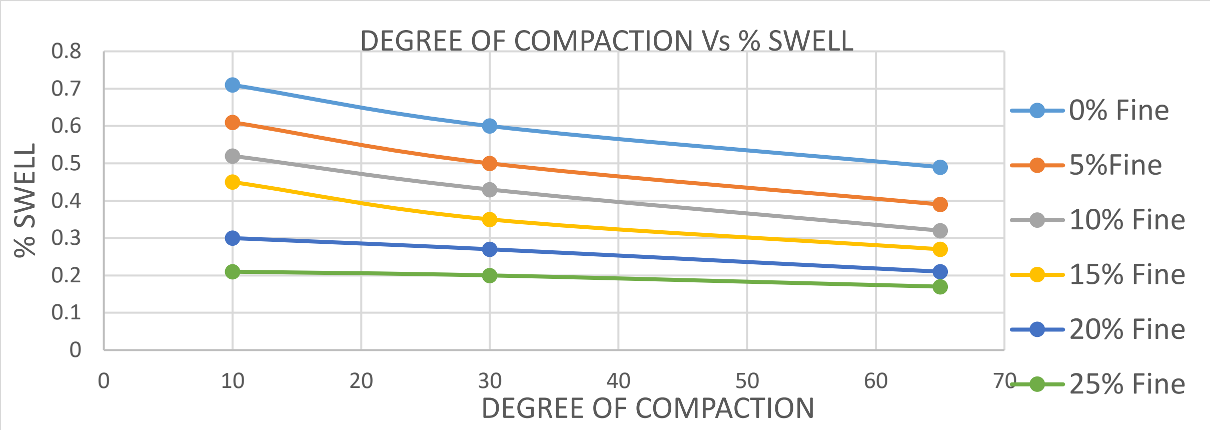

Figure 4-7 Effect of different no of compaction on percentage of Swell.

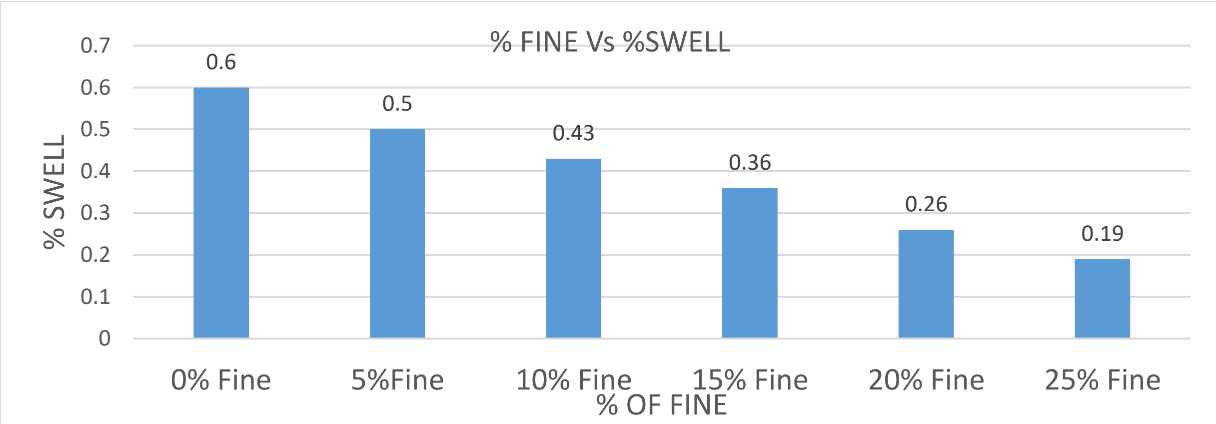

Figure 4-8 Effect of different percentage of fine soil on Swell.

The swell value for different percentage of natural fine soil decreased as the percentage of natural fine soil increased as indicated on figure 4.5 and Fig 4.8. The swell value for Natural fine soil of 5%, 10%, 15%, 20% and 25% increased by 16.67%, 28.4%, 40.0%, 56.7% and 68.33%respectively. A decrease in swelling potential due to anticipated moisture indicates the soil resistance for volume instability decreases. The materials having high plasticity indices which are 25% fine indicated decrease the CBR values which is because of quick soaking and swelling properties of fine soils

4.2.3 Atterberg’s Limits Characteristics

The Atterberg’s Limits test of the cinder gravel soil and soil with selected fine were conducted as per (ASTM D424 or AASHTO T90).Liquid limit and plastic limit values are indicated in the Table 4 -3. Figure 4-9 shows the variation in the Plasticity Index of the cinder gravel and fine - soil composites, the effect of adding the different fine soil in varying proportions. It is observed that Plasticity indexes (PI) of the natural cinder gravel soil is no value. In fine stabilization the liquid limit of soil generally increases but the plastic limit decreases. Thus the plasticity index of soil increases. In general addition in the liquid limit is the indicative of reduction in the compressibility and swelling characteristics. The general increase in liquid limit at all cinder gravel soil-fine soil combination is attributed to the fact that the fine forms bonding and eliminate voids properties with soil particles. The general trend of Plasticity index for fine stabilized soil is increasing with the fine materials increasing. From 5% to 25%% stabilized fine soil indicates almost same rate of in plasticity index (3.2%, 7.2% and 9.3%, 12.2% and 16.3%) with increase of percentage contribution of fine. But, before 5% fine stabilized soil shows there is no significant change in plasticity index with increase of percentage contribution of fine.

The behavior of fine-grained soils in gravel roads is related to the plasticity as measured by the liquid limit and plastic limit tests. A mixture in which the PI of the binder fraction is too high tends to soften in wet weather. A pavement constructed of such material develops ruts under traffic and may shift and shove (i.e., develop a washboard surface). On the other hand, if the mixture is non plastic in character, it will become friable in dry weather, ravel at the edges, and abrade severely under traffic. Such a pavement becomes dusty in service, and much of the binder soil may gradually be blown away in dry seasons of the year.

Table 4-3 Effect of Different percentage of fine soil on Atterberg limit.

% of grained soil	Liquid Limit	Plastic Limit	Plastic index (%)	Linear Shrinkage (%)	Swelling Potential
0%Fine + 100%Cinder	ND	ND	ND	0.14	low
5%Fine + 95%Cinder	19.3	16.1	**3.2**	0.36	low
10%Fine + 90%Cinder	25.5	18.3	**7.2**	0.57	low
15%Fine + 85%Cinder	30.2	20.9	9.3	0.86	low
20%Fine + 80%Cinder	34.1	22	12.1	1.14	low
25%Fine + 75%Cinder	57	21	16.4	1.43	low

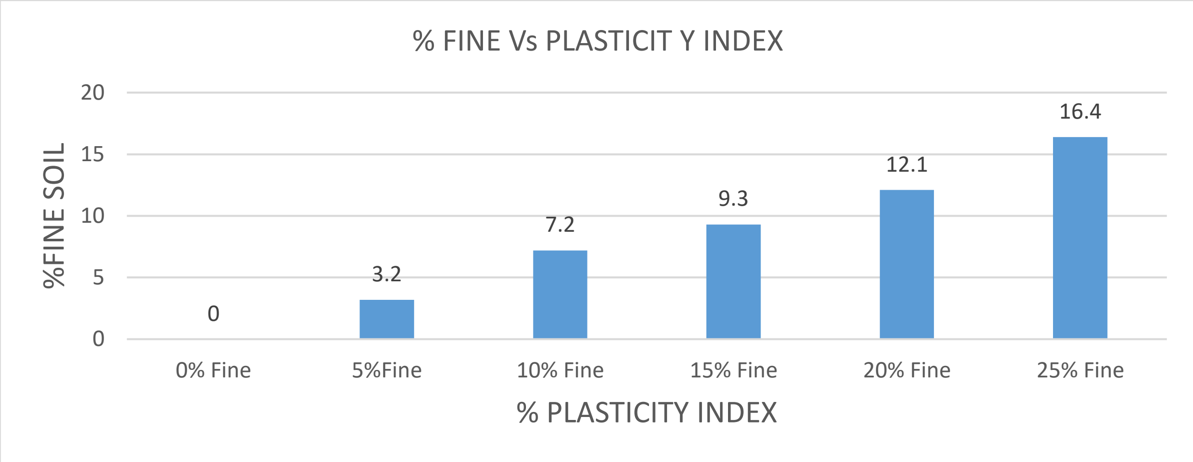

Figure 4-9 Effect of Different percentage of fine soil on Plasticity index.

4.2.4 Absorption and specific gravity.

In order to know some of the special characteristics of cinder gravel, it is important to determine the absorption of potential and specific gravity of natural cinder gravel.. Since cinder gravel is lightweight aggregate, the pores may or may not become essentially filled with water after immersion for 15 hours Therefore, AASHTO T-84 method which is used for the determination of absorption and specific gravity of grain size less than 4.75mm was followed. Accordingly, laboratory test results revealed that the absorption & specific gravity of the cinder gravels that pass sieve 4.75 mm are13.2 to7.5 % and 2.55 to 2.44 respectively as indicated in Figure 4.10. Therefore, the cinder gavel has high water absorption capacity before the addition of fine because of its high porosity then after stabilized the water absorption is decreased due to the space void filled by the fines particles of soil.

Figure 4-10 Effects of % fine replacement on Specific gravity

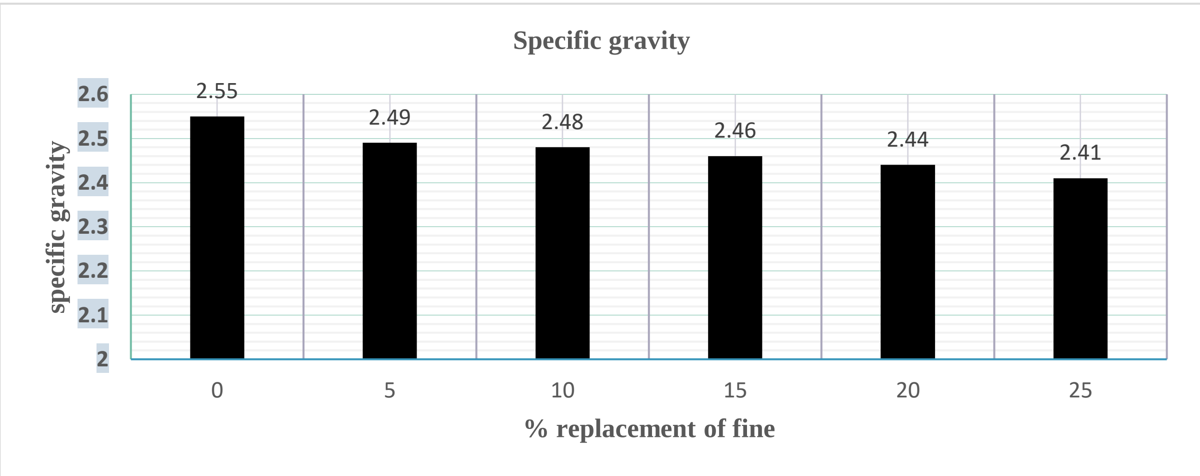

Table 4-4: Physical properties of cinder gravel

S/N	Property test	Result			ERA Specification
		Fine soil	Cinder gravel	80%Cinder +20% fine	
1	MDD, g/cc	1.58	1.71	1.77	Ns
2	OMC,%	19;99	5.59	12..23	NS
3	Specific gravity, g/cc	2.51	2.55	2.44	Min.2.63
4	CBR, %	16.9	64	85.9	>20
5	Plastic index, %	11	NP	12.1	6-12
6	Free swell	37'5	NP	NP	<51

4.3 Particle size distributions of fine grained soil

The stability of a soil-aggregate mix depends on particle-size distribution, particle shape, relative density, and the activity of clay-sized particles. A well-graded aggregate owes its stability to a good distribution of particle sizes, which provides grain-to-grain contact that maximize natural grain to-grain contact. An aggregate that contains few fine sizes usually has a lower density and is less stable but more pervious. However, an aggregate that contains sufficient fines to fill nearly all the voids between the aggregate grains will attain high density and low permeability, sometimes at the expense of increased frost susceptibility. Generally, it can be said that strength increases with maximum particle size. Desirable levels of the percentage of fines and maximum particle size of aggregates,

As part of this research, fine-grained soil obtained near the project site was blended with cinder gravel samples in order to make up for the deficiency of fine materials.

For the fine material that is used in this research the whole descriptive test results are shown below. The fine-grained soils obtained near Dabara are visually classified as yellowish silty and based on the laboratory test results and (AASHTO, 2002). AASHTO classification; it is classified as clay with in medium plasticity (A-6).

Table 4-5 Particle size distributions of fine grained soil

S/N	Sieve size (mm)	Passing (%)	ERA Specification	
			Lower Limit	Upper Limit
1	9.5	82.73	60	45
2	4.75	76.15	50	30
3	2	67.89	40	20
4	0.425	57.55	25	10
5	0.075	51.90	15	5

4.4 Strength of cinder gravel

4.4.1 Los Angeles abrasion

The average value of Los Angeles abrasion test results of cinder gravel had met the requirement set forth under the ERA standard specification for the abrasion resistance impact value. The test was also conducted on the natural wearing course materials, is used to established baseline data. The average percentage of wearing course for the Sigalo cinder gravel quarry site was 43.36% and represents good resistance because it is within the limit of the specification. The specification requires the value to be not more than 51%. Unless specified in the project specification when determined in accordance with the requirements of AASHTO T-96 (Kirk, 2000) .

.Hence the compacted abrasion values are good and are within the acceptable limit based on the project specification and ERA Standard Manual.

The abrasive action of traffic results in the development of ruts, the generation of loose material, and an overall loss of material with time, which necessitates re graveling, which is the most costly maintenance operation. Adequate cohesion and routine maintenance are required to reduce the abrasive action of traffic. The actual gravel loss depends mainly on the traffic volume. The Los Angeles Abrasion result of the cinder gravel shows that it is weak in resistance to abrasion. Even though cinder gravel is weak in resistance to abrasion according to the Los Angeles abrasion test, it does not necessarily tell its field performance as the test is an empirical test.

4.4.2 Aggregate Impact Value

. The AIV is a rapid technique that can be performed on site and provides a useful preliminary assessment of material suitability. It, therefore, helps resolve some of the logistical issues concerning high volume sample transportation to the laboratory and facilitates more representative testing on site.

AIV test focuses on a narrow size range of medium gravel. Given that the strength of smaller-sized clasts may be influenced by weathering to a greater extent than the larger material, this is a potentially significant source of error, and therefore future studies should also determine the field strength of the actual AIV sample in addition to that of the in situ material from the result the sigalo quarry site has little particle strength because it is more than 35%.

According to the test method stated in British Standard the aggregate impact value should be less than 35% in order to say that an aggregate has good resistance to impact. However, the result obtained was 39.84% which showed that cinder has insufficient toughness to resist disintegration due to impact.

4.4.3 Aggregate Crushing Value

As mentioned under 3.7.6, the laboratory test results of ACV were carried out as described in BS 812 in which the result of ACV not suitable above 30%. Based on laboratory test results of ACV of the Cinder gravel as shown in table 4.6 were 43.58%, this shows that weak aggregates give high aggregate crushed value therefore; the Neat cinder is not strong enough to resist crushing under traffic wheel loads.

4.4.4 Flakiness index

According to mentioned under 3.7.9, a Flakiness test was conducted to evaluate the shape of the aggregate as per BS 812 part 105-1990. The ERA manuals recommend as the FI of materials is not exceeds 35%. Based on the test result of FI of the Cinder gravel Sample as shown in table 4.6 below, were 26.23%. This Samples were satisfying the standard specification of ERA Manuals to make materials as wearing course for construction since the result was <35%.

Table 4-6: Strength property of cinder gravel

S/N	Property test	Result	ERA Specification
1	Los Angeles Abrasion, %	43.362	<51
2	Aggregate Impact value, %	39.87	<35
3	Aggregate crushing value, %	43.58	<30
4	Flakiness index, %	26.23	<35

4.5 Mechanical stabilization: the addition of fines to cinder gravel.

It has been shown that the effect of compaction improved the grading of cinder gravels but that there was still a deficiency in the fine fraction of material less than 75 microns. A further series of tests was, therefore, carried out with additional fine material added. In practice this would appear to be a feasible proposition as suitable material, fines, is invariably found adjacent to cinder cones and so is available locally

In the laboratory investigation, the Sigalo cinder gravel was used and 10 per cent by weight of Fine a soil from near the cone was added. The soil had a liquid limit of 43 per cent and a plasticity index of 11.

The tests carried out were the determination of dry density/CBR/moisture content relations at a compaction (4.5 kg hammers) with separate' samples used for each point of-the test as in the first series of compaction tests.

The effect of immersion in water for four days was also examined. The results are given in Table 4.7 which compares the density/CBR/ moisture content relations for the cinder gravel with and without the fines added.

The addition of fines increased the dry density for all levels of compaction by about 1.2 per cent and the CBR values were also increased with an improvement from 64 per cent to 85.9 per cent for the heavier level of compaction Soaking in water for 4 days reduced these values to those for the cinders without fines added.

A further effect of the addition of fines was that the moisture content at compaction could influence the density and CBR obtained, although not in a very marked way

Table 4-7: Results of mechanical stabilization of cinder with fine soils

Fine Soil by weight	OMC (%)	(MDD(g/cc)	CBR (%)
Neat Fine grained gravel	19.9	1.58	16.9
Neat Cinder gravel only	2.51	1.67	64.0
5%Fine grained soil+ cinder gravel blend	5.59	1.70	69.0
10% Fine grained soil +cinder gravel blend	9.81	1.72	74.5
15% Fine grained soil+ cinder gravel blend	11.28	1.75	80.1
20% Fine grained soil+ cinder gravel blend	12’23	1.77	85.9
25% Fine grained soil+ cinder gravel blend	13.02	1.72	74.9

4.6 Chemical Composition of Cinder Material

4.6.1 Geology survey of cinder gravel in Ethiopia: application to low volume roads

The chemical composition of the cinder material that passing 0.75mm was determined at the Geochemical Laboratory of Geological Survey of Ethiopia. The X-ray fluorescence result showed Pozzolanic property of the cinder. The chemical analysis of cinder resulted with the total compound content was conducted to determine the mineral composition of the cinder gravel material, and from the result obtained in Table 4.8 shown the cinder gravel materials contains a greater amount of silicon dioxide (48.62%), which is followed by aluminate and ferrite, with a percentage of 17.12% and 12.23%, respectively. The summation of these three oxide compositions was found to be 77.97%, which was above the minimum of 70% as per

ASTM C-618.and the material is classified as class F pozzolanic material according to (ASTMC618, 2012). It means the material was a good Pozzolan.

The cinder sample had a cementitious compound like calcium oxide, alumina, and iron oxide with a total of about 36.60%. The highest LoI value (3.00 for this study) is clearly related to the high goethite content Goethite is an iron hydroxide derived from the weathering of other iron-rich minerals. Samples with high hematite (Fe_2O_3) and goethite contents, such as those from this sample, might represent more weathered materials that are potentially weaker. According to the geological field descriptions in table 4.8 samples were found to be the weakest in both AIV tests and field descriptions. Therefore, there is an apparent relationship between mineralogy, as an indicator of weathering state, and strength.

Table 4-8. Chemical composition of cinder.

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
Content (%)	48.62	17.12	12.23	7.25	3.53	3.22	1.27	0.24	0.56	2.43	0.64	3.0

4.7 Optimum% of Blending of Fine soil Replaced with Cinder gravel

Table 4.9 shows the compaction and CBR test results conducted on mechanically stabilized cinder gravel with 0, 5,10,15,20 to 25% fine soils by mass to determine the optimum amount of fines. Fig 4.1, up to Fig 4.5 shows the plots of these results. In both cases, the results consistently indicate that MDD and CBR increase with increase in fine soils up to 20%. However, beyond 20%, this values decreased.

These result indicates that the optimum amount of fine soil that makes up for the deficiency of fines in cinder gravel samples from Sigalo areas is 20%. This optimum amount, 20% fine soils by mass, was mixed with the cinder gravel samples in order to investigate the improvement in strength that can be obtained when mechanically stabilized cinder is stabilized with fine.

Table 4.9 show the CBR test results carried out on Cinder gravel and stabilized cinder gravel with 20% fine soils the result are 64% and 89.5% respectively. The table 4.9 shows that the strength of stabilized cinder blended with 20% fine soils has increased compared with that of non-stabilized cinder without the addition of fine soils. Accordingly, the minimum strength requirement specified in ERA manual is attained at 20% of fine by mass.

As one can observe from the table, the percentage increase in Fine gained as a result of adding fine soils has an increasing trend up to 20 % fine and then starts falling. This clearly indicates that 20 % fine by mass is an optimum amount to stabilize cinder gravel with sufficient fines. The gradation of cinder gravel samples lacked fine particles and 20 % of fine soil by mass was found to be optimum for making up this deficiency cinder fine material.

Thus is has been conclude that replacing 20% of Natural fine grained soil with cinder gravel 80% material is a possible alternative.

Table 4-9: Summary Results on Cinder gravel replaced by Fine soil as per ERA.

% of Fine in the blend	0	5	10	15	20	25	Desirable Limits
CBR (%)	64.0	69.0	74.5	80.1	85.9	74.9	>30
OMC (%)	2.51	5.59	9.81	11.28	12.23	13.02	NS
MDD(g/cc)	1.67	1.69	1.72	1.74	1.77	1.68	NS
SG	2.74	2.725	2.70	2.695	2.685	2.67	Min.2.63
GM	2.74	2.69	2.59	2.51	2.45	2.20	>2
Water Abs. (%)	13.2	12.4	9.75	8.75	7..5	6.10	Not exceed 2
PI	NP	3.2	7.2	9.3	12.2	16.4	<12
AIV	39.87						<35
ACV(KN)	29.38						<30
FI (%)	26.23						<35
LAA (%)	33.59						<51

4.7.1 The arithmetic proportioning cinder and fine-grained soil

The arithmetic proportioning as discussed in Table 4.10 Is a rough approximation to determine the proportions of the blending material? It can serve as a reference to make a quick blending without making many trial proportioning tests (Yoder, 1991). It minimizes the number of trial proportioning tests. This method is used in this study to preliminary estimate the optimum proportions of cinder gravel and fine-grained soil.

The grading of natural cinder gravel in table 4.10 shows the deficiency in fine particle. Therefore, it is out of the specification. Blending of a trial proportion of fine-grained soil improves the gradation and the optimum proportioning is found to fulfill the ERA specification manual requirement. Among the trail proportioning of fine-grained soil 20 % are good proportioning from gradation point of view

%A = (∑B) / (∑A +∑B)) *100 --equation 4.1

%B = (∑A/ (∑A +∑B)) *100-- equation 4.2

Table 4-10: Determination of the proportions of cinder and fine-grained soil

Sieve size(mm)	Percent passing: Cinder(A) (1)	Percent passing: Fine-soil(B) (2)	Percent passing: Specification Lower (LL)	Percent passing: Specification Upper (UL)	Percent passing: s (3)	/S –A/	/S –B/	0.804A (4)	0.196B(5)	%passing final mix (4 + 5)
50	100.00	100	100	100	100	0	0	80.40	19.60	100.00
37.5	97.00	100	80	100	90	7	10	77.99	19.60	97.59
20	88.00	100	60	80	70	18	30	70.75	19.60	90.35
10	50.00	82.73	45	65	55	5	27.73	40.20	16.22	56.42
5	32.00	76.15	30	50	40	8	36.15	25.73	14.93	40.65
2.36	22.00	67.89	20	40	30	8	37.89	17.69	13.31	30.99
0.425	14.00	57.55	10	25	17.5	3.5	40.05	11.26	11.28	22.54
0.075	5.00	51.90	5	15	10	5	41.85	4.02	10.17	14.19
						Σ A= 54.5	Σ B= 223.67			

4.8 The potential Benefit of cinder gravel in the gravel road surfacing.

The importance of this study to overcome problems regarding shortage of standard materials near to project site by making use of locally available materials. promote use of locally available marginal materials so that the government of Ethiopia will benefit from using abundantly available resources instead of exploiting scare standard materials which imply conservation of natural resources and Reduces cost and environmental benefit gained from using abundantly available cinder gravel for projects to be built in the study area will help the government to build more networks by eliminating extra costs of hauling from far distance and time delay which is one of the problem to the completion of the road construction at planned construction period.

The potential benefits of using locally available cinder gravel materials for road construction are likely to outweigh the costs incurred in prospecting and testing procedures. If they are exploited using the environmental protection measures and design criteria recommended in the guideline, their use will facilitate the provision of low-cost roads for rural communities in Ethiopia in the areas where these materials occur.

The unpaved cinder gravel rural roads in Ethiopia are majorly surfaced with gravel and are called gravel roads or improved unpaved roads. Typically, gravel is practical, affordable and low maintenance surface for rural roads. Such road surfaces support low traffic volume, particularly of load-bearing trucks. Cinder Gravel can be easily put over freshly cut road and compacted or the existing surface is graded to create a crown, sloped shoulders and run-off ditches. In order to ensure that the cinder gravel roads do not damage easily, drains are added at intervals so as to remove rain water.

Advantages of gravel surfaced roads

1. These cinder gravel roads are low-cost roads.
2. They are easy to maintain.
3. Since these are basic roads, they preserve the rural ambience.

Disadvantages of gravel surfaced roads

1. Cinder Gravel surfaced roads can become difficult to use in wet weathers.
2. These roads require frequent maintenance especially after wet period or when the traffic at such roads increases.
3. These roads generate lot of dust and scattering of stones here and there.
4. Wash boarding is a problem with cinder gravel roads too.
5. Cinder gravel surfaces also absorb some of the surface water.
6. Cinder gravel roads deteriorate more quickly than bitumen surfaced roads.

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Although cinder gravels occur extensively in Ethiopia, rarely support any vegetation other than grasses, and relatively easy to dig with shovel or hand tools, their use for road construction is limited for the reason that they do not meet the specification requirements. In this investigation, mechanical stabilization techniques were used to improve their properties so that they are used as wearing course materials for low volume roads. Based on the results obtained, the following conclusions are made

1. The sieve analysis, which was conducted after the compaction of natural cider gravels, has shown that a significant amount of these materials have been broken down into fine grained sizes. However, the graduation requirement of ERA specification has not been satisfied.
2. The gradation of cinder gravel samples lacked fine particles and 20 % of fine soil by mass was found to be optimum for making up this deficiency of fine materials improves the compatibility and stability of cinder gravels which confirms the results of this studies.
3. Due to the weak nature of cinder particles, compaction causes the breakdown of particles which improves both grading and strength properties, but still needs an additional fine-grained soil to achieve the ERA specification
4. The optimum amount of Fine grained soil to be blended with cinder gravel was found to be 20% as determined through compaction method.
5. Changes in moisture content do not affect the properties of cinder gravels
6. . The blended wearing course material has no plasticity up to 10% beyond that the characteristics and the plastic product is changed.
7. Based on from MDD- and CBR of fine-grained soil curve respectively the optimum amount of fine-grained soil is 20% by mass. It can finally be concluded that Cinder gravel can be replaced with 20% of Fine grained soil in these mixtures.

5.2 Recommendations for future work

As cinder gravel deposits are widely distributed in Ethiopia, a feasible stabilization of these naturally occurring gravels to be used as a Wearing course material is of paramount importance.

The following recommendations are made based on the study of the potential use of cinder gravels as a wearing course material for gravel road when stabilized with Fine grained soil.

1. Based on literatures reviewed during the study and the outcomes of the study Based on the results of the research, it is recommended for consultants(designers) that utilization of the locally available cinder gravels shall be given due consideration for upcoming road construction projects in the study area or in other locations with similar characteristics.
2. The results obtained in this investigation ascertained that the properties of cinder gravel can be improved by stabilization and used for low volume wearing course. However, a full-scale road experiment is necessary in order to study the performance of stabilized cinder gravels against the possible detrimental effects of corrugation, dust, potholes and loose aggregate due to traffic movement. Moreover, the feasibility of Fine stabilized cinder gravels should be checked for every project versus expenses related to getting quality aggregate and hauling distance.
3. A special graduation requirement should be provided for natural gravels such as cinder gravel whose gradation changes significantly upon compaction.
4. Guidelines on the blending proportion of cinder gravel with Fine grained soil should be prepared for locally available cinder gravels and Fine grained soil found in different areas of our country.
5. The potential benefits of using locally cinder materials for road construction are likely to outweigh the costs incurred in prospecting and testing procedures. If they are exploited using the environmental protection measures and design criteria recommended in the guideline, their use will facilitate the provision of low-cost road s for rural communities in Ethiopia in the areas where materials occur.
6. Finally, it is recommended that further research study would be undertaken by other researchers to consider similar issues to verify the significance of mixing different sources of natural Cinder gravel to take samples from different areas of Ethiopia for road construction

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APPENDICES: DETAILED LABORATORY TEST RESULTS

Appendex A Laboratory results of Sieve analysis tests of the Samples

0 %FINE+100% CINDER BEFORE COMPACTION						
SIEVE size (mm)	weight retained	%retained	%Cum.% retained	BC.Cum.% passing	Upper limit	Lower limit.
50	0	0.00	0.00	100.00	100	100
37.5	328	5.29	5.29	94.71	100	80
20	1807	29.12	34.41	65.59	80	60
10	1497	24.13	58.53	41.47	65	45
5	1001	16.13	74.67	25.33	50	30
2.36	628	10.12	84.79	15.21	40	20
0.425	520	8.38	93.17	6.83	25	10
0.075	229	3.69	96.86	3.14	15	5
pan	195	3.14	100.00	0.00		
T0tal	6205					

0% FINE+100% CINDER AFTER COMPACTION						
SIEVE size (mm)	weight retained	%retained	%Cum.% retained	BC %Cum.% passing	Upper limit	Lower limit
50	0	0.00	0.00	100.00	100	100
37.5	194.82	3.00	3.00	97.00	100	80
20	584.46	9.00	12.00	88.00	80	60
10	2467.72	38.00	50.00	50.00	65	45
5	1168.92	18.00	68.00	32.00	50	30
2.36	649.4	10.00	78.00	22.00	40	20
0.425	519.52	8.00	86.00	14.00	25	10
0.075	584.46	9.00	95.00	5.00	15	5
pan	324.7	5.00	100.00	0.00		
	6494					

5 %FINE+95% CINDER BEFOER COMPACTION						
SIEVE size (mm)	weight retained	%retained	%Cum.%retained	AC.%Cum. passing	Upper limit	Lower limit.
50	0	0.00	0.00	100.00	100	100
37.5	50	1.00	1.00	99.00	100	80
20	750	15.00	16.00	84.00	80	60
10	1200	24.00	40.00	60.00	65	45
5	900	18.00	58.00	42.00	50	30
2.36	600	12.00	70.00	30.00	40	20
0.425	500	10.00	80.00	20.00	25	10
0.075	650	13.00	93.00	7.00	15	5
pan	350	7.00	100.00	0.00		
	5000					

5 %FINE+95% CINDER AFTER COMPACTION						
SIEVE size (mm)	weight retained	%retained	%Cum.% retained	AC.Cum.% passing	Upper limit	Lower limit.
50	0	0.00	0.00	100.00	100	100
37.5	0	0.00	0.00	100.00	100	80
20	858	17.75	17.75	82.25	80	60
10	994	20.56	38.30	61.70	65	45
5	590	12.20	50.51	49.49	50	30
2.36	730	15.10	65.60	34.40	40	20
0.425	773	15.99	81.59	18.41	25	10
0.075	522	10.80	92.39	7.61	15	5
pan	368	7.61	100.00	0.00		
T0tal	4835					

10 %FINE+ 90% CINDER BEFORE COMPACTION						
SIEVE size (mm)	weight retained	%retained	%Cum.% retained	BC.Cum.% passing	Upper limit	Lower limit.
50	0	0.00	0.00	100.00	100	100
37.5	428	6.28	6.28	93.72	100	80
20	1602	23.52	29.80	70.20	80	60
10	1768	25.96	55.76	44.24	65	45
5	1039	15.25	71.02	28.98	50	30
2.36	728	10.69	81.71	18.29	40	20
0.425	520	7.63	89.34	10.66	25	10
0.075	229	3.36	92.70	7.30	15	5
pan	497	7.30	100.00	0.00		
	6811					

10 %FINE+90% CINDER AFTER COMPACTION						
SIEVE size (mm)	weight retained	%retained	%Cum.% retained	AC.Cum.% passing	Upper limit	Lower limit.
50	0	0.00	0.00	100.00	100	100
37.5	0	0.00	0.00	100.00	100	80
20	934	19.49	19.49	80.51	80	60
10	965	20.13	39.62	60.38	65	45
5	577	12.04	51.66	48.34	50	30
2.36	699	14.58	66.24	33.76	40	20
0.425	599	12.50	78.74	21.26	25	10
0.075	452	9.43	88.17	11.83	15	5
pan	567	11.83	100.00	0.00		
	4793					

15 %FINE+85% CINDER BEFOER COMPACTION						
SIEVE size (mm)	weight retained	%retained	%Cum.% retained	BC. %Cum.% passing	Upper limit	Lower limit.
50	0	0.00	0.00	100.00	100	100
37.5	453	5.81	5.81	94.19	100	80
20	2000	25.65	31.46	68.54	80	60
10	1500	19.24	50.69	49.31	65	45
5	1000	12.82	63.52	36.48	50	30
2.36	863	11.07	74.58	25.42	40	20
0.425	735	9.43	84.01	15.99	25	10
0.075	648	8.31	92.32	7.68	15	5
pan	599	7.68	100.00	0.00		
	7798					

15 %FINE+85% CINDER AFTER COMPACTION						
SIEVE size (mm)	weight retained	%retained	%Cum.% retained	AC. %Cum.% passing	Upper limit	Lower limit.
50	0	0.00	0.00	100.00	100	100
37.5	0	0.00	0.00	100.00	100	80
20	1134	22.80	22.80	77.20	80	60
10	767	15.42	38.23	61.77	65	45
5	678	13.63	51.86	48.14	50	30
2.36	563	11.32	63.18	36.82	40	20
0.425	635	12.77	75.95	24.05	25	10
0.075	548	11.02	86.97	13.03	15	5
pan	648	13.03	100.00	0.00		
	4973					

20 %FINE+80% CINDER BEFORE COMPACTION						
SIEVE size (mm)	weight retained	%retained	%Cum.% retained	BC. %Cum.% passing	Upper limit	Lower limit.
50	0	0.00	0.00	100.00	100	100
37.5	230	3.63	3.63	96.37	100	80
20	1180	18.64	22.27	77.73	80	60
10	1060	16.75	39.02	60.98	65	45
5	1060	16.75	55.77	44.23	50	30
2.36	870	13.74	69.51	30.49	40	20
0.425	700	11.06	80.57	19.43	25	10
0.075	600	9.48	90.05	9.95	15	5
Pan	630	9.95	100.00	0.00	-	
	6330					

20 %FINE+80% CINDER AFTER COMPACTION						
SIEVE size (mm)	weight retained	%retained	%Cum.% retained	AC. %Cum.% passing	Upper limit	Lower limit.
50	0	0.00	0.00	100.00	100	100
37.5	0	0.00	0.00	100.00	100	80
20	1200	24.39	24.39	75.61	80	60
10	760	15.45	39.84	60.16	65	45
5	760	15.45	55.28	44.72	50	30
2.36	780	15.85	71.14	28.86	40	20
0.425	600	12.20	83.33	16.67	25	10
0.075	500	10.16	93.50	6.50	15	5
Pan	320	6.50	100.00	0.00	-	
	4920					

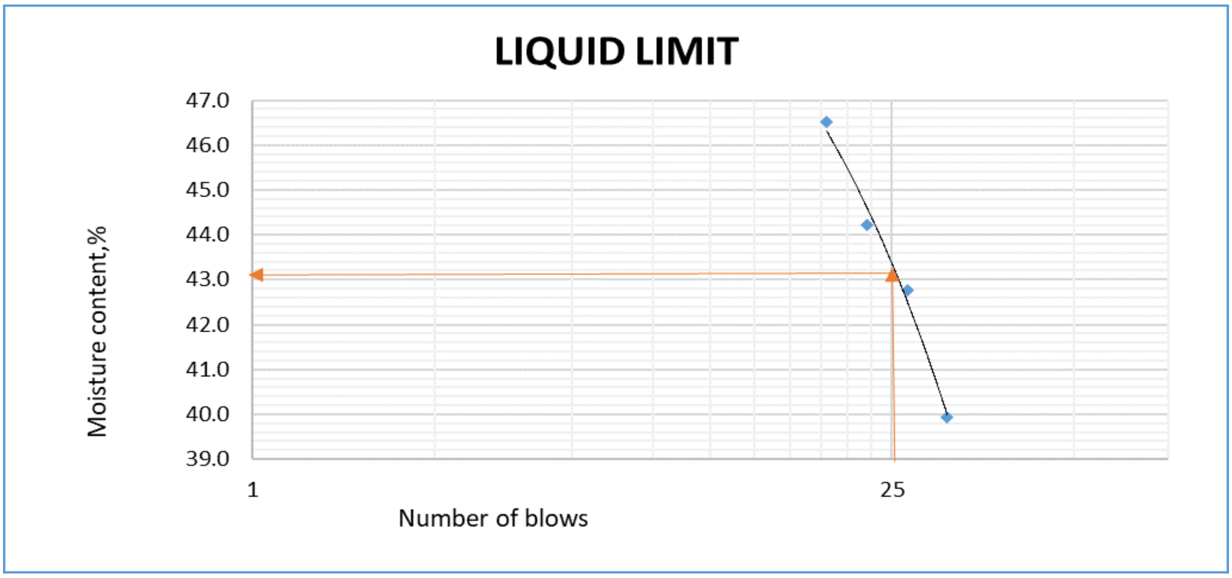
25 %FINE+75% CINDER BEFORE COMPACTION						
SIEVE size (mm)	weight retained	%retained	%Cum.% retained	BC. %Cum.% passing	Upper limit	Lower limit.
50	0	0.00	0.00	100.00	100	100
37.5	131	1.56	1.56	98.44	100	80
20	2135	25.46	27.02	72.98	80	60
10	1878	22.39	49.42	50.58	65	45
5	926	11.04	60.46	39.54	50	30
2.36	1053	12.56	73.01	26.99	40	20
0.425	818	9.75	82.77	17.23	25	10
0.075	700	8.35	91.12	8.88	15	5
pan	745	8.88	100.00	0.00		
	8386					

25 %FINE+75% CINDER AFTER COMPACTION						
SIEVE size (mm)	weight retained	%retained	%Cum.% retained	AC. %Cum.% passing	Upper limit	Lower limit.
50	0	0.00	0.00	100.00	100	100
37.5	0	0.00	0.00	100.00	100	80
20	1178	25.51	25.51	74.49	80	60
10	743	16.09	41.60	58.40	65	45
5	463	10.03	51.62	48.38	50	30
2.36	438	9.48	61.11	38.89	40	20
0.425	431	9.33	70.44	29.56	25	10
0.075	402	8.71	79.15	20.85	15	5
pan	963	20.85	100.00	0.00		
	4618					

Appendix B- Laboratory Results of Atterberg Limits of fine-grained Soil

Item Description	`Liquid Limit Trails				Plastic Limit trails	
Number of blows	33	27	22	18		
Trial	1	2	3	4	1	2
Container	B9	A17	A7	3,3	T1	B
Wt. of container + wet soil ,g	42.81	37.04	43.83	35.21	27.17	26.61
Wt. of container + dry soil ,g	35.94	31.84	37.85	29.49	25.1	24.41
Wt. of container(g)	18.74	19.68	24.33	17.19	18.71	17.5
Wt. of water (g)	6.87	5.2	5.98	5.72	2.1	2.2
Wt. of dry soil ,g	17.2	12.16	13.52	12.3	6.39	6.91
Moisture content,%	39.9	42.8	44.2	46.5	32.4	31.8
Liquid Limit/Plastic Limit	43				32	

L.L= 43 P.L= 32 pI= 11



Sieve Analysis (wet preparation method) fine material				
Sieve size (mm)	Mass of retain oneach sieve(g)	Percentage of retained soil	Cumulative % of retain soil	Percentage of passing particle
9.5	172.00	17.27	17.27	82.73
4.75	65.50	6.58	23.85	76.15
2.36	43.40	4.36	28.20	71.80
2	38.95	3.91	32.11	67.89
1.18	32.21	3.23	35.35	64.65
0.85	29.87	3.00	38.35	61.65
0.6	22.34	2.24	40.59	59.41
0.425	18.50	1.86	42.45	57.55
0.3	19.50	1.96	44.41	55.59
0.15	24.25	2.43	46.84	53.16
0.075	12.54	1.26	48.10	51.90
pan	516.90	51.90	100.00	0.00
Sum	996.0			

Before wash=996 After wash= 479.1 Loss= 516.9

Determination of specific gravity for cinder gravel with Fine grained soil						
Sample Fine soil	0%	5%	10%	15%	20%	25%
Determination code	P3	1	2	3	P2	P4
Mass of empty ,clean pycnometer (gm)	26.42	30.2	30.3	34.1	32.4	28.43
Mass of oven dry sample(gm) A	25	25	25	25	25	25
Mass o empty pycnometer+water (gm)B	123.02	122.9	164.53	127.8	123.25	122.23
Mass pycnometer+dry soil+wate (gm) C	138.23	137.89	149.6	142.74	138.02	136.85
Temperature 0C	23	23	23	24	23	24
K	1.0005	1.0005	1.0005	1.0003	1.0005	1.0003
Specific gravity= A*K/ (A+B-C)	2.55	2.49	2.48	2.46	2.44	2.41

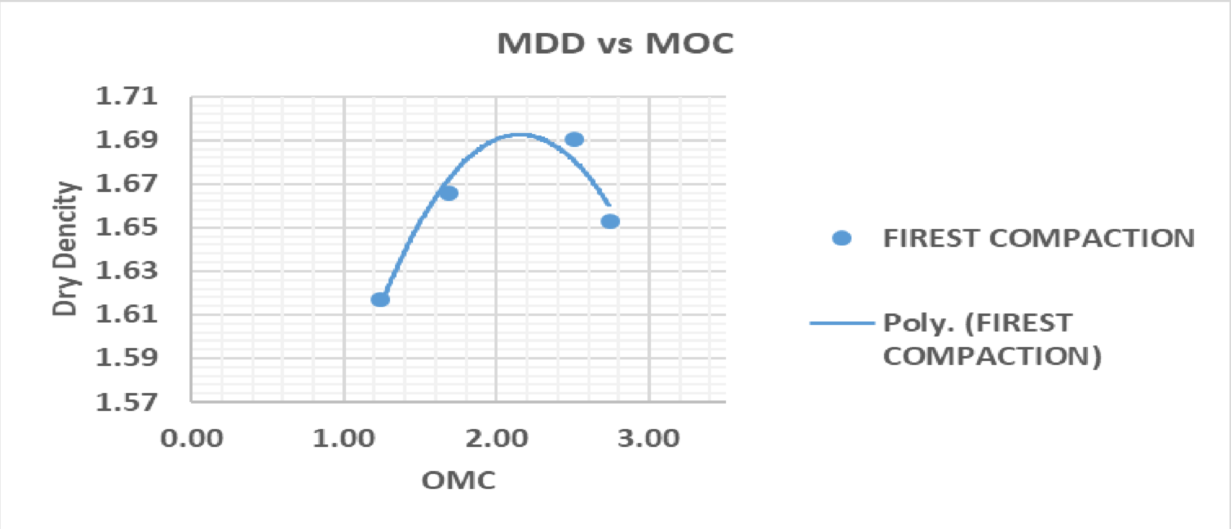
Absorption test result for blending cinder with Fine							
Weight of saturated, surface dry Cinder gravel in air	W1gm	0%	5%	10%	15%	20%	25%
		400	450	410	410	400	410
Weight of dry Cinder gravel	W2gm	347	394	370	365	370	385
Weight of absorbed water	W3gm	53	56	40	35	30	25
Absorption (%)	(W1− W2)/ (W1)	13.2	12.4	9.75	8.75	7..5	6.10

Determination of free swell index of Fine soil		
Trail no	#1	#2
Initial volume (ml)	10	10
Final volume (ml)	14	13
Free Swell Index (%)	40	30
Average	35 %	

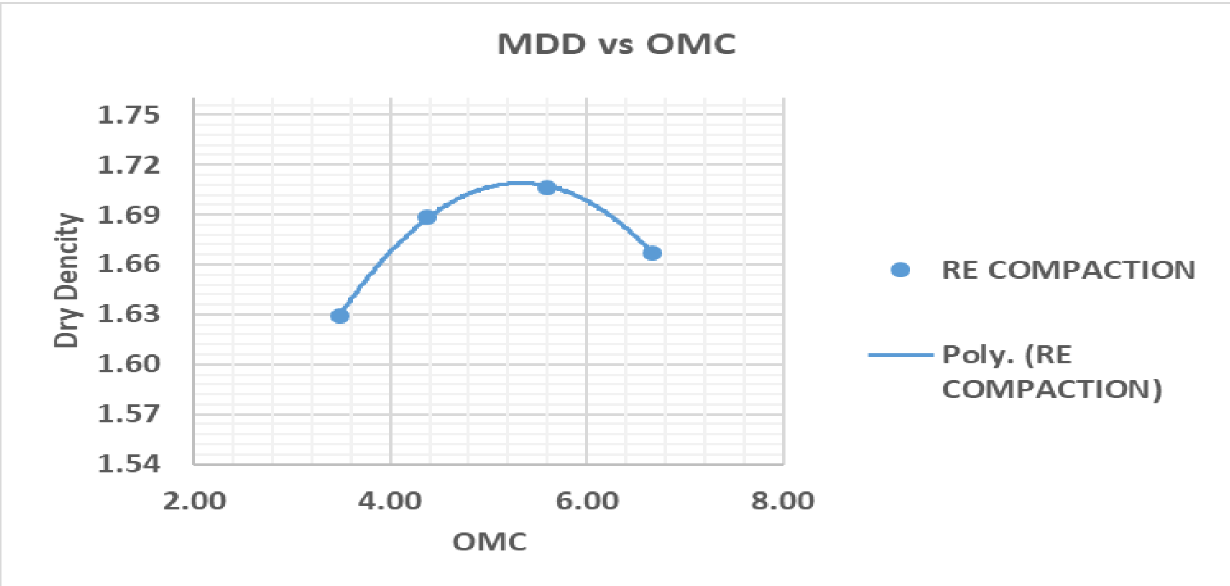
Determination of Linear shrinkage values			
% of grained soil	Ld(mm)	Lo(mm)	(%)LS
0%Fine + 100%Cinder	139.8	140	0.14
5%Fine + 95%Cinder	139.5	130	0.36
10%Fine + 90%Cinder	139.2	140	0.57
15%Fine + 85%Cinder	138.8	140	0.86
20%Fine + 80%Cinder	138	140	1.14
25%Fine + 75%Cinder	138	140	1.43

Appendex C-(Modified Procter Test Method of AASHTO T-180)

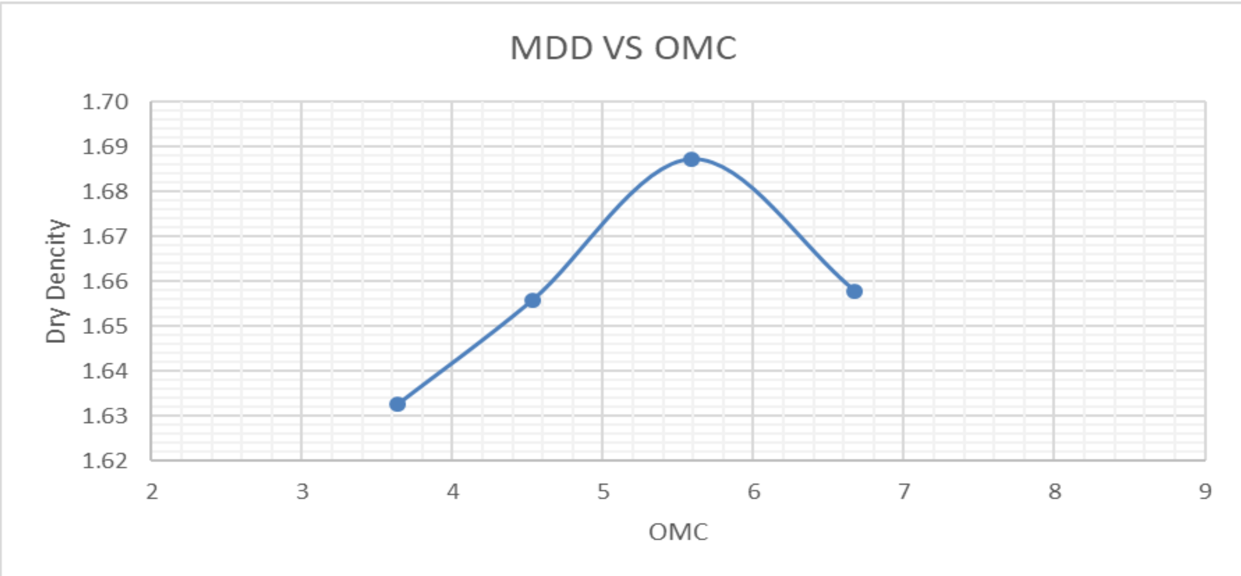
Moisture-Density relations of Soils for 100% cinder gravel first compaction				
Test No.	1	2	3	4
Mass of sample (gm)	4500	4500	4500	4500
Water Added(cc)	40	220	400	580
Mass of Mold Wet soil(gm)(A)	6192.3	6313.5	6396.5	6322.3
Mass of Mold(gm)(B)	2715.5	2715.5	2715.5	2715.5
Mass of Wet Soil(gm)A-B=C	3476.8	3598	3681	3606.8
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.64	1.69	1.73	1.70
Container Code.	G	A	A-16	G63
Mass of Wet soil Container(gm)(F)	204.23	217.78	208.6	224.62
Mass of dry soil container(gm)(G)	202.13	214.74	204.11	219.58
Mass of container(gm)(H)	32.51	34.52	25.25	35.91
Mass of moisture(gm)F-G=(I)	2.1	3.04	4.49	5.04
Mass of Dry soil(gm)G-H=(J)	169.62	180.22	178.86	183.67
Moisture content % (I/J)*100=K	1.24	1.69	2.51	2.74
Dry Density gm/cm^3 E/(100+K)*100	1.62	1.67	1.69	1.65



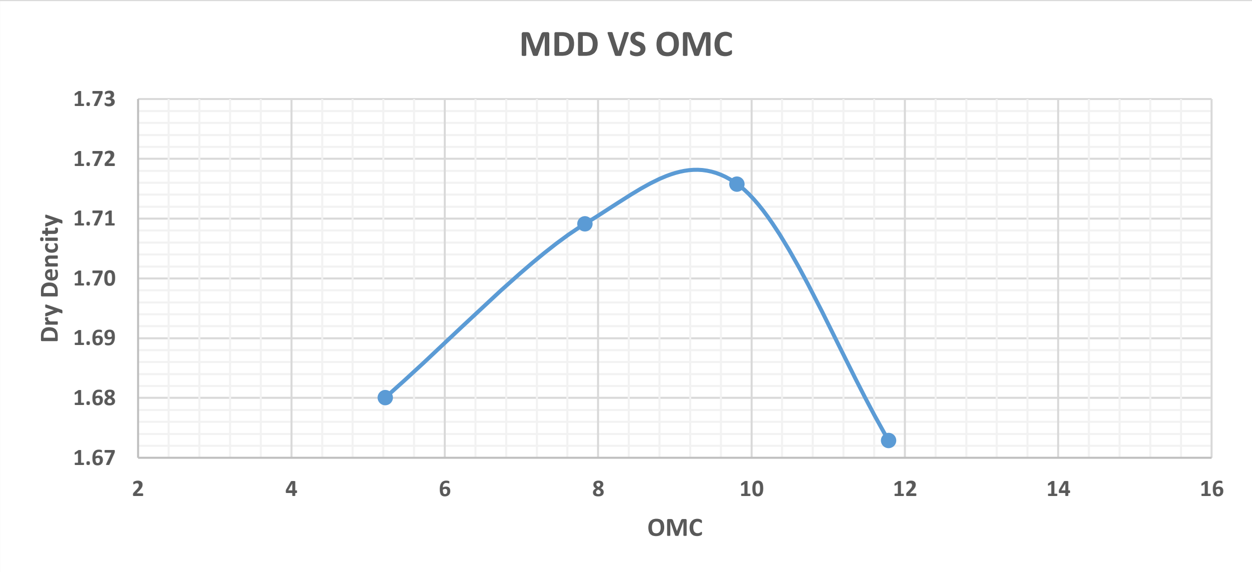
MDD relations of Soils for 100% cinder gravel Re- compaction				
Test No.	1	2	3	4
Mass of sample (gm)	4500	4500	4500	4500
Water Added(cc)	80	260	440	620
Mass of Mold Wet soil(gm)(A)	6307.2	6468.8	6552.3	6502.3
Mass of Mold(gm)(B)	2725.3	2725.3	2725.3	2725.3
Mass of Wet Soil(gm)A-B=C	3581.9	3743.5	3827	3777
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.69	1.76	1.80	1.78
Container Code.	E-11	T2	J41	G3T3
Mass of Wet soil Container(gm)(F)	214.23	202.34	213.43	218.62
Mass of dry soil container(gm)(G)	208.16	195.23	204.11	207.08
Mass of container(gm)(H)	34.3	32.52	37.41	34.12
Mass of moisture(gm)F-G=(I)	6.07	7.11	9.32	11.54
Mass of Dry soil(gm)G-H=(J)	173.86	162.71	166.7	172.96
Moisture content % (I/J)*100=K	3.49	4.37	5.59	6.67
Dry Density gm/cm^3 E/(100+K)*100	1.63	1.69	1.71	1.67



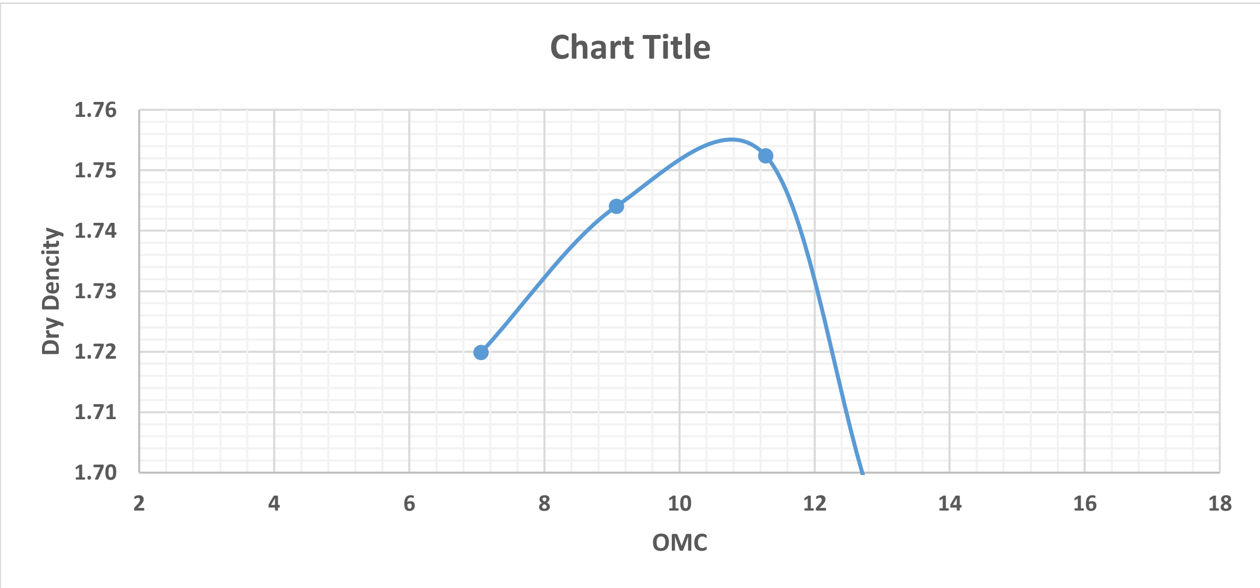
Moisture-Density relations of Soils for 5% Fine+95%Cinder compaction				
Test No.	1	2	3	4
Mass of sample (gm)	4500	4500	4500	4500
Water Added(cc)	150	330	510	690
Mass of Mold +Wet soil(gm)(A)	9936.2	10018.6	10126.4	10098.7
Mass of Mold(gm)(B)	6342.4	6342.4	6342.4	6342.4
Mass of Wet Soil(gm)A-B=C	3593.8	3676.2	3784	3756.3
Volume of Mold cm3(D)	2124	2124	2124	2124
Bulk Density gm/cm3 C/D=(E)	1.69	1.73	1.78	1.77
Moisture Content Determination				
Container Code.	G3T2	A-12	J41	G3T3
Mass of Wet soil +Container(gm)(F)	223.87	234.56	213.43	218.62
Mass of dry soil +container(gm)(G)	217.16	225.76	204.11	207.08
Mass of container(gm)(H)	32.56	31.48	37.41	34.12
Mass of moisture(gm)F-G=(I)	6.71	8.8	9.32	11.54
Mass of Dry soil(gm)G-H=(J)	184.6	194.28	166.7	172.96
Moisture content % (I/J)*100=K	3.63	4.53	5.59	6.67
Dry Density gm/cm3 E/(100+K)*100	1.63	1.66	1.69	1.66



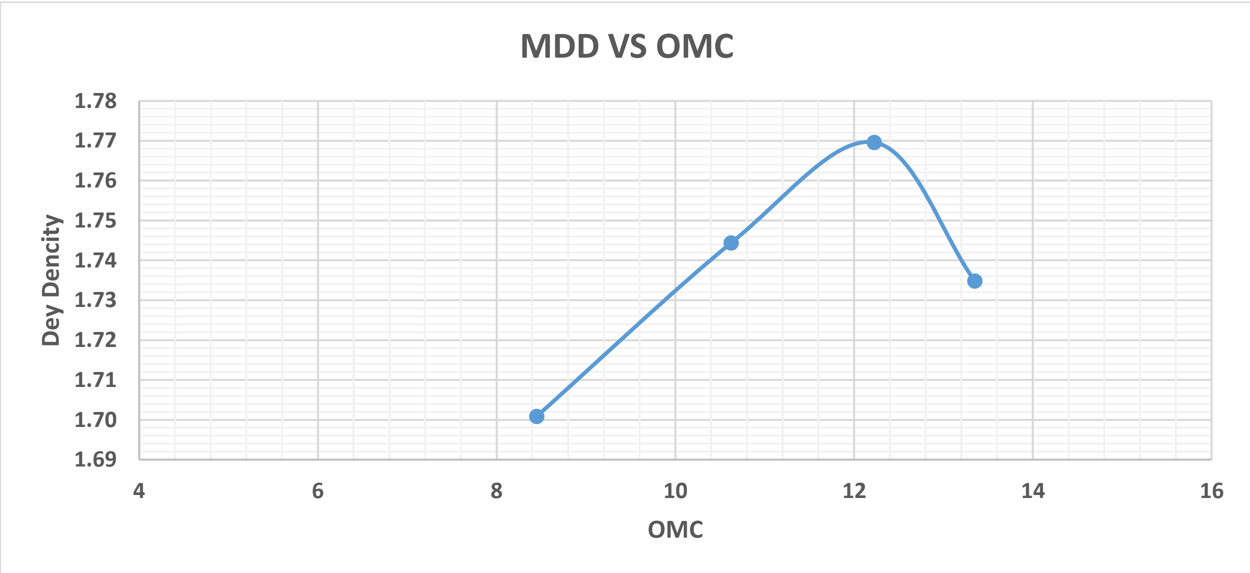
Moisture-Density relations of Soils for 10% Fine+90%Cinder compaction				
Test No.	1	2	3	4
Mass of sample (gm)	4500	4500	4500	4500
Water Added(cc)	220	400	580	760
Mass of Mold +Wet soil(gm)(A)	9967.45	10126.9	10214.43	10184.6
Mass of Mold(gm)(B)	6212.5	6212.5	6212.5	6212.5
Mass of Wet Soil(gm)A-B=C	3754.95	3914.4	4001.93	3972.1
Volume of Mold cm3(D)	2124	2124	2124	2124
Bulk Density gm/cm3 C/D=(E)	1.77	1.84	1.88	1.87
Moisture Content Determination				
Container Code.	G19	W02	A-16	G
Mass of Wet soil +Container(gm)(F)	185.96	205.65	206.3	197.48
Mass of dry soil +container(gm)(G)	178.36	193.34	190.4	180.08
Mass of container(gm)(H)	32.89	36.1	28.34	32.48
Mass of moisture(gm)F-G=(I)	7.6	12.31	15.9	17.4
Mass of Dry soil(gm)G-H=(J)	145.47	157.24	162.06	147.6
Moisture content % (I/J)*100=K	5.22	7.83	9.81	11.79
Dry Density gm/cm3 E/(100+K)*100	1.68	1.71	1.72	1.67



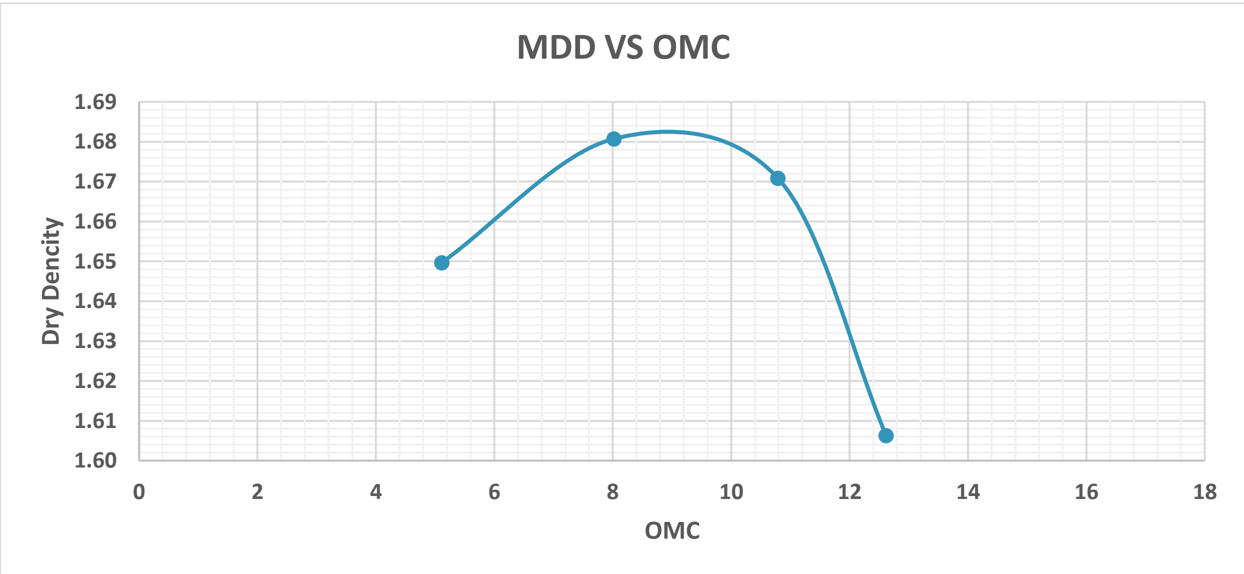
Moisture-Density relations of Soils for 15% Fine+85%Cinder compaction				
Test No.	1	2	3	4
Mass of sample (gm)	4500	4500	4500	4500
Water Added(cc)	220	400	580	760
Mass of Mold +Wet soil(gm)(A)	10067.6	10196.9	10298.43	10223.4
Mass of Mold(gm)(B)	6156.6	6156.6	6156.6	6156.6
Mass of Wet Soil(gm)A-B=C	3911	4040.3	4141.83	4066.8
Volume of Mold cm3(D)	2124	2124	2124	2124
Bulk Density gm/cm3 C/D=(E)	1.84	1.90	1.95	1.91
Moisture Content Determination				
Container Code.	P15	P65	E-12	K23
Mass of Wet soil +Container(gm)(F)	208.97	223.45	216.87	199.43
Mass of dry soil +container(gm)(G)	197.33	207.78	197.45	180.93
Mass of container(gm)(H)	32.51	34.97	25.25	35.9
Mass of moisture(gm)F-G=(I)	11.64	15.67	19.42	18.5
Mass of Dry soil(gm)G-H=(J)	164.82	172.81	172.2	145.03
Moisture content % (I/J)*100=K	7.06	9.07	11.28	12.76
Dry Density gm/cm3 E/(100+K)*100	1.72	1.74	1.75	1.70



Moisture-Density relations of Soils for 20% Fine+80%Cinder compaction				
Test No.	1	2	3	4
Mass of sample (gm)	4500	4500	4500	4500
Water Added(cc)	220	400	580	760
Mass of Mold +Wet soil(gm)(A)	10123.4	10304.3	10423.7	10382.3
Mass of Mold(gm)(B)	6205.6	6205.6	6205.6	6205.6
Mass of Wet Soil(gm)A-B=C	3917.8	4098.7	4218.1	4176.7
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.84	1.93	1.99	1.97
Moisture Content Determination				
Container Code.	G2	G19	P15	T2
Mass of Wet soil+ Container(gm)(F)	222.9	202.31	214.64	189.14
Mass of dry soil +container(gm)(G)	208.07	186.345	194.91	170.96
Mass of container(gm)(H)	32.52	36.08	33.52	34.78
Mass of moisture(gm)F-G=(I)	14.83	15.965	19.73	18.18
Mass of Dry soil(gm)G-H=(J)	175.55	150.265	161.39	136.18
Moisture content % (I/J)*100=K	8.45	10.62	12.23	13.35
Dry Density gm/cm^3 E/(100+K)*100	1.70	1.74	1.77	1.73



Moisture-Density relations of Soils for 25% Fine+75%Cinder compaction				
Test No.	1	2	3	4
Mass of sample (gm)	4500	4500	4500	4500
Water Added(cc)	220	400	580	760
Mass of Mold +Wet soil(gm)(A)	10025.4	10198.6	10274.2	10184.6
Mass of Mold(gm)(B)	6342.4	6342.4	6342.4	6342.4
Mass of Wet Soil(gm)A-B=C	3683	3856.2	3931.8	3842.2
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.73	1.82	1.85	1.81
Moisture Content Determination				
Container Code.	G3T2	A-12	J41	G3T3
Mass of Wet soil+ Container(gm)(F)	221.34	198.76	232.1	213.43
Mass of dry soil+ container(gm)(G)	212.16	186.34	213.14	193.34
Mass of container(gm)(H)	32.56	31.48	37.41	34.12
Mass of moisture(gm)F-G=(I)	9.18	12.42	18.96	20.09
Mass of Dry soil(gm)G-H=(J)	179.6	154.86	175.73	159.22
Moisture content % (I/J)*100=K	5.11	8.02	10.79	12.62
Dry Density gm/cm^3 E/(100+K)*100	1.65	1.68	1.67	1.61



Appendex D: Laboratory Results of California Bearing Ratio (CBR) Tests

0% Fine+100% Cinder gravel OMC and MDD from modified proctor	
MDD (g/cc)	1.67
OMC (%)	2.51
95% of MDD(g/cc)	1.587

Results of DD and MC before & after soaking for 0% Fine+100% Cinder gravel Samples

Compaction Data		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mold No.		N-4	N-4	N9	N9	M-30	M-30
0% Fine+100% Cinder gravel + Mold	g	10770.5	10899.5	10490.5	10671.5	10183	10390
Mass Mold	g	7016.5	7016.5	6930.5	6930.5	6940.5	6940.5
Mass of 0% Fine+100% Cinder gravel	g	3754	3883	3560	3741	3242.5	3449.5
Volume of Mold	g	2124	2124	2124	2124	2124	2124
Wet density of 0% Fine+100% Cinder gravel	g/cc	1.767	1.828	1.676	1.761	1.527	1.624
Dry density of 0% Fine+100% Cinder gravel	g/cc	1.685	1.708	1.548	1.605	1.382	1.456

Moisture Determination

Moisture Content Data		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		E-11	E	J2	T1	S2	A3

Mass of wet 0% Fine+100% Cinder gravel + Container	g	210.4	191.4	212.2	197.3	213.4	240.4
Mass of dry 0% Fine+100% Cinder gravel + Container	g	202.3	181.2	198.8	182.8	196.5	219.0
Mass of container	g	36.5	37.9	37.8	34.8	34.8	32.8
Mass of water	g	8.1	10.1	13.3	14.4	16.9	21.4
Mass of dry 0% Fine+100% Cinder gravel	g	165.8	143.3	161.1	148.1	161.7	186.2
Moisture content	%	4.9	7.1	8.3	9.7	10.4	11.5

Results for 0% Fine+100% Cinder gravel Samples of Penetration data.								
Penetration after 96 hrs. Soaking Period			Surcharge Weight:4.55 KG					
65 Blows			30 Blows			10Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.0		0.00	0.000		0.00	0.000	
0.64	2.765		0.64	1.687		0.64	1.042	
1.27	4.996		1.27	3.656		1.27	2.289	
1.91	7.021		1.91	5.976		1.91	3.987	41.52
2.54	8.981	68.04	2.54	7.896	59.82	2.54	5.480	
3.81	11.234		3.81	10.034		3.81	7.223	44.89
5.08	13.231	66.16	5.08	11.465	57.33	5.08	8.978	
7.62	16.034		7.62	14.067		7.62	10.640	

Laboratory Results for 0% Fine+100% Cinder gravel Samples of Swell tests.							
Date		65 Blows		30 Blows		10 Blows	
		Gauge reading (mm)	Swell in %	Gauge reading (mm)	Swell in %	Gauge reading (mm)	Swell in %
06/07/21	Initial	0.00	0.49	0.00	0.60	0.00	0.71
10/07/21	Final	0.49		0.60		0.71	

Results of CBR results @ 95% of MDD for 0% Fine+100% Cinder gravel					
No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	**% Compaction**	
10	10.4	1.382	44.9	83	
30	8.3	1.548	59.8	93	
65	4.9	1.685	68.0	101	
CBR (%) @ 95 % MDD			64.0	% Swell	0.57

5% Fine+95% Cinder gravel OMC and MDD from modified proctor test	
MDD (g/cc)	1.69
OMC (%)	5.89
95% of MDD(g/cc)	1.596

DD and MC before & after soaking for 5% Fine+95% Cinder gravel Samples							
Compaction Data		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mold No.		N4	N4	N2	N2	A1	N4
Mass of 0% Fine+100% Cinder gravel + Mold	g	10810.5	10989.5	10608.5	10821.5	10413.5	10810.5
Mass Mold	g	7003.6	7003.6	7004	7004	6913.4	7003.6
Mass of 0% Fine+100% Cinder gravel	g	3806.9	3985.9	3604.5	3817.5	3500.1	3806.9
Volume of Mold	g	2124	2124	2124	2124	2124	2124
Wet density of 0% Fine+100% Cinder gravel	g/cc	1.792	1.877	1.697	1.797	1.648	1.792
Dry density of 0% Fine+100% Cinder gravel	g/cc	1.668	1.685	1.549	1.575	1.471	1.668
Moisture Content Data		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		A	P3	A2	T1	2	A
Mass of wet 0%							

Fine+100% Cinder gravel + Container	g	221.3	197.7	223.7	201.2	223.7	221.3
Mass of dry 0% Fine+100% Cinder gravel + Container	g	208.5	181.2	206.3	180.5	203.3	208.5
Mass of container	g	37.1	36.9	25.2	33.3	34.7	37.1
Mass of water	g	12.8	16.4	17.3	20.8	20.3	12.8
Mass of dry 0% Fine+100% Cinder gravel	g	171.4	144.4	181.1	147.1	168.7	171.4
Moisture content	%	7.5	11.4	9.6	14.1	12.0	7.5

Results for 5% Fine+95% Cinder gravel Samples of Penetration data.								
Penetration after 96 hrs. Soaking Period			Surcharge Weight:4.55 KG					
65 Blows			30 Blows			10Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.0		0.00	0.000		0.00	0.000	
0.64	2.723		0.64	2.021		0.64	1.034	
1.27	5.232		1.27	4.231		1.27	3.023	
1.91	7.921		1.91	6.476		1.91	5.046	49.09
2.54	9.834	74.50	2.54	8.453	64.04	2.54	6.480	
3.81	12.134		3.81	10.879		3.81	8.234	46.94
5.08	13.863	69.32	5.08	12.532	62.66	5.08	9.387	
7.62	15.134		7.62	14.210		7.62	11.440	

Laboratory Results for 5% Fine+95% Cinder gravel Samples of Swell tests.							
Date		65 Blows		30 Blows		10 Blows	
		Gauge reading (mm)	Swell in %	Gauge reading (mm)	Swell in %	Gauge reading (mm)	Swell in %
06/07/21	Initial	0.29	0.39	0.22	0.5	0.24	0.61
10/07/21	Final	0.68		0.72		0.85	

Results of CBR results @ 95% of MDD for 5% Fine+95% Cinder gravel					
No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	12.0	1.471	49.1	88	
30	9.6	1.549	64.0	92	
65	7.5	1.668	74.5	99	
CBR (%) @ 95 % MDD			69.0	% Swell	0.48

Results for 10% Fine+90% Cinder gravel OMC and MDD from modified proctor test	
MDD (g/cc)	1.72
OMC (%)	9.81
95% of MDD(g/cc)	1.634

M DD and MOC before & after soaking for 10% Fine+90% Cinder gravel Samples.							
Compaction Data		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mold No.		M10	M10	N4	N4	I65	I65
Mass of 0% Fine+100% Cinder gravel + Mold	g	10897.5	11118.8	10702.1	10940.1	10593.6	10726.5
Mass Mold	g	6948.1	6948.1	7015.1	7015.1	6979.1	6979.1
Mass of 0% Fine+100% Cinder gravel	g	3949.4	4170.7	3687	3925	3614.5	3747.4
Volume of Mold	g	2124	2124	2124	2124	2124	2124
Wet density of 0% Fine+100% Cinder gravel	g/cc	1.859	1.964	1.736	1.848	1.702	1.764
Dry density of 0% Fine+100% Cinder gravel	g/cc	1.706	1.816	1.543	1.652	1.493	1.547
Moisture Determination							
Moisture Content Data		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		J2	P3	G3T3	W02	C3	ZE
Mass of wet 0%							
Fine+100% Cinder gravel + Container	g	212.8	210.6	206.3	206.7	205.9	196.4

Mass of dry 0% Fine+100% Cinder gravel + Container	g	198.0	197.4	187.6	187.8	183.9	176.2
Mass of container	g	34.8	36.0	37.7	28.3	26.6	33.0
Mass of water	g	14.7	13.1	18.7	19.0	22.0	20.1
Mass of dry 0% Fine+100% Cinder gravel	g	163.3	161.5	149.8	159.5	157.3	143.2
Moisture content	%	9.0	8.1	12.5	11.9	14.0	14.1

Results for 10% Fine+90% Cinder gravel Samples of Penetration data.								
Penetration after 96 hrs. Soaking Period			Surcharge Weight:4.55 KG					
65 Blows			30 Blows			10Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.0		0.00	0.000		0.00	0.000	
0.64	3.289		0.64	2.034		0.64	1.354	
1.27	5.916		1.27	4.043		1.27	2.789	
1.91	8.323		1.91	6.929		1.91	4.376	
2.54	10.556	79.97	2.54	8.854	67.08	2.54	6.267	47.48
3.81	12.996		3.81	11.113		3.81	7.993	
5.08	15.231	76.16	5.08	13.522	67.61	5.08	10.145	50.73
7.62	19.034		7.62	16.560		7.62	12.640	

Results for 10% Fine+90% Cinder gravel Samples of Swell tests.							
Date		65 Blows		30 Blows		10 Blows	
		Gauge reading (mm)	Swell in %	Gauge reading (mm)	Swell in %	Gauge reading (mm)	Swell in %
06/07/21	Initial	0.63	0.31	0.31	0.43	0.42	0.52
10/07/21	Final	0.95		0.74		0.94	

Laboratory results of CBR results @ 95% of MDD for 10% Fine+90% Cinder gravel					
No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	14.0	1.493	50.7	87	
30	12.5	1.543	67.6	90	
65	9.0	1.706	80.5	99	
CBR (%) @ 95 % MDD			74.5	% Swell	0.40

For 15% Fine+85% Cinder gravel OMC and MDD modified proctor test							
MDD (g/cc)			1.74				
OMC (%)			11.28				
95% of MDD(g/cc)			1.653				
DD and MC before & after soaking for 15% Fine+85% Cinder gravel: Samples.							
Compaction Data		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mold No.		N13	N13	N12	N12	J8	J8
Mass of 0% Fine+100% Cinder gravel + Mold	g	10898.5	11023.4	10801.2	10931.5	10567.8	10712.3
Mass Mold	g	6932.5	6932.5	6982.2	6982.2	6938.6	6938.6
Mass of 0% Fine+100% Cinder gravel	g	3966	4090.9	3819	3949.3	3629.2	3773.7
Volume of Mold	g	2124	2124	2124	2124	2124	2124
Wet density of 0% Fine+100% Cinder gravel	g/cc	1.867	1.926	1.798	1.859	1.709	1.777
Dry density of 0% Fine+100% Cinder gravel	g/cc	1.734	1.746	1.620	1.653	1.500	1.567
Moisture Determination							
Moisture Content Data		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		A2	A	G-63	2	ZE	P65
Mass of wet 0%							
Fine+100% Cinder gravel + Container	g	221.3	199.4	209.0	187.7	221.5	234.5
Mass of dry 0% Fine+100% Cinder gravel + Container	g	207.3	184.2	190.8	170.3	198.5	211.0

Mass of container	g	25.1	37.8	25.2	31.3	32.9	35.2
Mass of water	g	14.0	15.1	18.2	17.3	23.1	23.5
Mass of dry 0% Fine+100% Cinder gravel	g	182.2	146.4	165.6	139.0	165.6	175.8
Moisture content	%	7.7	10.3	11.0	12.5	13.9	13.4

Results for 15% Fine+85% Cinder gravel Samples of Penetration data.								
Penetration after 96 hrs. Soaking Period			Surcharge Weight:4.55 KG					
65 Blows			30 Blows			10Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.0		0.00	0.000		0.00	0.000	
0.64	3.489		0.64	2.234		0.64	1.442	
1.27	6.234		1.27	4.843		1.27	2.889	
1.91	8.998		1.91	7.829		1.91	4.876	
2.54	11.414	86.47	2.54	10.231	77.51	2.54	6.648	50.36
3.81	14.734		3.81	12.913		3.81	8.733	
5.08	16.934	84.67	5.08	14.675	73.38	5.08	10.243	51.22
7.62	19.637		7.62	17.560		7.62	12.940	

: Laboratory Results for 15% Fine+85% Cinder gravel Samples of Swell tests.							
Date		65 Blows		30 Blows		10 Blows	
		Gauge reading (mm)	Swell in %	Gauge reading (mm)	Swell in %	Gauge reading (mm)	Swell in %
06/07/21	Initial	0.51	0.27	0.35	0.35	0.14	0.45
10/07/21	Final	0.78		0.70		0.59	

Results of CBR results @ 95% of MDD for 15% Fine+85% Cinder gravel					
No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	13.9	1.500	51.2	86	
30	11.5	1.620	77.5	93	
65	7.7	1.734	86.5	100	
CBR (%) @ 95 % MDD			80.1	% Swell	0.34

Laboratory results for 20% Fine+80% Cinder gravel OMC and MDD from modified proctor	
MDD (g/cc)	1.75
OMC (%)	12.23
95% of MDD(g/cc)	1.663

MDD and M0C before & after soaking for 20% Fine+80% Cinder gravel Samples.							
Compaction Data		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mold No.		N-12	N-12	N9	N9	M-30	M-30
Mass of 0% Fine+100% Cinder gravel + Mold	g	11156.6	11234.5	10802	10949.6	10532.5	10842.3
Mass Mold	g	6965.5	6965.5	6944	6944	6962.5	6962.5
Mass of 0% Fine+100% Cinder gravel	g	4191.1	4269	3858	4005.6	3570	3879.8
Volume of Mold	g	2124	2124	2124	2124	2124	2124
Wet density of 0% Fine+100% Cinder gravel	g/cc	1.973	2.010	1.816	1.886	1.681	1.827
Dry density of 0% Fine+100% Cinder gravel	g/cc	1.723	1.851	1.586	1.716	1.451	1.636
Moisture Determination							
Moisture Content Data		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		P15	A-16	E-11	AS	G19	J2
Mass of wet 0%							
Fine+100% Cinder gravel + Container	g	193.1	194.0	194.3	197.3	219.9	240.4

Mass of dry 0% Fine+100% Cinder gravel + Container	g	172.8	181.2	174.3	182.8	194.7	219.0
Mass of container	g	33.5	32.9	36.6	37.0	36.1	34.8
Mass of water	g	20.3	12.8	20.0	14.4	25.2	21.4
Mass of dry 0% Fine+100% Cinder gravel	g	139.3	148.3	137.6	145.8	158.7	184.2
Moisture Determination	%	14.5	8.6	14.6	9.9	15.9	11.6

For 20% Fine+80% Cinder gravel Samples of Penetration data								
Penetration after 96 hrs. Soaking Period			Surcharge Weight:4.55 KG					
65 Blows			30 Blows			10Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.0		0.00	0.000		0.00	0.000	
0.64	4.087		0.64	2.834		0.64	1.342	
1.27	6.943		1.27	5.675		1.27	2.989	
1.91	9.722		1.91	7.976		1.91	5.467	
2.54	12.216	92.55	2.54	10.212	77.36	2.54	7.231	54.78
3.81	15.423		3.81	13.432		3.81	9.321	
5.08	18.292	91.46	5.08	15.332	76.66	5.08	10.678	53.39
7.62	21.432		7.62	18.212		7.62	12.378	

Results for 20% Fine+80% Cinder gravel Samples of Swell tests							
Date		65 Blows		30 Blows		10 Blows	
		Gauge reading (mm)	Swell in %	Gauge reading (mm)	Swell in %	Gauge reading (mm)	Swell in %
06/07/21	Initial	0.58	0.21	0.42	0.27	0.36	0.3
10/07/21	Final	0.79		0.69		0.66	

Laboratory results of CBR results @ 95% of MDD for 20% Fine+80% Cinder gravel					
No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	15.9	1.451	54.8	86	
30	14.6	1.586	77.4	93	
65	14.5	1.723	92.5	100	
CBR (%) @ 95 % MDD			85.9	% Swell	0.23

Modified Proctor: T 180	
MDD (g/cc)	1.68
OMC (%)	8.02
95% of MDD(g/cc)	1.596

Results of DD and MC before & after soaking for 25% Fine+75% Cinder gravel Samples.							
Compaction Data		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mold No.		T4	T4	N13	N13	N9	N9
Mass of 0% Fine+100% Cinder gravel + Mold	g	10770.5	10899.5	10490.5	10671.5	10283	10456.7
Mass Mold	g	6950.3	6950.3	6968.6	6968.6	6943.5	6943.5
Mass of 0% Fine+100% Cinder gravel	g	3820.2	3949.2	3521.9	3702.9	3339.5	3513.2
Volume of Mold	g	2124	2124	2124	2124	2124	2124
Wet density of 0% Fine+100% Cinder gravel	g/cc	1.799	1.859	1.658	1.743	1.572	1.654
Dry density of 0% Fine+100% Cinder gravel	g/cc	1.677	1.656	1.523	1.501	1.424	1.406
Moisture Determination							
Moisture Content Data		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		A	P3	A2	T1	2	G3T3
Mass of wet 0%							
Fine+100% Cinder gravel + Container	g	221.3	176.5	208.8	187.2	213.4	240.4

Mass of dry 0% Fine+100% Cinder gravel + Container	g	208.9	161.2	193.8	165.8	196.5	210.0
Mass of container	g	37.1	36.9	25.2	33.3	34.7	37.5
Mass of water	g	12.5	15.3	14.9	21.4	16.9	30.4
Mass of dry 0% Fine+100% Cinder gravel	g	171.7	124.4	168.6	132.5	161.8	172.5
Moisture content	%	7.3	12.3	8.9	16.1	10.4	17.6

Laboratory Results for 25% Fine+75% Cinder gravel Samples of Penetration data.								
Penetration after 96 hrs. Soaking Period			Surcharge Weight:4.55 KG					
65 Blows			30 Blows			10Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.0		0.00	0.000		0.00	0.000	
0.64	3.453		0.64	2.214		0.64	1.613	
1.27	6.021		1.27	4.789		1.27	2.643	
1.91	8.431		1.91	6.987		1.91	4.876	
2.54	10.587	80.20	2.54	9.251	70.08	2.54	6.990	41.00
3.81	13.021		3.81	11.634		3.81	8.944	
5.08	15.231	76.16	5.08	13.765	68.83	5.08	10.277	51.38
7.62	17.934		7.62	15.810		7.62	12.345	

Results for 25% Fine+75% Cinder gravel Samples of Swell tests							
Date		65 Blows		30 Blows		10 Blows	
		Gauge reading (mm)	Swell in %	Gauge reading (mm)	Swell in %	Gauge reading (mm)	Swell in %
06/07/21	Initial	0.32	0.17	0.65	0.20	0.32	0.21
10/07/21	Final	0.49		0.85		0.53	

Laboratory results of CBR results @ 95% of MDD for 25% Fine+75% Cinder gravel					
No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	10.4	1.424	53.0	85	
30	8.9	1.523	70.1	91	
65	7.3	1.677	80.2	100	
CBR (%) @ 95 % MDD			74.9	% Swell	0.18

Appendex E: Laboratory results of Los Angeles Abrasion Value tests

: Laboratory results for 100% Cinder gravel of LAA Value Samples		
Number of trails	A	B
100% Cinder gravel before the test on standard sieve of 9.5-6.3 and 6.3-4.75(M1(g)	5000	5000
100% Cinder gravel after abrasion, retained on 1.7mm sieves and oven-dried(M2(g)	2849.08	2814.12
100% Cinder gravel after abrasion, passing on 1.7mm sieves and oven-dried(M2(g)	2150.6	2185.6
Los Angeles Abrasion Value (LAA)=(M1- M2)/M1*100	43.012	43.712
Average=(trail+trail2)/2	43.362	

Appendix F: Laboratory results of Aggregate Impact Value tests

Determination of AIV 100% Cinder Gravel (neat Cinder gravel).		
Test No.	Trail 1	Trial 2
A. mass of cylindrical steel cup, M1 (gm)	3030.6	3030.6
B. Mass of cylindrical steel cup + 100% Cinder Gravel, passing 12.5 mm and retain on 10.0mm sieves, M2 (gm)	3398.2	3399.9
C. 100% Cinder Gravel, M3(gm)= M2-M1	367.6	369.3
D. 100% Cinder Gravel, After the test, passing 2.36mm Sieve M4(gm)	140.7	153.2
E. 100% Cinder Gravel, After the test, Retained 2.36mm Sieve M5(gm)	226.9	216.1
F. AIV=(M4/M3) *100	38.27%	41.48%
G. Average of AIV=	39.87%	

Appendex G: Laboratory results of Aggregate Crushing Value tests

Determination of AIV 100% Cinder Gravel (neat Cinder gravel).		
Test No.	A	B
Mass of aggregate passing 12.5 mm and retain 10.0mm sieves = M1, gm	1730	1700
Mass of aggregate after compression, Passing 2.36mm sieves = M2, gm	759.5	735.4
ACV (%) = (M2/M1)	43.9	43.25
AACV=A+B/2	43.58	

Appendex H: Laboratory results of Flakiness Index Value tests

Laboratory results of Flakiness Index Value tests							
Sieve (mm)	Mass (gm)	aggregate fraction trays, m1(g)	% aggregatee retained, m2(g)	aggregatee after discarding 5% or less	weight of aggregatee each passed gauge size (g)	aggregatee passed on thicknesss gauge size, m3 (g)	FI=(M3/M2)
50-37.5	0	5360	0	5160	0	1353.5	26.23
37.5-28	200		3.73		89		
28-20	1850		34.5		451		
20-14	2130		39.74		643		
14-10	850		15.86		103		
10-6.3	330		6.16		67.8		

Appendex I Average % major element and mineral content of cinder gravel

Composition	SiO2	Al2O3	Fe2O3	CaO	MgO	Na2O	K2O	MnO	P2O5	TiO2	H2O	LOI
Content (%)	48.62	17.12	12.23	7.25	3.53	3.22	1.27	0.24	0.56	2.43	0.64	3.0

Appendex J: Laboratory Photos















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