JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

AN EXPERIMENTAL EVALUATION OF THE SUITABILITY OF DEMOLISHED CONCRETE AGGREGATE AND CERAMIC WASTE AGGREGATE AS SUBSTITUTES FOR BASE COURSE MATERIAL

A Final Thesis Submitted To the School Of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Master's Degree of Civil Engineering (Highway Engineering).

By:

Eyerusalem Aschalew

July, 2023
Jimma, Ethiopia

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Main Advisor: Anteneh Geremew (Assi.Prof.)

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July 2023

Jimma, Ethiopia

APPROVAL SHEET

As member of Board of Examiners of the MSc Thesis Open Defense Examination, we certify that we have read, evaluated the thesis prepared by **Eyerusalem Aschalew** and examined the candidate. We recommended that the thesis could be accepted as fulfilling the thesis requirement for the Degree of Master of Science in Highway Engineering.

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DECLARATION

I, The Undersigned, Declare That This Research Entitled by "***An Experimental Evaluation of The Suitability of Demolished Concrete Aggregate and Ceramic Waste Aggregate as Substitutes for Base Course Material***"

is my original work and has not been presented by any other person on an award of degree in this or other university and all sources of materials used for this thesis have been duly acknowledged.

Candidate: Eyerusalem Aschalew _______________ _____/______/____

Signature Date

As Masters research advisors, we hear by certifying that we have read and evaluated this MSc research prepared under our guidance, by Eyerusalem Aschalew entitled by ***"An Experimental Evaluation of The Suitability of Demolished Concrete Aggregate and Ceramic Waste Aggregate as Substitutes for Base Course Material".***

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

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ABSTRACT

The highway and building industries have recently used an enormous quantity of conventional aggregates each year. Construction costs rise, natural resources are running out, and the condition of the earth's surface is still declining due to the rising demand for conventional aggregaetes, such as ceramic refuse and demolished concrete. However, this is a relatively recent idea that is not well applied in our home nation of Ethiopia. Recycling used construction materials has a number of advantages, including financial efficiency, environmental protection, and the preservation of natural resources. It is crucial to switch to high-quality, accessible, and renewable recycled aggregate materials instead of virgin crushed stone aggregates, especially in developing countries like Ethiopia. The major goal of this study was an experimental evaluation of the appropriateness of demolished concrete aggregate and ceramic waste aggregate as substitute base course material, By using Purposive sampling techniques were used to achieve the goals, and laboratory tests at different replacement percentages of conventional crushed stone aggregate with (0%, 10%, 20%. 30%, 40%, 50%, 100% of demolished concrete aggregate and ceramic waste aggregate weights were conducted. The ceramics were gathered from building construction sites in Jimma City, where demolished concrete had been collected from dumped areas. The standard specification for the ERA pavement design manual and AASHTO T-2 were followed for the sampling and testing procedures for each sample. According to the study's findings, neat CSA and demolished DCA have aggregate crushing values (ACV) of 18.8% and 22.9%, respectively, while blended CSA with 10%, 20%, 30%, 40%, and 50%, of DCA has an ACV of 20.1%, 20.9%, 21.3%, 21.5%, and 21.9%. Similar results were found for Los Angeles abrasion (LAA) (12.55% - 14.99%) and aggregate impact value (AIV) (19.6% - 21.9%). A commercially viable result of 82.6% was discovered at a 40% DCA mix at 98% maximum dry density (MDD) in the CBR test for various ratios of DCA (10% - 50%) combined with CSA. Additionally, the 100% DCA at 98% MDD test result for the California Bearing Ratio (CBR) test was 68.31%. On the other hand, the experimental tests were carried out using various ratios of ceramic waste aggregate (CWA) that satisfy the key mechanical properties of aggregate materials (10%, 20%, 30%, 40%, and 50%). As specified, the blended CWA-CSA aggregate was tested with 10%, 20%, 30%, 40%, and 50% of CWA with its complement of CSA. At 30% CWA replacement of CSA, test results were 22.3% for ACV, 17.01% for LAA, 84.3% for CBR, and 22.2% for AIV. Results that were economically acceptable for this study were attained by satisfying the Ethiopian Road Authority's (ERA) standard specification limit of 30% CWA and 40% DCA combined with CSA for base course construction material.

Key words: *Base Course, Ceramic West aggregate, Construction, Demolished Concrete Aggregate, Percentage by Weight, Standard Specification.*

ACKNOWLEDGMENT

First of all, I would like to thank the Ethiopian Ministry of Education for giving me the chance to pursue my postgraduate study in the prestigious highway engineering field of specialization. Jimma Institute of Technology deserves special thanks for accepting and nurturing me as a postgraduate student. My heartfelt gratitude goes to my advisor, Engr. Anteneh Geremew and my co-advisor, Engr. Basha Fayissa for all their limitless efforts in guiding me through my work and providing their valuable feedback. Lastly, I would like to express my humble gratitude to my family and my friends.

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ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
ASTM	American Society for Testing and Materials
BS	Base Course
CA	Crushed Aggregate
CSA	Crushed stone aggregate
CBR	California Bearing Ratio
CWA	Ceramic waste aggregate
DC	Demolished concrete
DRIP	Drainage Requirements in Pavements
ERA	Ethiopian Road Authority
FHWA	Federal High Way Administration
GDP	Gross Domestic Product
HMA	Hot Mix Asphalt
LAA	Loss Angeles Abrasion resistance
MOFED	Ministry of Finance and Economic Development
OGAB	Open Graded Aggregate Base
PCC	Portland cement Concrete
RSDP	Road Sector Development Program
SG	Specific gravity

CHAPTER ONE

INTRODUCTION

1.1 Background

Throughout countless years, humanity has traversed the surface of the planet by using its natural surface as a means of transportation. Since the road surface was widened and covered with rock and gravel to make it suitable to handle more traffic, there has been an increase in traffic. This has led to the establishment of pavement design guidelines involving two major pavement types. In Ethiopia, asphalt pavement development is growing even though the government invests a lot of money in constructing and maintaining the nation's current road system. In terms of the nation's economic growth, the road sector is essential. To preserve sustainable development in the nation, the government has established a series of Road Sector Development Programs to expedite network expansion and improvement(1). Even though it is believed that using virgin aggregate in the asphalt layer wastes precious natural resources, it is necessary for the nation's sustainable development. Pavements made of asphalt cannot be built all at once and will eventually wear out. It eventually needs repairs and renovations. Researchers have been testing whether it is economically viable to recycle materials in high-value products in various countries as a result of this. If an engineer takes this into consideration, it would be preferable to replace the virgin aggregate material in the asphalt layer with recycled material (2).

Sand, gravel, crushed stone, slag, or rock dust are all examples of hard, inert materials known as aggregates (or mineral aggregates). Pavements are created by combining properly chosen and graded aggregates with asphalt, which acts as a cementing agent. The main load-bearing elements of an asphalt concrete pavement are aggregates. They make up 90 to 95 percent by weight and 75 to 85 percent by volume of the mixture.

The base course, also known as basecourse in pavements, is a layer of material that is used in asphalt roads, racetracks, equestrian arenas, and sports fields. Under the wearing course and occasionally an additional binder course that make up the surface layer is where it is found.

The base course is built directly on top of any sub-base layers if there are any. In the absence of such, the subgrade is directly covered. According to the characteristics of the underlying layer, the typical base course thickness ranges from 100 to 150 millimeters (4 to 6 in). It typically consists of a specific kind of construction aggregate, which is placed by carefully spreading and compacting to a minimum of 95% relative compaction. This creates the stable foundation required to support either additional layers of construction aggregate or additional layers of concrete.

One of the primary building materials utilised in the majority of structures is ceramic items. Among the ceramic products that are frequently created are wall and floor tiles, sanitaryware, domestic ceramics, and technical ceramics. Most of the time, they are made from organic materials that are rich in the mineral clay (3). Based on the source of the raw materials, ceramic waste is divided into two catagories (4). One group is created by fired ceramic wastes produced by structural ceramic manufacturers that manufacture products only using red pastes (brick, blocks, and roof tiles). The second category includes fired ceramic wastes made of stoneware ceramic (wall, floor tiles, and sanitary ware). Studies have revealed that roughly 30% of the material used to produce ceramics is wasted (5,6), and currently, they are not beneficially utilized. This confirms the necessity to investigate creative options for recycling ceramic trash. In the manufacture of concrete, aggregates make up around 70% of all ingredients. High demand from rural and urban communities is driving up the price. Ceramics may eventually take the place of natural aggregates, according to numerous studies (7,8). Several studies have suggested that ceramic wastes are suitable materials to replace traditional aggregates in concrete (9). Overall, using ceramic waste can help construction sites where there are shortages of aggregate. Also, it can lessen environmental issues caused by the mining of aggregate and the disposal of debris. Unfortunately, the majority of earlier studies used ceramics for electrical insulators and sanitary ware, and there was little data on ceramic floor and wall tiles. Due to the fact that ceramic floor and wall tiles are created at various temperatures, which usually affects their microstructure, it is necessary to investigate their usability.

Demolished concrete material (DCM) is a waste product created in significant quantities after the demolition of outdated structures and those with poor design decisions. The large amount of waste produced during the demolition process causes numerous environmental issues. Because there is cement in the DCM combination, this trash is both biodegradable and dangerous. It is typically disposed of in landfills or illegal dumps, which pollutes the environment and takes up a lot of room. Recycling the vast amount of concrete that is produced through demolition is necessary for environmental sustainability, more environmentally friendly manufacture, and cost-effective reuse. This substance could be used to make sustainable civil engineering materials as coarse or fine aggregates. Also, it is utilised to improve the engineering qualities (10).

1.2 Problem of the statement

The environmental contamination is being caused by an increase in recycled and discarded materials globally. These waste products include demolished concrete remnants and ceramic debris. The main ceramic "clusters" can be found in Brazil, with one in Santa Catarina and two in the state of Sao Paulo; in Portugal, in the Aveiro region; in Castellan, Spain; and in the province of Emilia Romagna, Italy. With 35% of global production in recent years, China's ceramics industry has also started to gain more prominence. The ceramics industry is divided into the following subsectors: wall and floor tiles, sanitary ware, bricks, and roof tiles, refractory materials, technical ceramics, and ceramic materials for residential and ornamental use. Construction and demolition wastes (CDW), solid wastes (SW), and by-products from industrial processes are the primary sources of recycled materials utilized in asphalt pavements and base/sub-base applications. Concrete and ceramic make up 40% and 30%, respectively, of the total demolition and construction trash (10).

In Ethiopia, the old houses and roads are under demolishing. A lot of old buildings in Egypt are collapsed. As a result, the demolition and structure processes naturally introduce the problem of recycling materials where many waste materials are also produced as byproducts from various industries and construction sites, the disposal of which cause a major problem. Thus it becomes necessary to find an alternate source of raw material for infrastructure development and a proper method of utilization of waste materials from industries and demolished buildings (11). Because of the disposal of waste concrete and waste ceramic, municipalities find it difficult to spend their budget on waste management. Also, there is a growing awareness among the general public regarding the usage of ceramic waste aggregate and demolished concrete as a mix for making road building materials, which requires specific and structured thought to address the issue that results. In affluent nations, it is common practice to use demolition and construction debris to build roads, but Ethiopia has never tried this. As a result, this study focuses on the combination of used ceramic waste and crumbled concrete used as road base course material in order to conduct and offer a long-term solution. A combination of waste ceramic and dimolished concrete was examined through basic experimental study as a potential base course material. Finding ways to minimize, reuse, and recycle waste will help us keep it out of our landfills. Environmental pollution brought on by an increase in waste production is the main issue. In our nation, proper garbage disposal has emerged as a serious issue.

1.3 Research questions

The primary research questions are:

1.What are the Physical and Mechanical Properties of Ceramic Waste aggregate, demolished concrete aggregate, and Crushed stone Aggregate in the study area?

2. What are the effects of replacing conventional aggregate with ceramic waste aggregate and demolished concrete aggregate at different proportions on the quality requirements of base course materials?

3.What will be the laboratory test result when compared with the standard specification of a base course?

1.4 Objectives

1.4.1 General objective

The general objective of the study was an experimental evaluation of the appropriateness of demolished concrete aggregate and ceramic waste aggregate as substitute base course material for road construction.

1.4.2 Specific objectives

- ✓ To determine the Physical and Mechanical Properties of Ceramic Waste aggregate, Demolished Cocrete Aggregate, and Crushed stone Aggregate in the study area.
- ✓ To replacing conventional aggregate with ceramic waste aggregate and demolished concrete aggregate at different proportions on the quality requirements of base course materials?
- ✓ To compare the laboratory test result when compared with the standard specification of a base course.

1.5 Significance of the Study

One of the factors contributing to the rise in the cost of road construction in recent years is the lack of aggregate manufacturing. This study sheds light on the potential application of crushed stone aggregate mixed with waste ceramic and demolished concrete aggregate for the construction of roads. An additional source of aggregate for road construction is provided by recycling used concrete and waste ceramic. This research has therefore been used as a foundation for additional information to be provided for further investigation and formulation of policies on recycling of waste ceramic and demolished concrete to be included in the specifications for the next amendment by the relevant road authorities and other stakeholders.

1.6 Scope of the research

This study was done in a lab to see if it was appropriate to mix crushed stone aggregate with ceramic waste from demolition of concrete in base course material. The Gradation test, ACV, AIV, LAA test, Compaction test, CBR test, Water absorption, SG and Atterberg's (liquid limit, plastic limit, and plastic index) tests were the pertinent laboratory tests that were carried out. In order to meet the study's goal, only base course construction that complied with ERA, AASHTO, and ASTM criteria was considered suitable. This thesis examines the literature on blended waste ceramic and demolished concrete with crushed stone aggregate used as base course material and performs laboratory tests to assess the physical and mechanical properties of waste ceramic, concrete, and a blended waste ceramic and demolished concrete with crushed stone aggregate. Finally, the results of the study have been compared to the AASHTO, ERA, BS, and ASTM specifications following laboratory tests for each test that had a specific purpose to explore.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The main purpose of a highway pavement is to disperse the applied vehicle loads to the sub-grade. A highway pavement is a structure made up of layers of processed materials that are overlaid above the natural sub-grade soil. Sub-grade, sub-base, base course, and surface layer are the several layers that make up the pavement structure, which is made up of both flexible and rigid pavement. Throughout the design process, it is necessary to take into account the many roles that each pavement layer must accomplish. In flexible pavements, dense-graded unbound aggregate base and sub - base layers serve as significant structural elements of the pavement system to provide load distribution (i.e., absorption of high wheel load stresses with depth) and offer enough support and stability for the asphalt surfacing (7).

2.2 Typical layers of a flexible pavement

Typical layers of a flexible pavement include surface course, base course, sub-base course, compacted sub-grade, and natural subgrade

Surface Course: - Surface course or wearing course is the top most layer of flexible pavement which has direct contact with the vehicular loads. Since it is directly in contact with traffic, good quality aggregates and high dense bitumen or asphalt is recommended for the construction of surface course. The main function of surface course is to provide skid-resistance surface, friction and drainage for the pavement. It should be water tight against surface water infiltration. Surface courses are most often constructed out of HMA. They are usually constructed with dense graded asphalt concrete (AC). The functions and requirements of this layer are (8):

- ✓ It offers qualities like friction, smoothness, drainage, etc. Moreover, it will stop excessive amounts of surface water from penetrating the subsurface base, base, and subgrade.
- ✓ It must be durable to withstand distortion from traffic while still maintaining a smooth, skid-resistant riding surface.
- ✓ To prevent water from undermining the entire base and sub-grade, it must be waterproof.

Base Course: - The base course is important layer of pavement structure and it distributes the loads from top layers to the underneath Subbase and sub-grade layers. It provides structural support for the pavement surface. It is constructed with hard and durable aggregates which may either stabilized or granular or both. The thickness of base course must be great enough to reduce the load capacity on sub-grade and Subbase courses. The base course also contributes to subsurface drainage, resists the accumulation of permanent deformation within each layer, provides an adequately strong layer on which the overlying layers can be compacted, and serves as a long-lasting and rigid layer to support any overlaying layers under working conditions.

Sub-base:- The base course is followed by a layer of material whose main purposes are to support the pavement structure, enhance drainage, and lessen the incursion of particles from the sub-grade. The sub - base course with additional fines can act as a filler between the sub-grade and the base course if the base course is open-graded. Not always is a sub-base course required or used. For instance, the additional qualities provided by a sub - base course may not be necessary for a pavement built over a high-quality, rigid sub-grade. The sub-base course might not be offered in such cases (8).

Sub-grade:- Subgrade is the bottom most layer which is nothing but natural soil layer compacted up to required depth generally about 150 to 300 mm to receive the loads coming from top layers. This layer is termed as foundation for the pavement system. The sub-grade should be strong enough to take the stresses and also it is important to keep the stresses coming from top layers should be within the limit of sub-grade capacity. To reduce the amount of stress on soil sub-grade, provide thick layers of base course, Sub-base course and surface course. It should be compacted to the desired density, near the optimum moisture content (8).

2.2 Base course

The Base course is the principal structural layer of a flexible pavement whose function is to support the applied wheel stress and strains incident on it which is coming from traffic and distribute the same in such a manner that the materials beneath it will not become overloaded (11). Besides this other functions of the base course include resistance to the built-up of permanent deformation within each layer, provision of an adequately stiff layer on which the overlying layers can be compacted and provision of a sufficiently durable and stiff layer to support any overlaying layers in the long term during in-service conditions.

Base course in the pavement is a layer of material in an asphalt roadway, race track, riding arena, or sporting field. It is located under the surface layer consisting of the wearing course and sometimes an extra binder course. If there is a sub-base course, the base course is constructed directly above this layer. Otherwise, it is built directly on top of the subgrade. Typical base course thickness ranges from 100 to 150 millimeters (4 to 6 in) and is governed by underlying layer properties. Generally consisting of a specific type of construction aggregate, it is placed by means of attentive spreading and compacting to a minimum of 95%relative compaction, thus providing the stable foundation needed to support either additional layers of asphalt concrete wearing course which is applied directly on top of the base course (12,13). The base course serves as a foundation for the paving. Depending on the stresses to be expected the road comprises various layers of different thicknesses in order to withstand the most diverse weather condition and remain serviceable for many decades.

It is the portion of the pavement structure immediately beneath the surface course. It is ‘constructed on the sub-base course, or, if no sub-base is used, directly on the roadbed soil. Its primary function in the pavement is structural support. It usually consists of aggregates such as crushed stone, crushed slag, crushed gravel, and sand, or combinations of these materials. It may be used untreated or treated with suitable stabilizing admixtures, such as Portland cement, &asphalt, $lime, cement-fly ash, and lime-fly ash(5).

2.2 Design and construction of base course

Base course in flexible pavement structures that must carry heavy traffic requires certain important considerations in their design and construction that are often neglected. The thicknesses of these bases are 8 inches to 16 inches, depending on the type of subgrade on which they rest, which introduce the compaction problem. If the base is not compacted to a degree equal to that will be produced by traffic, rough pavements or even failures will be the result. It is also important that during the construction of the base course each layer be dense in order that water from rains will not often be the subgrade. This dense condition is dependent upon the grading of material and its degree of compaction. The use of calcium chloride in the construction of these bases has proven very m,jadvantageous (14).

2.3 Base Course Materials for Pavement Construction.

Pavement design requires the efficient use of locally available pavement materials if economically constructed roads are to be built. A wide range of materials can be used as a base course and sub-base courses including crushed and quarried rock, crushed and screened, mechanically stabilized, modified or naturally occurring “as dug” or “pit run” gravels. Their suitability for use depends primarily on the design traffic level of the pavement and climate. However, such materials must have a particle size distribution and particle shape which provide high mechanical stability and should contain sufficient fines to produce a dense material when compacted. The use of locally available materials is encouraged, particularly at low traffic volumes. Their use should be based on the results of performance studies and should incorporate any special design features which ensure their satisfactory performance (11).

2.4 Aggregate and their property

2.4.1 Aggregate

Sand, crushed marble blocks, crushed concrete from demolition projects, and other similar solid waste elements are all included in the base course term "Aggregate" (15). Aggregates can be created artificially, organically, or by recycling. Recovered aggregates are frequently made by crushing solid waste, much like natural aggregate is. Aggregates make up the majority of the base course and principal materials that were employed. The aggregate for a base course must consist of robust, long-lasting chunks or shards of crushed stone, crushed slag, crushed or natural gravel, and filler consisting of natural or crushed sand or other finely divided mineral elements. To offer a strong, stable foundation, the substance must be easily compactible. The design traffic level of the pavement and climate are the main determinants of the acceptability of base course material for usage. A basic course is required for traffic of a higher class (16).

Aggregates bear stresses occurring due to the wheel loads and they should be hard, strong and of the required size and gradation to bear the stress. Therefore, the properties of the aggregates are of considerable significance to highway engineers.

2.4.2 Desirable Properties of Aggregates

The selection of aggregate material for use in an Asphalt Concrete pavement depends on the availability, cost, and quality of the material, as well as the type of construction for which it is intended. To determine if an aggregate material is suitable for use in asphalt construction, evaluate it in terms of the following properties:

Size and grading. The maximum size of an aggregate is the smallest sieve through which 100 percent of the material will pass. How the Asphalt Concrete is to be used determines not only the maximum aggregate size but also the desired gradation (distribution of sizes smaller than the maximum).

Cleanliness. Foreign or deleterious substances make some materials unsuitable for paving mixtures.

Toughness. When an aggregate is tough or firm, it can withstand crushing or disintegration while mixing, placing, and compacting, as well as when it's being loaded by traffic.

Soundness. Although similar to toughness, soundness is the aggregate's ability to resist deterioration caused by natural elements such as the weather.

Particle shape. The shapes of aggregate particles influence the asphalt mixtures' overall strength and workability as well as the density achieved during compaction.

When compacted, irregular particles such as crushed stone tend to lock together and resist displacement.

Surface texture. Surface texture affects workability and pavement strength. A texture with a rough, sandpaper-like surface has higher strength than one with a smooth surface. Smooth-faced aggregates are simple to coat with an asphalt coating, although they typically aren't as good as surfaces with a rough texture. The asphalt has a difficult time clinging to the smooth surface.

Absorption. An aggregate's porosity enables it to absorb asphalt and create a connection between the asphalt and the particle. Although a certain amount of porosity is preferred, very absorbent aggregates are rarely employed.

2.4.3 Aggregate Base

High-quality aggregate bases are constructed with high-quality aggregates. The seven classes of aggregates used for base courses are described in Mn/DOT's Specification 3138. Classes 1 through 6 consists of 100 percent virgin aggregate materials. These materials consist of durable particles of gravel and sand, crushed quarry, or mine rock. Class 7 consists of salvaged or recycled aggregate materials that may or may not be blended with virgin aggregate. The salvaged and recycled aggregates that are permitted include bituminous mixtures, crushed concrete, and reclaimed glass. Specific restrictions apply to these materials depending on their intended use; for example, recycled glass is only allowed to make up a maximum of 10 percent of the mass (17). Aggregate bases can be designed and built using any one of three methods. These methods can produce base courses that are heavily graded or permeable (drainable). (relatively impermeable). Below is a discussion of aggregates for both categories.

Permeable or drainable base courses are designed to rapidly drain moisture from the pavement structure. The combination of base thickness and material permeability should be such that moisture rapidly flows through the base, preferably draining the layer in fewer than two hours following a precipitation event. An FHWA study showed that the presence of a permeable base course enhanced the performance of the pavement, especially in areas where the pavement materials were affected by the presence of moisture. Essential to the good performance of such permeable bases, however, was the design and construction of adjacent layers, the design and placement of outlet drains, and the presence of a properly designed filter layer between the permeable layer and the subgrade soils beneath it.

Permeable aggregate bases should consist of a hard, durable, crushed, angular aggregate with fewer than 3% fines (material passing the 0.075mm (No. 200) sieve). The LA abrasion index of the aggregate must be 40 or less and the aggregate must contain less than 10 percent minus 0.075mm (No. 200) sieve size insoluble residue (Mn/DOT’s laboratory manual test method No. 1221). Permeable bases may be unstabilized (Open Graded Aggregate Base (OGAB)), or susceptible to deformation from construction equipment, and care must be exercised to not damage them during construction (18).

As was previously said, the performance of the permeable base layer depends on the location of a well-designed filter layer. This layer's function is to stop particles from entering the drainage layer's voids and clogging them, decreasing the base's permeability in the process. The cost of permeable aggregate bases in the new design is typically higher than that of traditional dense-graded materials. Longitudinal edge drains must be added before installing a permeable foundation layer. These drains have the function of removing the moisture that has accumulated in the drainage layer from the pavement construction. The goal of edge drains, which come in a variety of shapes and sizes, is to quickly remove any moisture that has accumulated in the drainage layer. This is most easily accomplished in new designs with a properly constructed longitudinal trench collector system, which makes use of collector pipes, geotextiles, and backfill material of the proper size. It is not advised to utilise geocomposite (fin) drains with permeable bases.

Detailed information on the design and construction of the filter layer, edge drains, and other aspects of providing subsurface drainage is provided in the FHWA's Technical Paper 90-01, Subsurface Pavement Drainage and in FHWA’s Pavement Subsurface Drainage Design Reference Manual, January 1999, ERES Consultants, Inc. In addition, the FHWA has developed a Windows-based program called Drainage Requirements in Pavements (DRIP). Its applications of interest include the hydraulic design of permeable bases, the design of separation layers, and longitudinal edge drains.

2.4.4 Dense-graded Aggregate Bases

The other type of aggregate base is a dense-graded granular material. Granular materials meeting Mn/DOT's Specifications for Classes 3, 4, 5, 6, and 7 may meet the definition of a dense-graded material. These materials will provide adequate support to the pavement structure provided that they have the proper gradation and are not saturated. A saturated base may lose fines due to pumping when subjected to loading, which can reduce the support it provides to the surface layer. In general, saturated bases lose stiffness: modulus reductions of more than 50% have been reported in the literature. In order to reduce or eliminate the moisture-related damage and increase the overall pavement service life, permeable bases and/or edge drains have been incorporated into some designs.

2.5 Ceramic waste as recycled aggregate

Recycled aggregates can be defined as the result of waste treatment and management where, following a process of crushing to reduce the size, sieving, and laboratory analysis, the waste complies with technical specifications for use in the construction sector and civil engineering (19) . Recycling pavement materials has become a viable alternative in road maintenance and rehabilitation. Conservation of resources, preservation of the environment, and retention of existing geometrics are some of the benefits obtained by reusing pavement materials. Ceramic wastes are separated into two categories in accordance with the source of raw materials (3). One category is formed through generated fired ceramic wastes by structural ceramic factories that use only red pastes for product (brick, blocks, and roof tiles) manufacture. The second encompasses fired ceramic wastes which are produced in stoneware ceramic (wall, floor tiles, and sanitary ware). Meanwhile, during ceramic production, studies have shown that about 30% of the material goes to waste (4,5), and currently, they are not beneficially utilized. This attests to the need for exploring innovative ways of re-using ceramic wastes. Aggregates constitute about 70% of total constituents in concrete production. The cost is increasing as a result of high demand from rural and urban communities. Numerous researchers have identified ceramics as having the potential to replace natural aggregates (6,7).

Some investigations have suggested that ceramic wastes are good materials that could substitute conventional aggregates in concrete (20–22).

Overall, ceramic waste utilization can solve problems of aggregate shortages in various construction sites. Moreover, it can reduce environmental problems related to aggregate mining and waste disposal. However, most of the previous investigations were carried out using sanitary ware and electrical insulator ceramics, with not much information as regards the use of ceramic floor and wall tiles. Thus, there is a need to explore the usability of ceramic floor and wall tiles, because these ceramic products are produced at different temperatures which invariably determine their microstructure

2.6 Construction and demolishing concrete waste

Reuse and recycling of concrete demolished materials conserves landfill space, reduces the environmental impact of producing new materials, creates jobs, and can reduce overall building project expenses through avoided purchase/disposal costs. The diversion of construction, renovation, and demolition waste from landfill sites is an issue that has been gaining attention within both the public and private sectors. Many of our landfill sites are reaching capacity. In addition, demolish waste is sometimes illegally dumped or burned causing land, air, and water pollution. The increasing costs of disposal are ultimately reflected in project costs, as contractors must incorporate anticipated disposal costs in their bid costing. While serious pollution is generated from construction activities, comprehensive construction waste management is urgently needed on every construction site. It is of great importance to structure ways for minimizing waste generation which is seen as the most favorable solution to waste problems of any kind. Typical materials recycled from building sites include metal, lumber, asphalt, pavement (from parking lots), concrete, roofing materials, corrugated cardboard, and wallboard (23).

2.7 History of Recycled Concrete Aggregate

Australian authorities started employing RCA in the construction of light-traffic roads in 1990 due of the need to protect natural resources and expand landfill space (24). In 2004 and 2005, South Australia produced over 1.5 million tonnes of construction and demolition trash, of which only 70% was recycled. In recent years, South Australia has produced about 500 million kg of RCA annually, largely from building demolition debris, and a sizable percentage of this is used in the creation of pavement (25). In Europe, from 1945 to 2000, around 600×106 m 3 of waste masonry was used in the rebuilding of Germany after World War II. In 1998 about 350,000 tons of crushed concrete were used in the base and sub-base layers of Finland's road construction (25). Department of Transportation released a memorandum in 2002 that has accentuated the interest of FHWA in using recycled material products in the national highway system (26). After that, over 130×106 tonnes of construction and demolition (C&D) waste are produced annually in the United States. Of this amount, 70% of RCA can be used in the construction of pavement, primarily as a granular material in base layers (27)

2.8 Use of recycled concrete

The consumption of natural aggregate is decreased when demolished concrete is recycled, reducing the depletion of natural resources. Because concrete is recycled and new aggregate manufacturing for building is avoided, it decreases environmental pollution. Recycled aggregate can be made from old, unnecessary concrete.

However, it can also be combined with virgin materials and utilised as an aggregate in fresh concrete. Recycled aggregate is typically used as sub-base material. Common aggregates made from concrete are grade 8 recycled concrete and CA6 recycled PCC. They are frequently employed as backfill material, shoulder stone, and a base for roads, parking lots, and driveways.

Recycling concrete offers many benefits to the budget and the environment. Landfill costs for construction-related debris continue to rise and the cost of transporting the debris from one area to another is an additional expense. Instead of spending money on transport and disposal, recycling creates considerable savings. In addition to rising costs, landfills are also becoming more heavily regulated, which means that many contractors and homeowners are finding it difficult to dispose of certain materials including concrete. Recycling concrete is also extremely beneficial for the environment. Concrete waste takes up a significant portion of landfills and many cannot accommodate its size and volume. Recycling keeps these materials out of the landfill and allows them to be reused in other applications. Recycling also saves energy that would otherwise be used to mine processes, or transport new aggregates, which is also beneficial to the environment.

Transportation agencies' experiences and research studies have shown that recycled concrete aggregate (RCA), under specific conditions, has the potential to produce strong, durable materials suitable for use in the highway infrastructure. The coarse aggregate portion of RCA has no significant adverse effects on desirable mixture proportions or workability. Recycled fines, when used, are generally limited to about 30 percent of the fine aggregate portion of the mixture. According to (28), recycled concrete aggregate (RCA) has the following advantages.

2.8.1 Resource Conservation

Reduced land disposal and dumping: The growth of concrete waste stockpiles is prevented by the use of recycled concrete pavement. Additionally, since recycled materials can be used in the same metropolitan area, using less energy is possible when hauling and making aggregate. Additionally, fewer emissions from transportation sources can contribute to better air quality.

Conservation of virgin aggregate: substituting recycled aggregates for virgin ones. An affordable and environmentally good solution is to use recycled aggregate. The usage of virgin aggregates is subject to tax in a number of European nations. The adoption of this procedure encourages the recycling of aggregates. It should be mentioned that several states charge substantial tipping fees for the disposal of RCA; this is done to reduce the amount of RCA that ends up in landfills and increase its potential for recycling.

Reduce impacts on the landscape: When concrete demolition waste is reused, it lowers unattractive piles of concrete debris, animal infestation in piles, and overall environmental improvement.

2.8.2 Angularity

Building pads (residual cementation), which provide a sturdy, long-lasting platform upon which to build, provide a better control over gradation, enabling RCA to meet gradation and angularity requirements. RCA has good angularity, which contributes to increasing structural strength in the base and improving load carrying capacity.

2.8.3 Construction of Pavements

Recycling demolished materials can be used in a variety of ways to improve pavement quality, including increasing and improving its durability. When building roads and pavements, DCM can be used as an aggregate material for the sub-base layer of the road. The DCM demonstrated good outcomes comparable to those attained using the standard aggregate (29).

DCM is used in the construction of embankments, sub-bases, and foundations of roads where unbound materials are used to replace natural aggregates. The main objective of their study was to develop better stiffness of the materials forming the pavement by adding recycled additives such as the DCM. An experimental embankment was built and tested with four sections of different recycled materials. The results showed that recycled aggregates obtained from DCM had good performance when compacted properly and formed cementing agents. It is clearly shown from the reviewed studies that DCM could be implemented in improving the materials used in pavements' design. Utilizing the DCM in road construction contributes to reducing the amount of waste generated by the accumulation of concrete at the construction sites. Besides, the utilization of DCM to replace the pavements' materials revealed an acceptable performance of design (30).

2.8.4 Environmental Benefits

The use of recycled concrete pavements eliminates the development of waste stockpiles of concrete. Also, as recycled material can be used within the same suburban area, this can lead to a decrease in energy consumption and can help improve air quality through reduced mobile source emissions (31). Study mentioned that reconstruction of urban streets and expressways results in an enormous waste concrete, creating a massive disposal problem(32). Recycling can eliminate many of these issues. One of the major waste-generating industries is the construction and marble processing industry. Nearly 70% of this precious mineral resource gets wasted in the mining, processing, and polishing procedures (33). Massive disposal of this waste material will cause pollution of the environment such as waterlogging, reduces the porosity of soils, and increases in alkalinity of soils, which results in soil fertility and other health problem (34). Therefore, it is essential to recycle concrete for road construction.

2.9 Physical and Mechanical Properties of Aggregate

The most visible aggregate characteristics are the most significant physical and mechanical characteristics of aggregates, and they also have the most immediate impact on how an aggregate performs either independently as a base or subbase material or as a component of pavement materials. The performance of asphalt pavements is significantly impacted by the physical and mechanical characteristics of the aggregates. Separating the effects of various aggregate properties on asphalt performance, however, is challenging. Commonly measured physical and Mechanical properties aggregate include (3).

- Gradation
- Toughness and Abrasion Resistance
- Durability and Soundness
- Particle Shape and Surface Texture
- Cleanliness and deleterious material
- Moisture content
- Absorption and Particle density
- Hardness and Resistance to polishing

The purpose of an unbound layer in a pavement is to provide as a solid foundation on which the pavement's upper layers can be built and compacted. The unbound layers needs to be breathable, frost-resistant, and act as a frost protection layer to shield the subgrade from freezing. In addition to the bound layers, an unbound layer should distribute the traffic load to lessen stress on the subgrade and the underlying pavement layer, minimising overstress and rutting in the subgrade(35).

2.10 Specifications and Quality Requirements of Aggregates as Base course

Any constructed pavement system's performance is primarily influenced by the quality of the materials used in every layer. Transportation agencies have created criteria that address particular minimal features or qualities of construction materials in order to confirm the sufficient performance of pavements under loads (7).

The stiffness and stability of an unbound aggregate material determine how much it will deform under load. Stiffness, or the capacity to distribute the load, is a measurement indicating durable deformation resistance. It is described in terms of an elastic or resilient modulus that is applied while planning the pavement. A measure of stability is the capacity to withstand long-term deformation. Another word is load-bearing capacity, which can be interpreted as the weight that a layer of material can support without deforming excessively. Therefore, a limiting deformation value is necessary for determining the bearing capacity (35).

Aggregates play a vital role in the construction of pavement. They have a great capability of load transfer to the Subgrade soil. Aggregates have different properties which are tested individually with different types of tests for the construction of pavement. Aggregate should qualify all the tests conducted to give better results after construction. The properties of aggregate and their respective tests are given below (13).

Table 2. 1: The properties of aggregate and their respective tests

Aggregate property	**Test to be conducted**
Strength	Crushing strength test,CBR test
Hardness abration test	Abration test
Impact value	Impact test
Resistance against weathering	Soundness test
Shape of aggregate	Shape test
Bitumen adhesion bitumen adhesion test	Bitumen adhesion test
Specific gravity	Specific test
Water absorption	Water absorption test
Particle size	Gradation test

The performance of a material depends on where it exists in the pavement structure. Trafficinduced stress is highest on the road surface and diminishes with depth according to the load-spreading capacity of the different materials. Bitumen-bound materials have a greater load-spreading ability than unbound materials (35).

Materials used for base course layer construction shall consist of hard, durable, tough and strong particles or fragments of stone which must be resistant to carry the 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 (11).

As shown in table below materials acquiring Suitable for base course construction have been labeled by ERA as standard materials designated as GB1, GB2, GB3, and GB2A with a certain specification of grading, shape and minimum strength. A wide range of materials are included in these categories, and the selection among them depend upon traffic level and local climate.

Table 2. 2: Properties of unbound materials (11)

Code	Description	Summary of Specification
GB1	Fresh, crushed rock	Dense-graded, un weathered crushed stone, non-plastic parent fines
GB2	Crushed weathered rock, gravel or boulders	Dense grading, PI<6, soil or parent fines; PP<60
GB2A	Dry-bound and water-bound Macadam	Aggregate properties as for GB2 PI<6; PP<60
GB3	Natural coarsely graded granular material, including processed and modified gravels	Dense grading, PI<6, CBR after soaking>80%
GS	Natural Gravel	CBR after soaking >30%
GC	Gravel or gravel-soil	Dense-graded; CBR after soaking>15%

These specifications are sometimes modified according to site conditions, material type, and principal use.

- PP= Plastic product= PI*(percent passing 0.075mm sieve).
- GB=Granular base course, GS= Granular sub base, GC =Granular capping layer.

Material requirements for naturally occurring granular materials, boulders, weathered rock (GB2 and GB3).

As base course materials, a variety of substances, such as lateritic, calcareous, and quartzite gravels, river gravels, boulders, and other transported gravels, or granular substances produced by the weathering of rocks, can be utilised successfully. The material must be able to be easily dispersed, compacted, and transported without needing to be separated.

Grading

Table 2. 3: Recommended Particle Size Distributions for Mechanically Stable Natural Gravels and Weathered Rocks for Use as Base Course Material (GB2, GB3) (36).

Test sieve (mm)	**Percentage by mass of total aggregate passing test sieve**	
	Nominal maximum particle size	
	37.5mm	**20mm**
50	100	-
37.5	80-100	100
20	60-80	80-100
10	45-65	55-80
5	30-50	40-60
2.36	20-40	30-50
0.425	10-25	12-27
0.075	5-15	5-15

A. Plasticity Index

When measured in accordance with AASHTO T-90, the fine fraction of a GB1 material must be non-plastic or have a Plasticity Index no higher than 6.

B. Californian Bearing Ratio (CBR)

The material should be compacted to a density that is equal to or higher than 98 percent of the maximum dry density attained in the ASTM Test Method D 1557 when used as a base course (Heavy Compaction). The material should have a minimum CBR of 80 percent after four days of water immersion when compacted in the lab to this density (ASTM D 1883).

C. Aggregate Crushing Value (ACV)

Minimum soaked Ten percent Fines Value (TFV) Value (BS 812, Part 111) shall be 50 KN.

When calculated in line with the specifications of AASHTO T-27, the particle size distribution should be roughly parallel with the grading envelope to guarantee that the material has maximum mechanical stability. These grading limits are presented in Table 2-7. According to the specifications of AASHTO T-11, the mass of material passing through the 0.075mm sieve must be calculated. For appropriate materials with maximum nominal diameters of 37.5 mm and 20 mm, Table 2-7 provides two recommended particle size distributions.

2.9 Summary of Literature Reviews

The results of the literature reviews show that other parts of the world have a well established recycling industry for ceramic and concrete materials. Ethiopian authorities don't yet know how to recycle materials from concrete and ceramic demolition, nevertheless. This can be because natural aggregate is more readily available now, or it might be because there hasn't been enough recycling study done. It is prudent to recycle solid wastes like dismantled concrete and ceramic waste as traditional aggregate because the rate of consumption of natural aggregate is rising as the demand for various construction sectors rises and landfills fill up. To lower the natural aggregate consumption rate and reduce pollution, using waste is crucial. Therefore, the purpose of this study was to determine if recycled concrete and ceramic wastes were suitable alternatives to standard aggregates for base coarse material. The engineering characteristics of these materials as the foundation layer of pavements were finally reviewed and compared to ERA standard specifications.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Study Area

This research was conducted in Jimma town. Jimma is found in the southwestern part of Ethiopia which is 345 km far from Addis Ababa, the capital city of Ethiopia. It covers a total surface area of 19,305.5 km2. Jimma is geographically located between 7° 38’52” and 7° 43’ 14” N latitude, and between 36° 48’ 00” and 36° 53’ 24” E longitude. In general, the topographical features' elevation varies from 1780 to 2000 m above sea level with average maximum & minimum temperatures in the range of 25-30°C. It was founded in 1837 E.C by the king of Abba Jifar and has a town administration, municipality, and 17 kebele (N.B. Kebele is the smallest administrative unit in Ethiopia (25). There is a reason to choose Jimma Zone as the study area; this research was conceded to find and gives the alternatives construction material, for road construction and maintenance because construction and maintenance are obvious around Jimma town.

3.2 Study period

The study was conducted from October 2021 to 2023 G.C for developing a proposal, collecting data, and analysis which includes data collection Sampling, evaluation, writing up and finally, dissemination is executed.

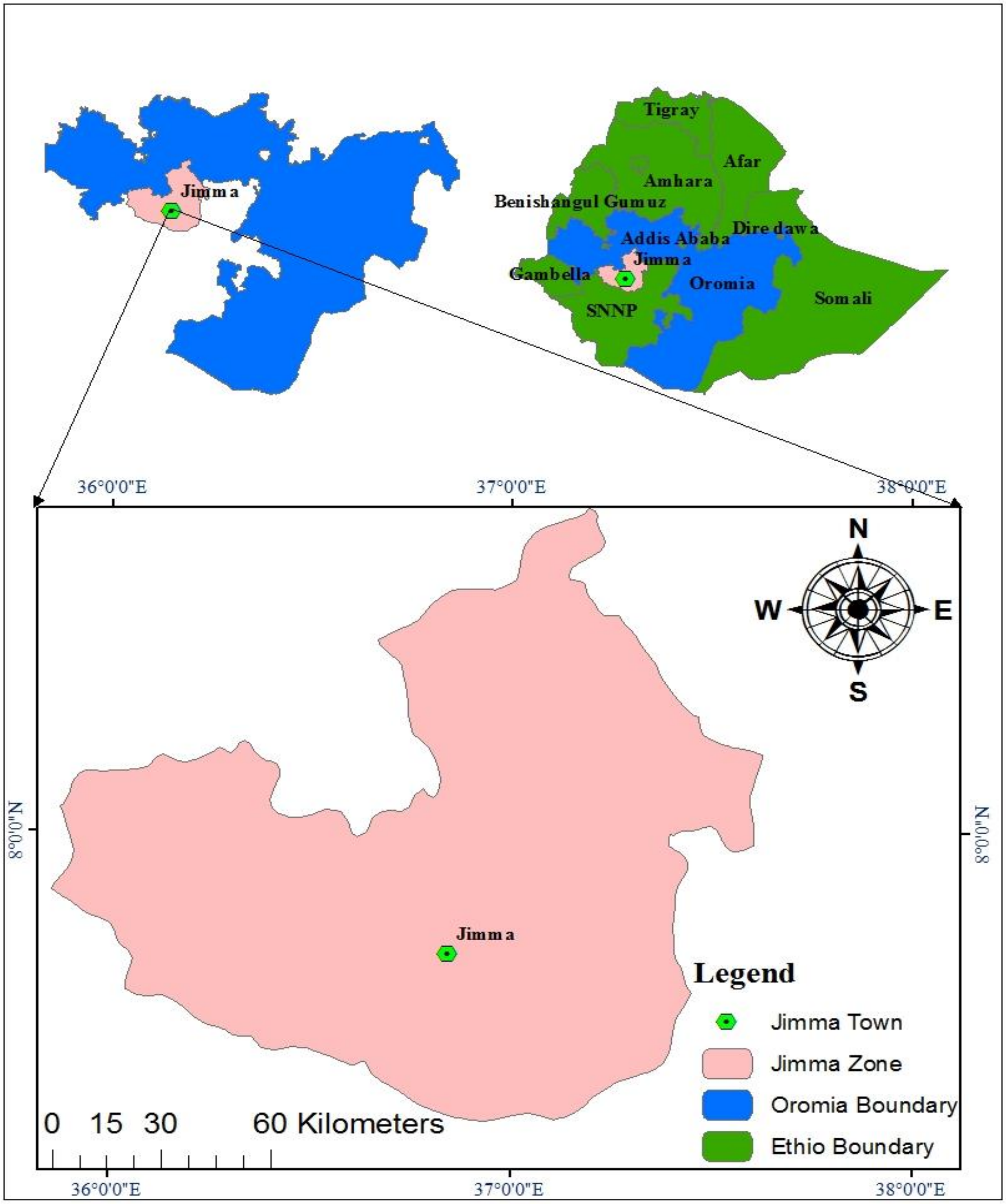

Figure 3. 1 Study area (ArcGIS 10.3.1)

3.3 Research design

The research was designed to be an experimental study. Different laboratory tests were conducted in order to assess the properties of ceramic waste, demolished concrete, and crushed stone. Then, the results of laboratory experiments were compared to standards to identify the suitability of ceramic waste and demolished concrete as a base course

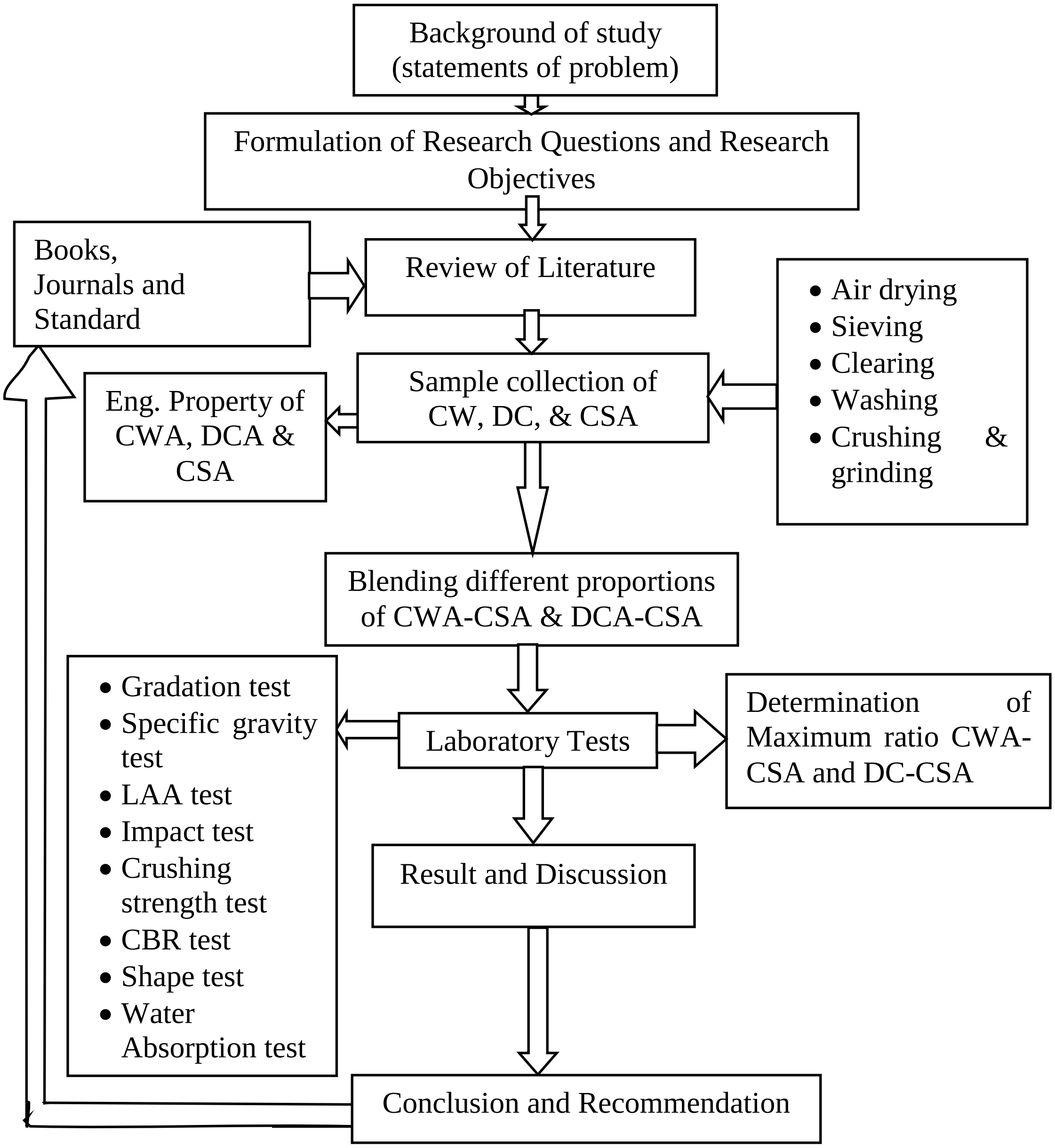

Figure 3. 2 Flow chart showing of study design

3.4 Study variable

3.4.1 Dependent variables

The dependent variables are more related to the general objective of the study which is an experimental evaluation of the appropriateeness of demolished concrete aggregate and ceramic waste aggregate as substitute base course material mix with CSA as an alternative for base course material.

3.4.2 Independent variables

- ✓ Engineering properties of ceramic west aggregate, demolished concrete aggregate and Crushed stone aggregate.
- ✓ flakiness index
- ✓ Gradation
- ✓ Specific gravity and water absorption
- ✓ Aggregate crushing value
- ✓ Aggregate Impact value
- ✓ Los Angeles abrasion value
- ✓ Moisture-Density relation (Compaction) Test
- ✓ California Bearing Ratio
- ✓ Percentage by weight

3.5 Sample preparation procedures

The ceramic west was collected from different ceramic sales sites and building construction in Jimma city and demolished concrete was collected from building construction sites in Jimma city. Representative Samples were collected by the AASHTO T-2 methodology for sampling from stockpiles. The specimen was collected from the site and transported to JIT laboratory; the mechanical splitter was used to obtain a uniform and a representative sample for all tests. Details of this procedure can be referred to in AASHTO T – 248 reducing samples of aggregate to testing size (26,37).

3.6 Laboratory test

The laboratory test was conducted to thoroughly evaluate the physical and mechanical properties of DC, ceramic west, and CSA in a detailed procedure.

To ensure the accuracy of laboratory results, a careful following of proper test procedures as described by AASHTO, BS, and ASTM standard specifications was carefully undertaken. Before commencing the laboratory test, the prepared samples were first air-dried under the sun to allow moisture to evaporate and the samples were fully mixed in the lab to create a situation in which any amount of sample obtained is a representative of the entire sample and by the extension of the soil in the site. Quartering was used to achieve this. To quarter a sample, divide it into two equal parts first using a set of tools known as the quartering box. Then, two equal sections of one part are once more divided. This operation is continued until the homogeneity of the material and the level of mixing are both satisfied in accordance with procedures outlined in AASHTO T-248 various laboratory tests were conducted on the samples of DCA, ceramic west and CSA materials. The gathered representative samples for laboratory test were performed in the laboratory of JIT

The following tests were carried out in the study: Sieve analysis, Atterberg's limits, compaction and CBR tests, ACV, AIV, LAA, SG, and Water absorption had been conducted on demolished concrete aggregate and ceramic west samples were collected from different locations. On crushed stone aggregate received from the stockpile for base course construction at the Jimma site. In order to choose the initial DCA and CSA mixing ratio, it was necessary to characterise the qualities of the materials and determine the type and severity of deficiencies in the quality of the DCA and ceramic west materials. The necessary tests were conducted for all the samples, and the summary of the results is presented in a tabulated form to achieve the above-stated objectives.

3.6.1 Flakiness index

The flakiness index shall not exceed 30% when determined in accordance with BS 812 Part105-1990. The flakiness index of an aggregate is the percentage by weight of particles whose least thickness is less than three-fifths of their mean dimension. The use of the shape tests in specifications is based on the view that the shapes of the particles influence both the strength of aggregate particles and internal friction that can be developed in the aggregate mass. For base course and wearing coarse aggregates, the presence of flaky particles is considered undesirable as they may cause inherent weakness with the possibility of breaking down under heavy loads. The Flakiness Index of an aggregate sample is found by separating the flaky particles and expressing their mass as a percentage of the mass of the sample. The value of the Flakiness Index is calculated from the expression:

Flakiness Index, FI=$\frac{M_3}{M_2} * 100$ ………………..……………………………......………Eq. (3.1)

Where: M_2 is a sum of the mass of the sample after discarding 5% or less (g)

M_3 is the mass of all particles passing each of the gauges (g)

Figure 3. 3 Photos while conducting Flakiness and Elongation Tests

3.6.2 Gradation

Particle gradation was conducted according to AASHTO T -27. Since the objective of this study was to evaluate the suitability of DC, CWA, and CSA in order to eliminate the effect of gradation on the material properties.

This was done to determine the percentage particle size distribution of a given sample of demolished concrete, ceramic waste, and crushed stone aggregate. A dry sieving analysis was performed. This procedure is suitable for coarse aggregate. This test is aimed at determining the particle size distribution or gradation of the aggregate used. This was presented in form of a graph plotted on a grading chart.

Figure 3. 4 Photos while conducting a gradation test

3.6.3 Specific gravity and water absorption

Specific gravity is the ratio of the mass (or weight in air) of a unit volume of material to the mass of the same volume of water at the stated temperature to the weight in air of an equal volume of gas-free distilled water at the same temperature. The specific gravity may be expressed as dry bulk specific gravity, saturated bulk specific gravity SSD, or apparent specific gravity. 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 degree celsius plus or minus 5 degree selsius for sufficient time to remove all. The bulk specific gravity and absorption are based on aggregate after 24 +4 hours of 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 (5).

Figure 3. 6 Photos while conducting Specific gravity and water absorption

3.6.4 Aggregate crushing value

The aggregate crushing test evaluates the resistance of aggregates against the gradually applied load. Aggregate used in road construction should be strong enough to resist crushing under traffic wheel loads. If the aggregates are 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 applies to a standard fraction aggregate passing a 14mm sieve and retained on a 10mm sieve. If the standard size fraction is 14 - 10 mm on BS 812: Part 110:1990.

Aggregate crushing value, ACV $=\frac{M_2}{M_1} * 100$ ………………..………………......………Eq. (3.2)

Where M_1 is the mass of the test specimen (in g)

M_2 is the mass of the material passing the 2.36 mm sieve (in g)

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

Figure 3. 7 Photos during performing Aggregate crushing value

3.6.5 Aggregate impact value

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

The Aggregate Impact Value (AIV) is the percentage of fines passing 2.36 mm sieve after 15 blows

Aggregate Impact Value (AIV) is expressed as a percentage to the first decimal Place for each test specimen from the following equation:

Aggregate Impact Value, AIV $=\frac{M_2}{M_1} * 100$ ………………..…………………......………Eq. (3.3)

Where M_1 is the mass of the test specimen (in g)

M_2 is the mass of the material passing the 2.36 mm sieve (in g)

Figure 3. 8 Photos during performing Aggregate Impact Value

3.6.6 Los Angeles abrasion value

The abrasion test is used to know how the aggregate is sufficiently hard to resist the abrasive effect of traffic over its service life. Due to the movement of traffic, the road stones used in the surface course are subjected to wearing action at the top. Resistance to wearing or hardness is hence an essential property for road aggregates, especially when used in wearing course.

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 steel drum containing a specified number of steel spheres, the number depending upon the grading of the test sample.

The contents then roll within the drum with an abrading and grinding action until the shelf plate impacts and the cycle is repeated specification on ASTM C 131 – 89. Express the loss from the equation.

LAA Value (%) $=\frac{M_{1-M_2}}{M_1} * 100$ ……………………………………………………........…Eq. (3.4)

Where M_1 is the mass of the test specimen (in g)

M_2 is the mass of the material retained on 1.7 mm sieve (in

3.6.7 Moisture - density relationship (compaction) test

The objective of this test is to obtain relationships between compacted dry density and aggregate moisture content. The test is used to provide a guide for specifications on-field compaction.

The first is a light compaction test using a 2.5Kg rammer (standard proctor). The second is a heavy compaction test using a 4.5Kg rammer with a greater drop on thinner layers of aggregate (modified proctor). The dry density which can be achieved for an aggregate depends on the degree of compaction applied and the moisture content. The moisture content which gives the highest dry density is called the optimum moisture content for that type of compaction.

The modified proctor compaction test was conducted to determine the optimum moisture content (OMC) and maximum dry unit weight (MDUW) in accordance with ASTM D 1557 Method, because less than 30 percent by mass of the material is retained on the 19 mm (3/4 inch) sieve. This procedure uses a 48 N (10 lb) hammer and a 45.72 cm (18 inches) drop height.

Particles retained on the 19- mm (0.75 inches) sieve was removed before Compaction and samples were compacted in five lifts in a 152- mm (6 inches) mould using 56 blows per layer.

This test was done to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the material. It was done on the aggregate sample and then various percentages of recycled asphalt aggregate were added and MDD and OMC determined.

The wet density, moisture content, and dry density are calculated from the following equation:

W1 = (A-B)/V

$$W_1 = \frac{A-B}{V} \quad \text{……Eq. (3.5)}$$

Where, W_1 is wet density;

A is the mass of compacted specimen and mold;

B is the mass of mold;

V is the volume of mold

Figure 3. 9 Photos while compaction test was performed

3.6.8 California bearing ratio (CBR)

CBR test was done to determine the strength of a given material and how it will behave when subjected to loading. This was determined by measuring the relationship between force and penetration when a cylindrical plunger of cross-sectional area 1935square mm is made to penetrate the aggregate at a given rate. At any penetration value, the ratio of the force to a standard force is defined as the California Bearing Ratio.

The primary element affecting the necessary thickness of flexible pavements for highways and airfields is the base course's strength. The California Bearing Ratio (CBR) value served as a measure of the materials' strength for the subgrade, subbase, and base courses. Natural gravel pavement materials must meet the CBR value criterion. In ASTM Standard D1883-05 (for laboratory-prepared samples), the CBR test is detailed. The one pointe method is used to determine in a laboratory the California Bearing Ratio (CBR) of a soil sample that has been dynamically compacted by metal rammers.

Figure 3. 10 Photos during performing CBR tests

3.7 Data analysis and presentation

In the current study, the analysis of the potential use of ceramic waste and demolished concrete were conducted and as well as the optimum content of demolished concrete and ceramic waste mixed with virgin aggregate which gives better results for the best use of this ceramic waste and demolished concrete were checked. For this different laboratory tests such as Gradation, Flakiness index, Atterberg’s limit, Specific gravity, and Water Absorption, ACV and TFV, AIV, LAA, Moisture-density relation, CBR test were carried out and compared with standard guidelines. Further, the test result was presented using narratives, tables, and graphs as necessary. Finally, discussion, conclusion, and possible recommendations were forwarded based on the findings of the analysis.

3.8 Data quality assurance

To achieve the intended result careful selection of a sample from the site and appropriate laboratory tests were carried out based on a standard operating procedure by the relevant experienced professionals in the area. Before the procedure, the objective of the study was explained and training was provided for professionals involved in the investigation. Further care and full and regular supervision by the principal investigator were conducted.

3.9 Ethical consideration

All pertinent data were collected after receiving an ethical clearance endorsement from Jimma University Student Research Technical and Ethical Review Committee. In addition, a possible standard operating procedure for laboratory test were observed.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Properties of Demolished Concrete, Ceramic Waste, and CSA

This chapter summarises the findings of a laboratory experiment and data analysis to determine the impact of employing ceramic waste and crushed stone aggregate in place of some of the base course material in asphalt concrete. After the laboratory testing were finished, the test results were examined to determine the base course aggregate's physical and mechanical characteristics. The aggregate's suitability for usage as a better base course material was tested. Procedures from the AASHTO, BS, and ERA standard specification documents are used while conducting testing and collecting specimens. Lab tests are done on DCA, CSA, and CW after samples were collected, and different percentages of CA were replaced with DC and CW in varied amounts based on the weight of conventional aggregate. The goal of this test study was to evaluate the viability of using CW and DC for the unbound base course layer, compare their engineering properties, and reuse the waste material as a partial replacement for conventional aggregates for heavily traveled roads in Ethiopia.

4.1.1 Particle Size Distribution of DCA, CWA, and CSA

The grading of materials that were being proposed for use as aggregates or that were already being utilized as aggregates in the construction of pavement was primarily determined using sieve analysis. The findings are used to identify opportunities for particle size distribution that meet applicable specification needs and to give the information needed to govern the manufacture of various aggregate products and combinations that contain aggregates. The density, strength, and economy of the pavement construction are all impacted by the aggregate gradation, or the combination of different particle sizes. The outcome of the gradation tests is used to establish the particle size distribution and the necessary specification requirements. It is also helpful in establishing soil classification and Atterberg's limits. In contrast, ceramic waste aggregate is categorized as mechanically stable natural gravel and weathered rocks used as coarse base materials (GB2 and GB3), grading limits for CW and DCA of 37.5mm NMA was used for these studies. According to ERA 2013, pavement design manual, the conventional aggregate was classified as graded crushed stone (GB1), and a grading limit of this material for 37.5mm nominal maximum aggregate size was used.

Table 4. 1 Results of Sieve Analysis for CSA, DCA, and CWA

Sieve size (mm)	Percentage of passing			
	Crushed stone aggregate	Demolished concrete aggregate	Ceramic waste aggregate	ERA,2013 specification for GB2 and GB3 base course material
50	100.02	100.00	100.00	100-100
37.5	84.20	86.33	95.95	80-100
20	65.97	65.75	70.69	60-80
9.5	49.00	46.59	51.02	45-65
4.75	33.13	33.40	34.42	30-50
2.36	22.80	22.84	22.38	20-40
0.425	10.81	12.74	11.24	10-25
0.075	5.33	7.81	4.56	5-15
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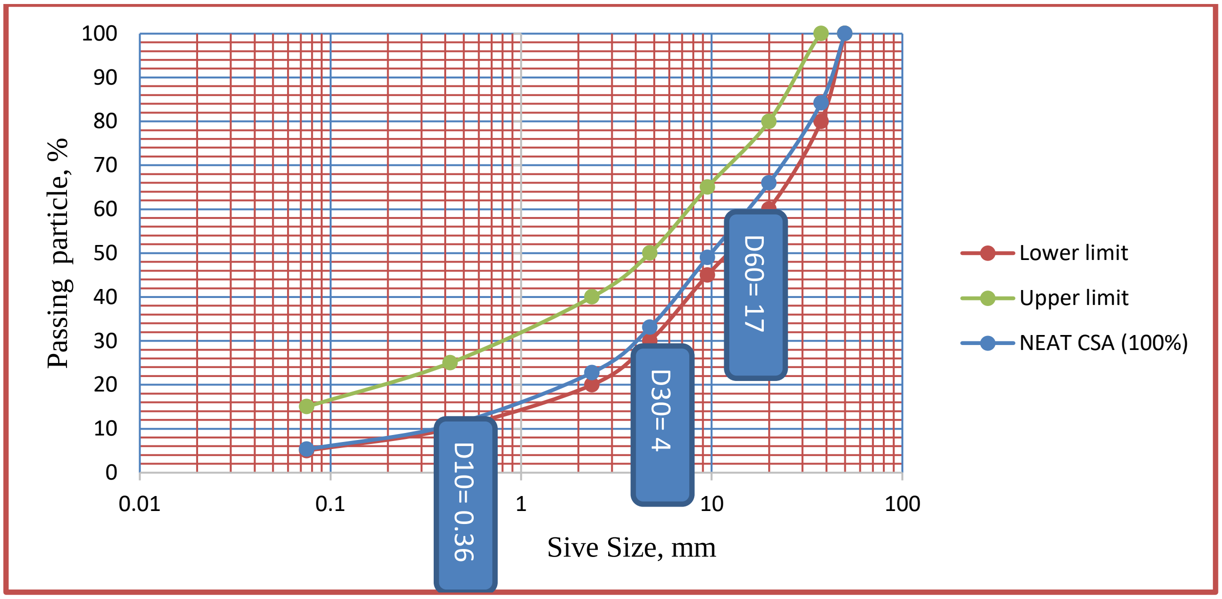

Figure 4. 1 Particle size distribution curve for CSA

Particle Size Distribution from fig. 4.2. The conventional aggregate particle diameter at 60% passing (D60), 30% passing (D30), and 10% passing (D10) curves were 17, 4, and 0.36, respectively. Since the values of the two shape parameters known as the coefficient of uniformity, CU, and the coefficient of curvature, CC, have been given as Cu = D60/D10=47.22 and Cc=(D30)2 /D60*D10=2.61 respectively, aggregates are classified as being well graded or poorly graded depending on these values. Since Cu is above 4 and Cc is between 1 and 3, the CA was therefore considered to be well-graded.

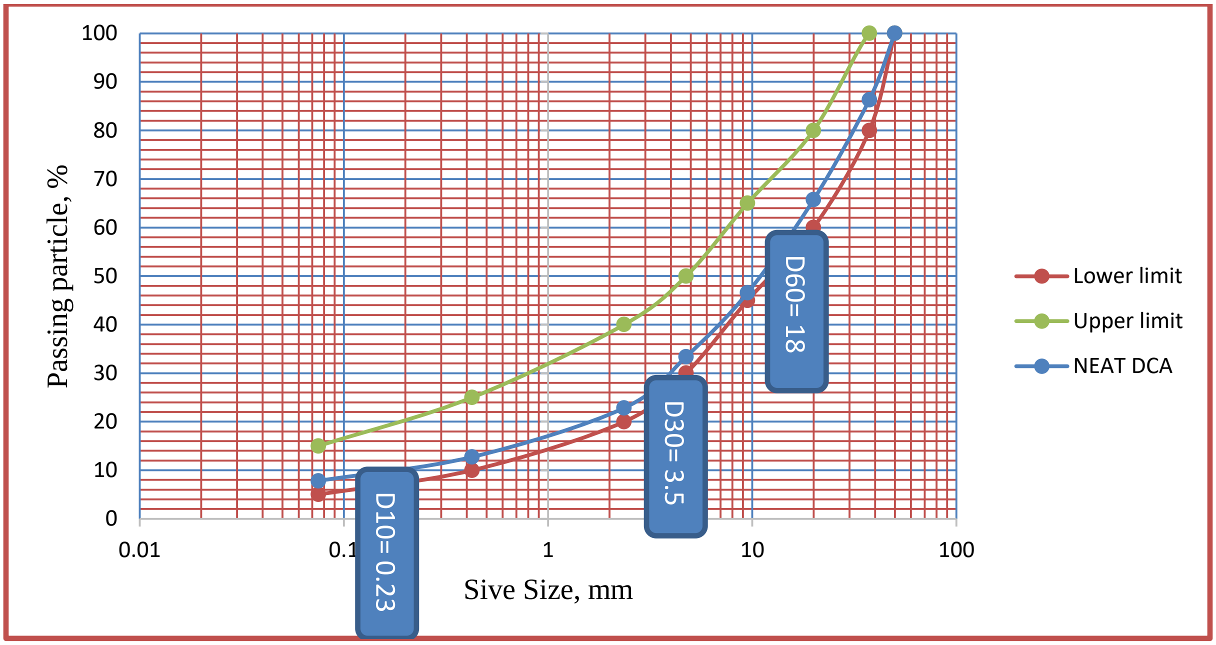

Figure 4. 2 Particle size distribution curve for DCA.

Figure 4.2, Particle Size Distribution The curves for demolished aggregate particle diameter at 60% passing (D60), particle diameter at 30% passing (D30), and particle diameter at 10% passing (D10) were 18, 3.5, and 0.23, respectively. Since the values of two shape parameters, the coefficient of uniformity, or Cu, and the coefficient of curvature, or CC, have been given as Cu = D60/D10=78.2 and Cc=(D30)2/D60*D10=2.9 respectively, aggregates are classified as being well-graded or poorly-graded depending on these values. As a result, the DCA was deemed to have a good grade because Cu is greater than 4 and Cc is between 1 and 3.

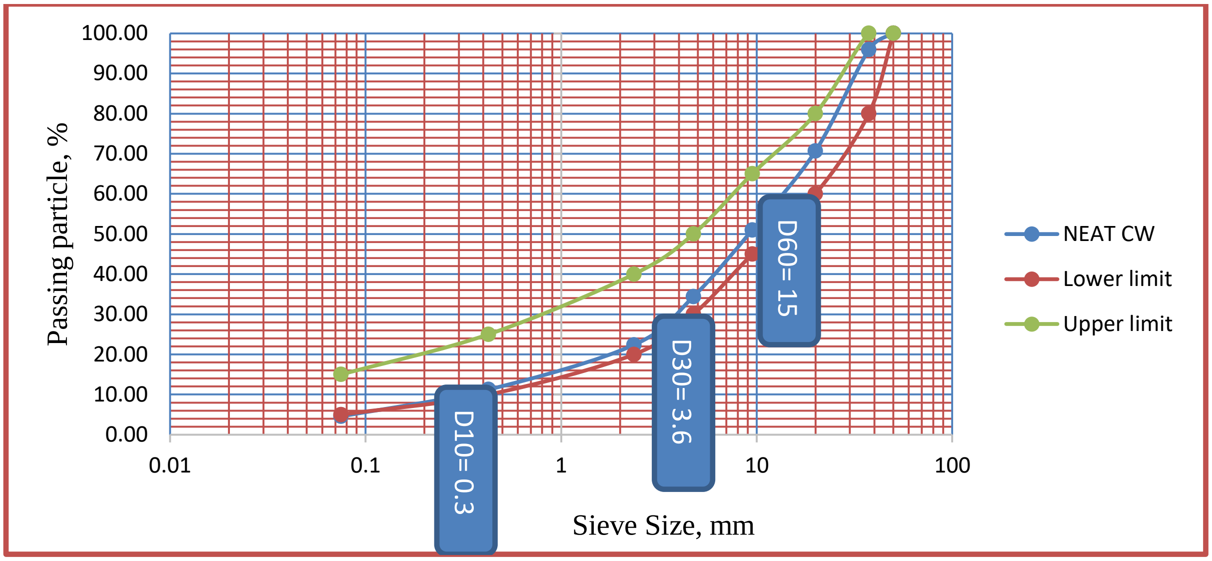

Figure 4. 3 Particle size distribution curve for CWA.

Fig. 4.3 illustrates the particle size distribution. The ceramic west aggregate particle diameter curves at 60% passing (D60), 30% passing (D30), and 10% passing (D10) were 15, 3.6, and 0.30, respectively. Since the values of two shape parameters known as the The coefficient of uniformity, CU, and the coefficient of curvature, CC, have been given as Cu = D60/D10 = 50 and Cc=(D30)2 /D60*D10=2.88 respectively, aggregates are classified as well-graded or poorly-graded depending on these values. Since Cu is above 4 and Cc is between 1 and 3, the CWA was therefore considered to be well-graded.

The results of a particle size analysis test for crushed stone aggregate, demolished concrete aggregate, and ceramic waste aggregate are displayed in Table 4.1. Three nominal maximum aggregate sizes—37.5 mm, 20 mm, and 10 mm—were set by the ERA standard specification for particle size distribution study of naturally occurring granular materials, boulders, and weathered rock (GB2 and GB3) base course materials for construction. As a result, 37.5mm NMA was taken into account for this particular investigation. As can be seen in the figure, the aggregate's gradation falls within the standard range in the majority of sieve openings.

4.1.2 Engineering Property Quality Test Results of DCA, CWA, and CSA

Table 4. 2 Engineering Property Test Result for Neat DCA, CWA, and CSA

Engineering properties		Materials			ERA,BS,AASHTO,ASTM standard limit
		DCA	CWA	CSA	
Apparent specific gravity,%		2.52	2.54	2.69	2.5-3%
Water absorption,%		2.27	1.32	1.76	<2%
Flakiness index,%		22.13	24.32	18.08	<30%
Aggregate crushing value,%		22.9	26.4	18.8	<29%
Aggregate impact value,%		22.6	25.5	17.8	<30%
Loss Angeles abrasion value,%		15.47	19.39	11.95	<45%
Compaction	OMC,%	12.59	5.36	6.34	NS
	MDD,%	1.79	1.70	2.19	NS
California bearing ratio	%CBR	68.31	64.4	116.5	>80%
	SWELL	0.01	0.01	0.00	

Specific Gravity:

Table 4.2 shows Results of laboratory tests on aggregates' apparent average specific gravity and water absorption are completed. Because CWA is lighter than conventional aggregate in terms of weight, it has a lower specific gravity than that material. Due to its large porosity, the aggregate from destroyed concrete has a high water absorption capacity, whereas the aggregate from ceramic waste has a low water absorption capacity as compared to CSA due to its smoothness and extremely low porosity.

Flakiness Index:

According to Table 4.2, The flakiness index for DCA that was determined by laboratory testing was 22.13. Because it falls within the ERA standard specification limit, this result suggests that the DCA sample tested was appropriate for use as a base course material. The maximum value of FI is recommended to be 30% by ERA and BS standard specifications. CWA and CSA have flakiness indices of 24.32% and 18.08%, respectively. As a result, each material complied with the requirements set down by the ERA for Base Course Materials in Pavement Construction.

Aggregate Crushing Value (ACV): The test's outcome is shown in Table 4.2. The test result clearly shows that the aggregate crushing value for CWA, demolished concrete aggregate, and crushed stone aggregate, respectively, was 26.4%, 22.9%, and 18.8%. It is expected that CWA will have less resistance to progressively compressive force than DCA and crushed stone aggregate, however all of the materials met the requirements set forth by the ERA for base course materials.

Aggregate Impact Value: For DCA, CWA, and CSA materials, aggregate impact value testing were performed using the BS812 part112 technique from 1990. The test's goal was to see how well aggregates maintained up against abrupt or shock impact loading. Table 4-2's AIV test results demonstrate that all test specimens meet the ERA 2013 Standard Specification limit's minimal requirements.

Los Angles Abrasion Test (LAA): According to ASTM C 131-98, loss angles abrasion was performed on neat DCA, CWA, and crushed stone aggregate in order to assess the aggregate's resistance to abrasion and impact. For DCA, CWA, and CSA, the test findings of 15.47%, 19.39%, and 11.95% respectively show that all samples fell within the permitted ERA standard specification for the base course materials requirement. Since the maximum value of LAA 45% is specified by the ERA standard specification for the unbounded base course (GB2 and GB3).

Moisture Density Relation: According to AASHTO T180, the moisture density tests for DCA, ceramic waste aggregate, and crushed stone aggregate were carried out independently. For DCA, CWA, and CSA, respectively, the percentages of the optimum moisture contents are 12.59%, 5.36%, and 6.34%. Maximum dry densities of 1.79gm/cm3, 1.70gm/cm3, and 2.19gm/cm3 were reached at the optimum moisture content for each material. Due to the cement paste's effect on the materials' porosity, DCA materials acquired a high level of water, but CWA materials required a low level of water to reach their MDD due to their poor water absorption characteristic.

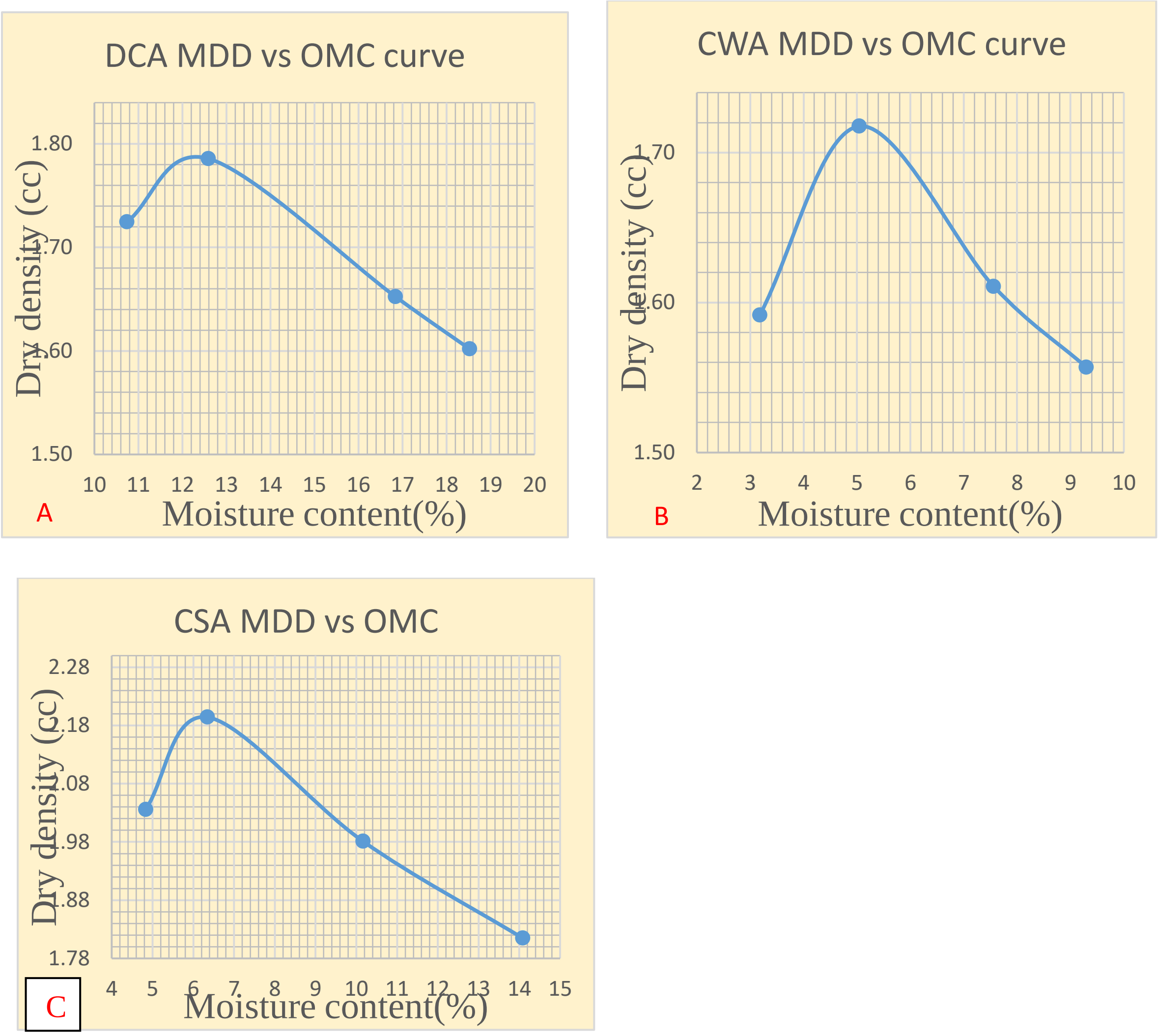

Figure 4. 4 A) DCA moisture density curve, B) CWA moisture density curve, C) CSA moisture density curve

California bearing ratio (CBR): The minimum soaking CBR is 80% in accordance with ERA standard specifications for (GB2 and GB3) base course materials. The obtained soaked CBR for Demolished Concrete Aggregate and Ceramic Waste Aggregate were 78.9% and 73.8, respectively, at 98% of compaction MDD, which does not meet the ERA minimum standards, according to the independently conducted soaked CBR test results presented in table 4-2. However, CSA received 116.8%, which satisfies the standards of the ERA standard specification. Therefore, the results of the laboratory tests show that the demolished concrete and ceramic debris were low-quality materials that lacked sufficient strength to be used separately as base course construction materials.

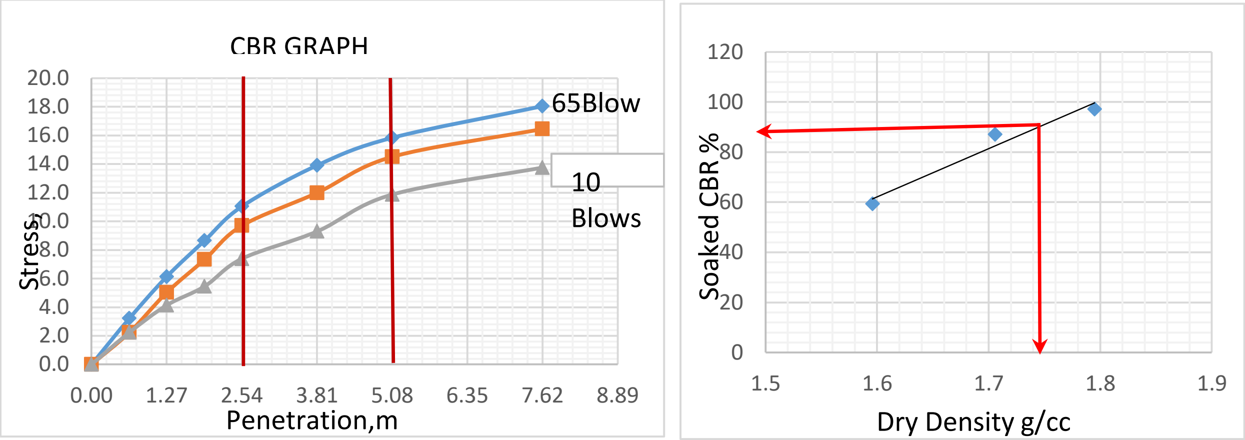

Figure 4. 5 DCA Load versus Penetration and Soaked CBR versus Dry Density graph

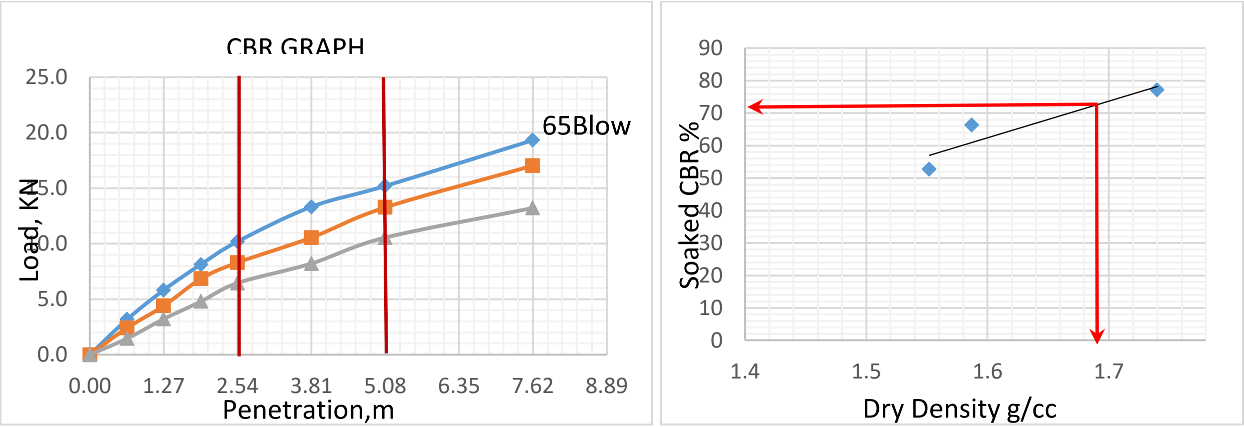

Figure 4. 6 CWA Load versus Penetration and Soaked CBR versus Dry Density graph

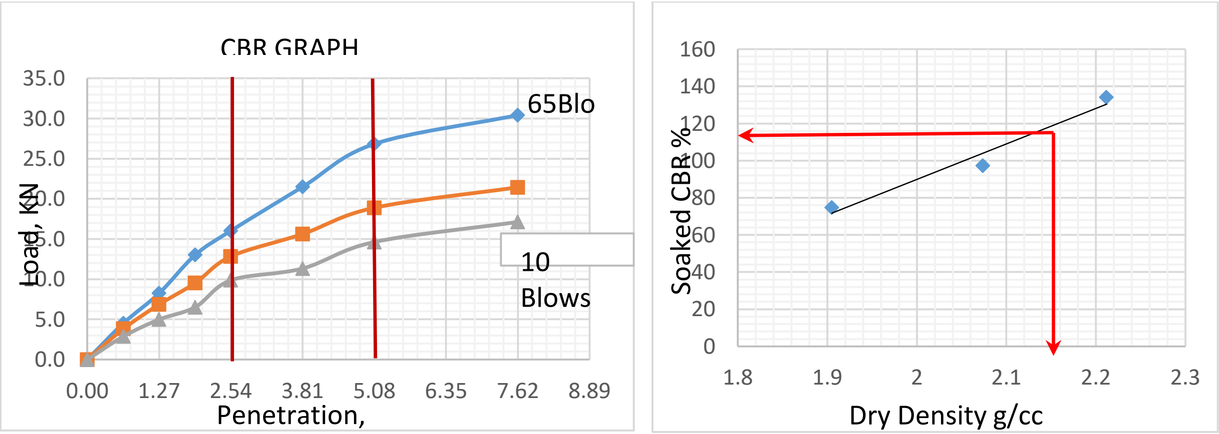

Figure 4. 7 CSA Load versus Penetration and Soaked CBR versus Dry Density graph

4.2 Soil classification system AASHTO and USCS basis

The grouping of various soils with comparable characteristics into groups and subgroups according to their intended use is known as soil classification. Since the first quarter of the 20th century, numerous classification schemes have been put forth. The majority of soil categorization systems created for engineering reasons are based on straightforward index characteristics like particle-size distribution and plasticity.

Table 4. 3 Aggregate classification by using AASHTO and USCS

Parameter used for classification	Aggregate materials		
	DCA	CWA	CSA
$D_{10(mm)}$	0.36	0.3	0.23
$D_{30(mm)}$	4	3.6	3.5
$D_{60(mm)}$	17	15	18
Coefficient of uniformity (Cu)	47.2	50	78.28
Coefficient of curvature(Cc)	2.61	2.88	2.96
Gravel content	66.89	65.58	66.60
Sand content	27.80	29.86	25.59
Fine content	5.33	4.56	7.81
AASHTO classification	A-1-a	A-1-a	A-1-a
USCS classification	GW	GW	GW

According to the AASHTO soil classification system, materials are classified as granular if less than 35% of all samples fail to pass through sieve size #200 (0.075mm). This granular material also contains sub-classifications A-1, A-3, and A-2. The aggregates are once more classed based on the percentage of sieve sizes #10, #40, and #200 that pass as well as the value of LL and PL. All materials are categorised as A-1, a type of soils with less than 15% of particles passing a sieve opening of size 0.075mm and a PI of zero, based on the test results from DCA, CWA, and CSA. Sand and gravel can be found in the substance. Soil classed as A-1-a was selected for road construction, as per the AASHTO standard of soil classification.

According to USCS CWA, which is coarse-grained aggregate with more than 50% retained on #200 sieve and 5%–12% fines (i.e., 4.56%), it is classified as GW (well-graded gravel with sand) because it has a CU value of 50 that is greater than 4, a CC value of 2.88 that is between 1 and 3, and more than 15% of sand (i.e., 29.86%). Similar to CA, which was defined as coarse-grained aggregate with more than 50% retained on #200 sieve size and less than 5% fines (i.e. 7.81%), well-graded gravel with sand (GW) was defined as having a CU value of 78.28, which was significantly higher than 4, a Cc value of 2.96, which is between 1 and 3, and more than 15% of sand (i.e. 25.59%).

4.2.1 Particle Size Distribution DCA and CA

For the most part, sieve analysis was used to grade materials that were either being used as aggregates in the construction of pavement or that were being suggested for use as aggregates. The final results are used to identify opportunities for particle size distribution with applicable specification criteria and to give data for controlling the manufacture of various aggregate products and combinations incorporating aggregates. The density, strength, and economy of the pavement construction are all impacted by the aggregate gradation, or the combination of different particle sizes. The outcome of the gradation tests is used to establish the particle size distribution and the necessary specification requirements. It also aids in establishing the soil classification and Atterberg's limits. According to ERA 2013, typical aggregate used in pavement design manuals was categorised as graded crushed stone (GB1) and graded to a nominal maximum aggregate size of 37.5mm.

Table 4. 4 Results of sieve analysis for DCA and CSA blended

Sieve size(mm)	Passing sieve size%							
	Grading for 37.5mm NMA	CA:DCA	CA:DCA	CA:DCA	CA:DCA	CA:DCA	CA:DCA	CA:DCA
		100:0	90:10	80:20	70:30	60:40	50:50	0:100
50	100	100.00	100.00	100.00	100.00	100.00	100.00	100.00
37.5	80-100	84.17	95.35	95.81	97.14	97.95	96.55	86.33
20	60-80	65.95	71.54	74.42	75.33	74.79	75.16	65.75
9.5	45-65	48.97	53.28	54.75	52.71	50.39	54.60	46.59
4.75	30-50	33.11	37.42	37.79	35.90	36.59	36.89	33.40
2.36	20-40	22.78	25.15	23.47	21.50	22.69	24.60	22.84
0.425	10-25	10.79	12.57	11.19	10.88	13.10	13.72	12.74
0.075	5-15	5.31	5.48	4.45	5.27	6.24	5.76	7.81
pan		00	00	00	00	00	00	00

According to the AASHTO manual, aggregate particles smaller than 0.075 mm cannot be sieved, which is why a pan is required. If the aggregate contains a significant amount of grains smaller than 0.075 mm, however, grain distributions of this fine fraction are assessed using hydrometer analysis or wet analysis. According to Table 4.4, the fine-grained aggregate passing 0.075mm is small and contains a significant amount of coarse and sand, therefore a hydrometer study is not necessary. The results of the particle size distribution curve are shown in Figure 4.6, and each gradation curve has a smooth slope. For GB2 and GB3 base course construction material values, this mix proportions gradation curve was parallel to the lower and upper ERA particle size distribution boundary limits, and the percentage passing was close to the goal value of the regulating specification.

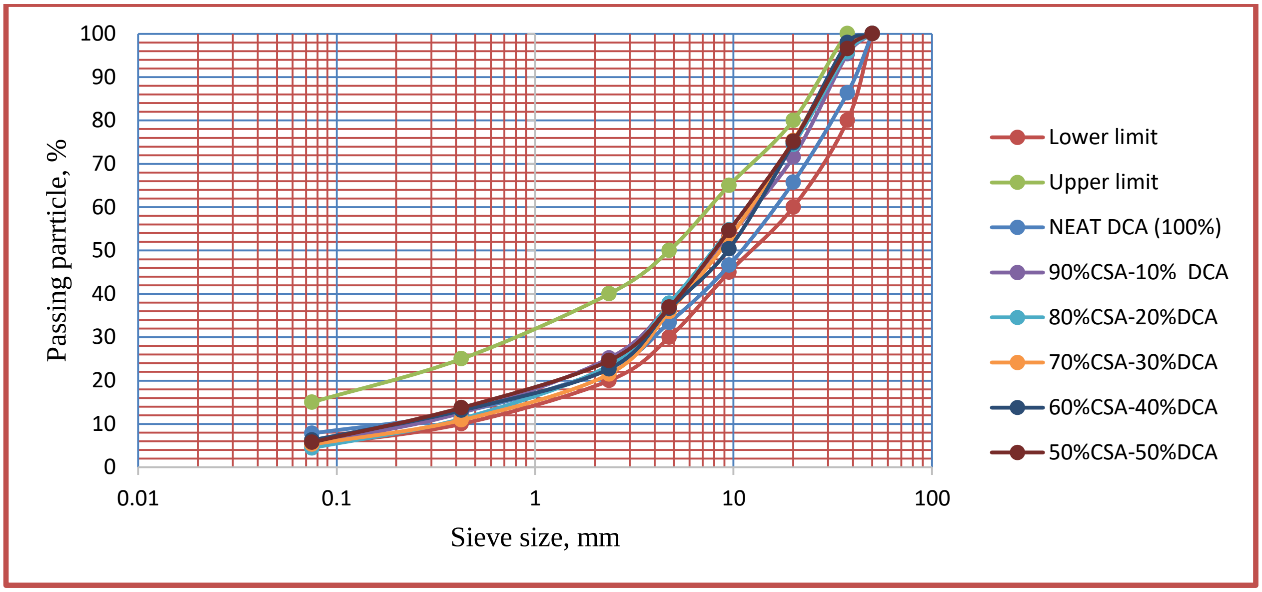

Figure 4. 8 Particle Size Distribution of all blended CSA and DCA

Table 4. 5 Grading and Fineness modulus of aggregate mixes used in this study

Types of mixture	Grading modulus, (GM)	Fineness modulus, (FM)
CSA	2.60	3.96
90%CSA-10%DCA	2.56	3.99
80%CSA-20%DCA	2.6	3.98
70%CSA-30%DCA	2.62	4.01
60%CSA-40%DCA	2.57	3.98
50%CSA-50%DCA	2.56	3.92
DCA	2.55	3.89

The minimum Grading Modulus for natural materials used as base course is 2 per ERA standard technical specification. The grading modules for various CA and DCA proportions are determined in Tables 4-5. In every instance, the values of the grading modulus exceed the minimal criterion needed. Therefore, the employed aggregates are meeting the grading modulus criteria at all mix proportions as base coarse materials. For coarse aggregate, the fineness modulus ranges from 5.5 to 8.0. And the fineness modulus ranges from 3.5 to 6.5 for all aggregates or combination aggregates. Fine aggregate has a fineness modulus that ranges from 2.0 to 3.5mm. Fine aggregates with fineness moduli more than 3.2 shouldn't be regarded as such [40]. Because FM ranges from 3.89 to 4.01, which lies between 3.5 and 6.5, which was FM of all in aggregate or combined aggregates, it may be concluded from this constraint that the aggregate mixes utilized in this research were not entirely coarse or fine, but rather a combination of the two.

4.2.2 Specific Gravity and Water Absorption

The specific gravity and water absorption test results for demolished concrete aggregate, conventional aggregate, and various mix proportions of these aggregates are compiled in Table 4.6 and analyzed by the graph of Fig. 4-7 below for fine and coarse aggregates, respectively.

Table 4. 6 Results of specific gravity and water absorption for DCA and CSA blended

Blended ratio% CSA-DCA	Average Specific Gravity			Average Absorption, %
	The bulk (Dry)	The bulk (SSD)	Apparent specific gravity	
100:0	2.57	2.61	2.69	1.76
90:10	2.52	2.56	2.64	1.8
80:20	2.46	2.53	2.61	1.88
70:30	2.47	2.51	2.59	1.92
60:40	2.44	2.49	2.57	1.97
50:50	2.42	2.47	2.55	2.11
0:100	2.39	2.44	2.53	2.27
specification			2.5-3%	<2%

According to AASHTO, the water absorption limit is (2%), as stated in Table 4.6, although the water absorption of DCA and CA blends ranges from 1.76% to 2.27%, which is considerably higher than that of CA. With an increase in the proportion of DCA, the blend's water absorption grew. Comparatively speaking, DCA has a smaller bulk density than CA. Because it has more pores than CA does, DCA has a lower value for bulk density. In general, DCA particles are more absorbent than CA and have lower Gsb values than CA, which makes them less dense than CA due to their porosity from the cement paste. Apparent specific gravity greater than bulk specific gravity implied materials had a valid relationship.

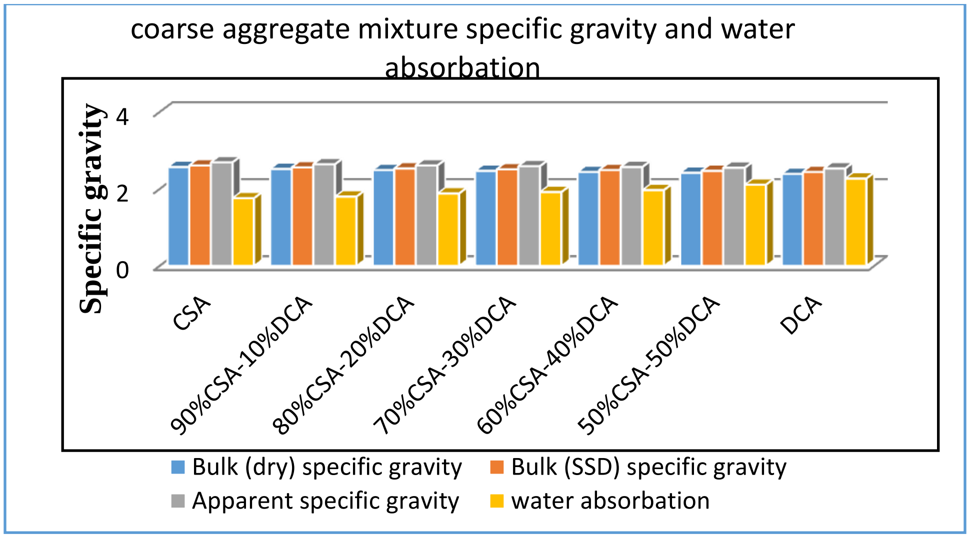

Figure 4. 9 Results of Specific Gravity and Water Absorption Test analysis

The density of soil or aggregate in relation to water is measured by its specific gravity. Accordingly, an aggregate with a high specific gravity has a high density or strength, whereas an aggregate with a low specific gravity has a low strength. Destroyed concrete aggregate (DCA) has a low specific gravity when compared to CSA; this suggests that DCA is weaker than CSA. Materials used for base coarse and sub-base construction must have a minimum specific gravity of 2.5, according to ERA 2013. The aggregates are therefore suitable to use as a base coarse material based on their specific gravity and water absorption value, as evidenced by the test results provided in Table 4.6, where the values obtained from the test result were larger than the minimum ERA suggested value in every case.

4.2.3 Plasticity

As shown in Table 4.7 according to ASTM, a fine fraction of RCA is non-plastic. That means there are no or little clay contents in its particles and it is suitable material as base course material and attain higher dry density (compacted to very dense condition).

Table 4. 7 Results of plasticity for DCA and CA blended

Blended Ratio: CSA: DCA	Plasticity
100:0	Non-Plastic
90:10	Non-Plastic
80:20	Non-Plastic
70:30	Non-Plastic
60:40	Non-Plastic
50:50	Non-Plastic
0:100	Non-Plastic
specification	<6

Greater plasticity is a result of increased clay concentrations since the Atterberg limit is directly related to clay mineralogy. Clay content is extremely low in DCA and CA materials, nevertheless. The DCA and CA samples' liquid and plastic limits could not, therefore, be determined. This makes it non-plastic (NP), which is what it is. According to ERA and MS-2 requirements, the hot mix asphalt aggregate and base course (GB1) are both to have the desirable quality of being NP.

4.2.4 The Flakiness Index for DCA and CA

Shape tests like flakiness were conducted for evaluating the suitability of materials produced by the crushing operation of aggregates for pavement construction. Flaky materials should be avoided because they cause reduced resistance to the traffic load during their service life. The flakiness test is conducted as per BS-812-Part-105.1

Table 4. 8 Results of shape factors for DCA and CA blended

Aggregate mix type	Flakiness index(FI,%)
100%CSA-0%DCA	18.08
90%CSA-10%DCA	19.36
80%CSA-20%DCA	20.13
70%CSA-30%DCA	21.27
60%CSA-40%DCA	21.58
50%CSA-50%DCA	21.97
0%CSA-100%DCA	22.13

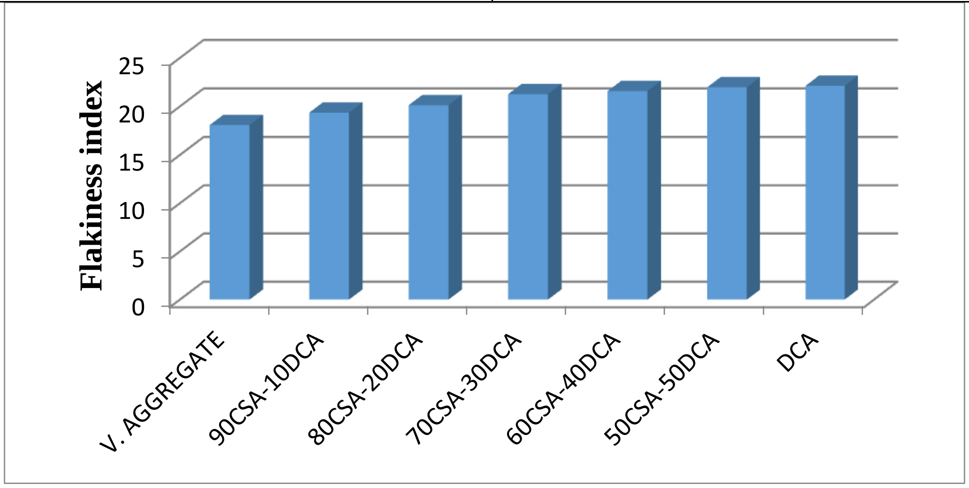

Figure 4. 10 Flakiness Index of Different proportion of DCA and CA

As seen in Table 4.8 and fig. 4-8, the results of shape tests, such as the flakiness index, were tabulated and analysed by the graph for various blended proportions of DCA and CA. The graph shows that as the percent of DCA grows, the flakiness index similarly rises, yet all blends are within the ERA and BS standard specification's recommended maximum FI of 30%. However, the blended aggregate's flakiness index ranged from 18.08% to 22.13 percent, which was within the permitted range.

4.2.5 Aggregate Crushing for blended CSA and DCA

The laboratory tests are completed, and Table 4-19 presents the test findings. The tests are performed on specimens by mixing various percentages of conventional aggregate with aggregate from demolished concrete used as base course material. The aggregate crushing value test result makes it abundantly evident that changing from CSA to all percentages of DCA complied with the maximum value of 29% ACV specified in the ERA standard specification for GB2 and GB3 base course material.

Table 4. 9 Results of aggregate crushing values for DCA and CA blended

Blended ratio of CSA-DCA	ACV, (%)
100%CSA-0%DCA	18.8
90%CSA-10%DCA	20.1
80%CSA-20%DCA	20.9
70%CSA-30%DCA	21.3
60%CSA-40%DCA	21.5
50%CSA-50%DCA	21.9
0%CSA-1005DCA	22.9

As can be seen from tables 4.9, the loss from crushing increased as the percentage of DCA increased. Nevertheless, it complies with the requirements set forth in the ERA manual for usage as a base course resource. This demonstrates that DCA has weaker material than CSA to withstand gradually crushing force. The crushing resistance characteristics of the samples with greater DCA % are poor. Since samples with larger DCA percentages had higher crushing values, it is likely that the base course made of DCA was more susceptible to crushing than base course made of conventional aggregate.

4.2.6 Aggregate Impact Value of blended CSA and DCA

Table 4. 10 Results of aggregate impact value

Blended ratio: CSA-DCA	AIV	ERA 2013 Governing Specification
100%CSA-0%DCA	17.8	AIV<30
90%CSA-10%DCA	19.6	
80%CSA-20%DCA	20	
70%CSA-30%DCA	21.2	
60%CSA-40%DCA	21.5	
50%CSA-50%DCA	21.9	
0%CSA-100%DCA	22.6	

Table 4.10 displays the test results for various CA replacement percentages by DCA replacement weights. AIV increased from 17.8% of neat CA to 21.9% at 50% DCA replacement, as can be seen plainly from the table. Therefore, the resisting power of the material under a sudden impact load decreases as AIV increases.

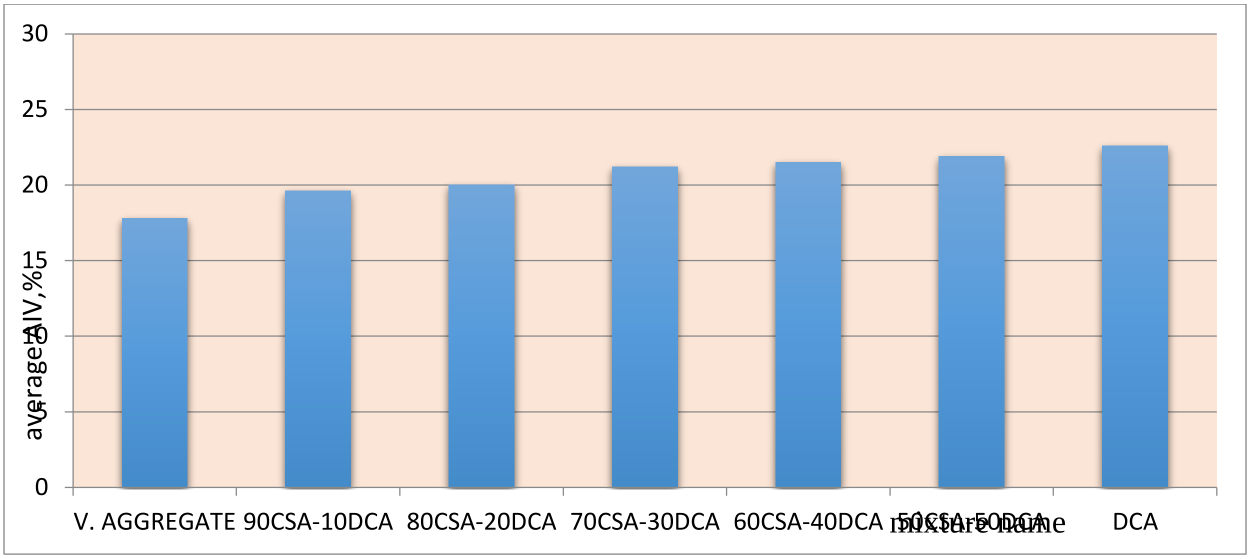

Figure 4. 11 Average AIV of Blended CSA and DCA

As can be seen in figure 4.11, the aggregate impact value was calculated in accordance with BS 812: Part 112:1990 to determine the impact resistance of both conventional aggregate and aggregate made from crushed concrete. According to the study's findings, adding aggregate made from crushed concrete greatly improved the data of the minimal impact value. In regard to this, the aggregate impact value varies between 17.8%, 19.6%, 20%, 21.2%, 21.5%, 21.9%, and 22.6% aggregate after mixing with 0% (the conventional aggregate), 10% DCA, 20% DCA, 30% DCA, 40% DCA, 50% DCA, and 100% DCA, respectively. One can confidently infer from the statistics above that as the proportion of aggregate made of crushed concrete increases, the resistance to impact falls. In any case, the materials satisfy the ERA standard specification criterion for basic coarse materials, which suggests an aggregate impact value of less than 30%.

4.2.7 Los Angles Abrasion Value (LAAV) for blended CSA and DCA

Table 4. 11 LAA Test Result of Blended demolished concrete and Conventional Aggregate

Blended ratio of, CSA: DCA	Average LAAV (%)	ERA 2013 Governing Specification
100%CSA-0%DCA	11.95	LAAV<45%
90%CSA-10%DCA	12.55	
80%CSA-20%DCA	13.13	
70%CSA-30%DCA	13.59	
60%CSA-40%DCA	14.02	
50%CSA-50%DCA	14.99	
0%CSA-100%DCA	15.47	

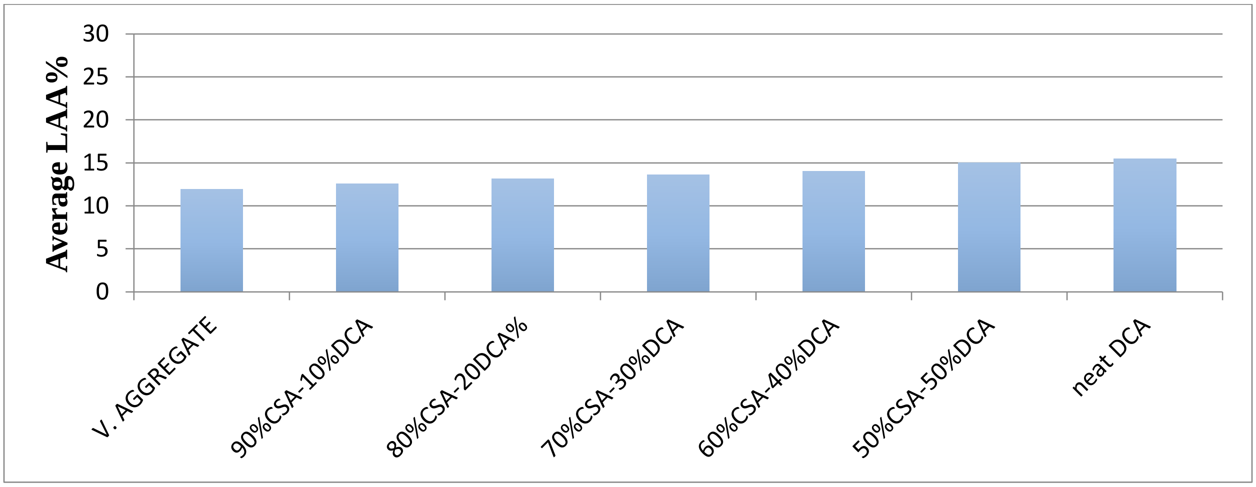

Figure 4. 12 Los Angles Abrasion Test (LAA) Results for blended CSA and DCA

The maximum abrasion value of the base course is limited to 45% in accordance with ERA regulations. Figure 4.10 shows that the combination including DCA has a lower abrasion value than conventional aggregate and that resistance to abrasion and impact declines as DCA is added to the mixture at higher concentrations. As a result, the test's findings show that using 100% DCA to build base courses does not result in any abrasion issues.

4.2.8 Moisture-density relationship of blended CSA with DCA

Results for the compaction curve are shown in table 4.12. The term "optimum moisture content" refers to the moisture level that results in the highest dry density for that type of compaction. The OMC of blended DCA and CAS ranges from 6.34 to 12.59%, as shown in table 4-12, while MDD ranges from 2.19 g/cm3 to 1.79 g/cm3. It was implied that OMC would rise and MDD fall as the DCA share increased. It implied that DCA and CSA have different densities (compacted to low dense condition versus optimal moisture content).

Table 4. 12 Result of the compaction test for Blended CSA and DCA

Blended ratio of CSA-DCA	OMC,(%)	MDD,(gm./cm3)
100%CSA-0%DCA	6.34	2.19
90%CSA-10%DCA	7.28	1.98
80%CSA-20%DCA	7.62	1.95
70%CSA-30%DCA	9.53	1.91
60%CSA-40%DCA	10.17	1.87
50%CSA-50%DCA	10.99	1.84
0%CSA-100%DCA	12.59	1.79

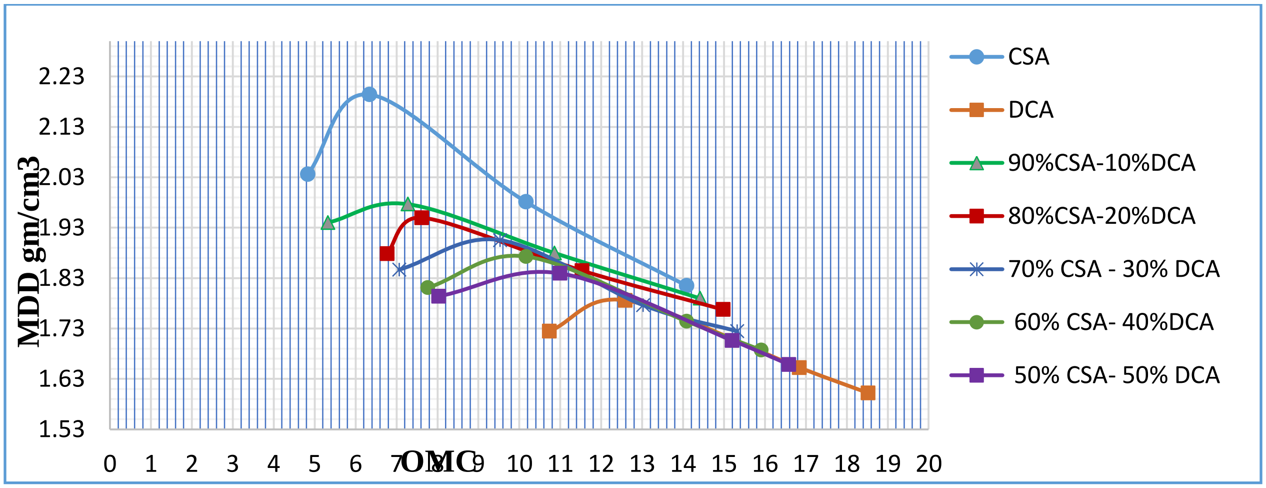

Figure 4. 13 Moisture-Density relation curve of blended CSA and DCA

4.2.9 California Bearing Ratio (CBR)

Table 4. 13 Result of the CBR test for blended CSA and DCA

Aggregate type	CBR at 98%MDD,%	Dry density at 98%MDD,(gm./cm^3)	Swell,(%)
90%CSA-10%DCA	105.3	1.94	0.00
80%CSA-10%DCA	97.25	1.91	0.00
70%CSA-30%DCA	90.1	1.84	0.00
60%CSA-40%DCA	82.6	1.83	0.00
50%CSA-50%DCA	78.9	1.8	0.00

Table 4.13 displays the dry density and moisture content of CBR specimens for RCA and CA mixed materials. The findings demonstrate that as the amount of conventional aggregate substitution with RCA grew, its porosity as a result of cement paste caused a decrease in dry density and an increase in moisture content.

As can be seen from the values for all blending conditions (10% to 40%), it meets the ERA standard specification recommendation, which is >80% for base coarse material of (GB2 and GB3). The value of swelling was between 0.00 and 0.01; this demonstrates that soaking of aggregate material has little impact on the values of swelling property. For the unbounded base course (GB2 and GB3) materials in pavement construction, the demolished concrete aggregate can therefore be utilized up to 40% without losing any strength issues.

4.2.10 Effect of DCA on ACV, AIV, LAA, Flakiness Index, and Water Absorption Value of CSA

As shown in Table below, different percentages of DCA were substituted for the base course material (10%, 20%, 30%, 40%, and 50%) while the physical properties of CSA were examined in the lab. The ACV result shows that substituting CSA with different percentages of DCA were within the ERA standard specification requirements for the GB1 basc course material, which requires a maximum value of 29%. The ACV for 50% DCA was 21.9%, and it was determined that this value was within the ERA standard specification limit. Table 4.13 Shows a considerable difference between the two materials' AIV test scores, 22.6 and 17.8. The capacity for resisting an impact (toughness) abrupt load increases with decreasing aggregate impact value. In accordance with ERA specifications, the combined test results of the two materials demonstrated good resistance to sudden traffic force when CSA was combined with various percentages of DCA (10%, 20%, 30%, 40%, and 50%). Table 4.14 further demonstrates that the flakiness and elongation index for DCA acquired through laboratory testing was 22.13%, showing that the DCA sample was eligible for use as a base coarse material because it is within the ERA standard specification limit, which is FI 30%.

Additionally, DCA meets both of the shape test's conditions. Fresh stone aggregate used for this study's base course material had a flakiness index value of 18.08%, which was significantly lower than the specification's upper limit.

Table 4. 14 Physical properties of crushed stone aggregate with demolished concrete aggregate mixes

Tests	CSA: DCA	CSA: DCA	CSA: DCA	CSA: DCA	CSA: DCA	CSA: DCA	CSA: DCA	ERA Specification requirements
	100:0	90:10	80:20	70:30	60:40	50:50	0:100	
Bulk dry S.G	2.57	2.52	2.46	2.47	2.44	2.42	2.39	
Bulk SSD S.G	2.61	2.56	2.53	2.51	2.49	2.47	2.44	
Apparent S.G	2.69	2.64	2.61	2.59	2.57	2.55	2.53	2.5-3%
Water absorption, %	1.76	1.8	1.88	1.92	1.97	2.11	2.27	<2%
Flakiness Index	18.08	19.36	20.13	21.27	21.58	21.97	22.13	<30%
Los Angeles Abrasion (LAA	11.95	12.55	13.13	13.59	14.02	14.99	15.47	<45%
Aggregate crushing value (ACV), %	18.8	20.1	20.9	21.3	21.5	21.9	22.9	<29%
Aggregate Impact Value (AIV), %	17.8	19.6	20	21.2	21.5	21.9	22.6	<30%

4.3 Physical and Mechanical Properties of Ceramic waste

4.3.1 Particle Size Distribution of blended CW and CSA

Table 4. 15 Results of sieve analysis for CWA and CSA blended

Sieve size(mm)	Passing sieve size%							
	Grading for 37.5mm NMA	CA:CWA	CA:CWA	CA:CWA	CA:CWA	CA:CWA	CA:CWA	CA:CWA
		100:0	90:10	80:20	70:30	40:60	50:50	0:100
50	100	100.00	100.00	100.00	100.00	100.00	100.00	100.00
37.5	80-100	84.17	96.34	97.59	100.00	100.00	100.00	95.95
20	60-80	65.95	89.91	83.16	94.81	96.99	93.30	70.69
9.5	45-65	48.97	59.64	53.83	56.29	58.86	57.19	51.02
4.75	30-50	33.11	39.15	36.04	38.60	34.16	33.99	34.42
2.36	20-40	22.78	25.91	28.12	28.62	22.09	24.90	22.38
0.425	10-25	10.79	10.35	16.90	17.09	16.96	16.39	11.24
0.075	5-15	5.31	5.78	9.20	10.85	11.30	11.92	4.56
pan		00	00	00	00	00	00	00

Table 4.14 indicates that a hydrometer study is not required because the fine-grained aggregate passing 0.075mm is modest and comprises a sizable percentage of coarse and sand. Figure 4.6 displays the results of the particle size distribution curve, and each gradation curve has a smooth slope. This mix proportions gradation curve for GB2 and GB3 base course construction material values was parallel to the lower and upper ERA particle size distribution boundary limitations, and the % passing was close to the target value of the regulatory specification.

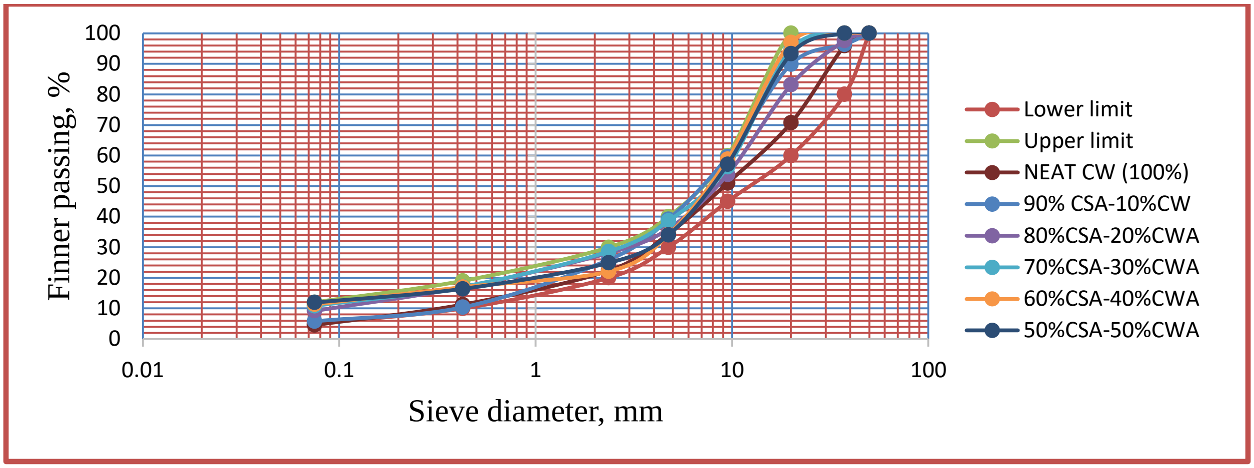

Figure 4. 14 Particle Size Distribution of all blended CSA and CWA

Table 4. 16 Grading and Fineness modulus of aggregate mixes used in this study

Types of mixture	Grading modulus, (GM)	Fineness modulus, (FM)
CSA	2.60	4.12
90%CSA-10%CWA	2.56	3.99
80%CSA-20%CWA	2.6	3.98
70%CSA-30%CWA	2.62	4.01
60%CSA-40%CWA	2.57	3.98
50%CSA-50%CWA	2.56	3.92
CWA	2.55	4

According to ERA standard technical specification, the Grading Modulus for natural materials used as base course must be at least 2. Tables 4-15 list the grading modules for different CA and CWA proportions. The values of the grading modulus are always higher than the bare minimum required. As base coarse materials, the utilized aggregates, therefore, satisfy the grading modulus criteria at all mix proportions. The fineness modulus for coarse aggregate varies from 5.5 to 8.0. Additionally, the fineness modulus for all aggregates or aggregate combinations ranges from 3.5 to 6.5. The fineness modulus of fine aggregate ranges from 2.0 to 3.5mm. The definition of fine aggregates should not include those with fineness moduli more than 3.2 [40]. Given that the FM of all aggregates or mixed aggregates ranged from 3.92 to 4.12, which is between 3.5 and 6.5, it may be deduced from this restriction that the aggregate mixes used in this research were not wholly coarse or fine, but rather a blend of the two.

4.3.2 Specific Gravity and Water Absorption Blended CWA and CSA

Tables 4-15 summarise and analyse the specific gravity and water absorption test findings for conventional aggregate, ceramic waste aggregate, and various mix proportions of this aggregates, respectively, for coarse aggregates.

Table 4. 17 Specific gravity of blended CSA and CWA

Blended ratio% CSA-CWA	Average Specific Gravity			Average Absorption, %
	The bulk (Dry)	The bulk (SSD)	Apparent specific gravity	
90:10	2.55	2.59	2.66	1.73
80:20	2.51	2.55	2.61	1.62
70:30	2.48	2.52	2.58	1.55
60:40	2.47	2.51	2.57	1.5
50:50	2.46	2.49	2.55	1.43
specification			2.5-3%	<2%

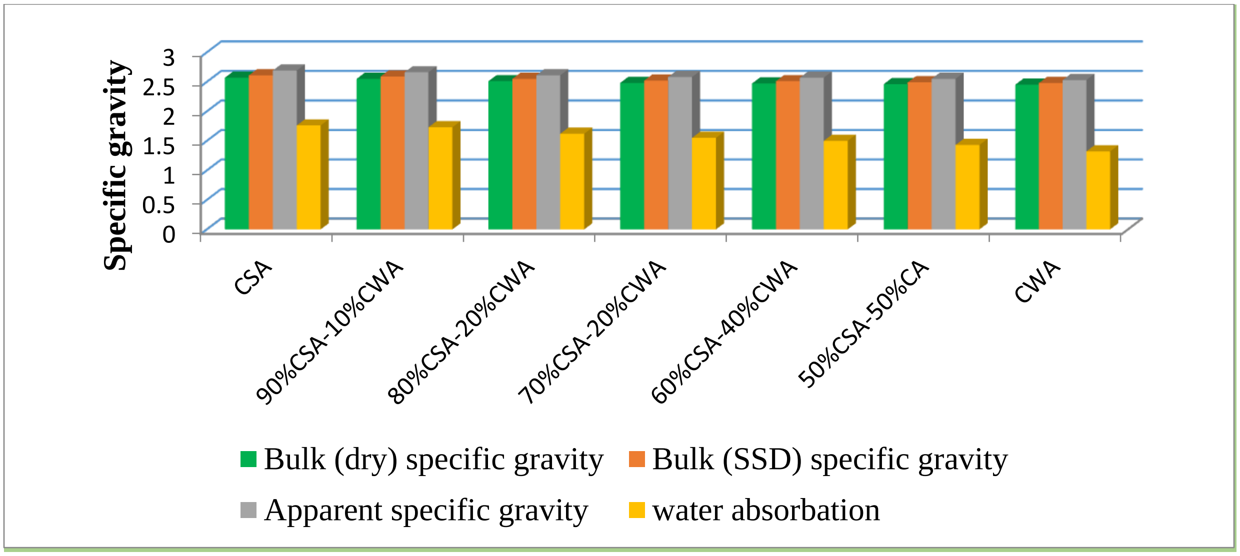

Figure 4. 15 Results of Coarse Aggregate Specific Gravity and Water Absorption Test analysis

The ratio between the weight of a particular volume of aggregates to the weight of an equivalent volume of water was used to compute the specific gravity of the coarse aggregate sample. It is clear from Fig. 4.15 that there is a true connection between the various forms of specific gravities for all combination types employed in this research. Bulk (dry) specific gravity is lower than bulk (SSD) specific gravity, and this is likewise lower than apparent specific gravity.

The limit as per ERA standard specification for maximum absorption for using aggregate material in pavement construction was 2%. Therefore, the results of all tested aggregates are much less than the specification value as shown in table 4.15.

The density of soil or aggregate in relation to water is measured by its specific gravity. Accordingly, an aggregate with a high specific gravity has a high density or strength, whereas an aggregate with a low specific gravity has a low strength. Ceramic waste aggregate (CWA) has a lower specific gravity than CSA, which suggests that it is weaker than CSA. Materials used for base coarse and sub-base construction must have a minimum specific gravity of 2.5, according to ERA 2013. Accordingly, based on the test results provided in Table 4.15, where all values were higher than the minimum ERA suggested value, the aggregates are suitable for usage as a base coarse material due to their specific gravity and water absorption value.

4.3.3 Plasticity

According to ASTM, a small portion of CW is non-plastic, as shown in Table 4.16. This indicates that the particles of the material have little to no clay content and are ideal as base course material since they have a greater dry density (compacted to a highly dense condition). The results of plasticity for blended CSA and CW are shown in Table 4.16.

Table 4. 18 Results of plasticity for CSA and CW blended

Blended Ratio: CSA: CWA	Plasticity
100:0	Non-Plastic
90:10	Non-Plastic
80:20	Non-Plastic
70:30	Non-Plastic
60:40	Non-Plastic
50:50	Non-Plastic
0:100	Non-Plastic
specification	<6

4.3.4 The Flakiness Index for CWA and CA

The base course material for CWA had an appropriate shape, as specified in Table 4.18 in accordance with ERA 2013 (BS-812-Part105). The CWA and CA blend's flakiness index ranged from 30% to 18% with an average value of roughly 22%, indicating that they are less flaky.

Table 4. 19 Results of shape factors for CW and CA blended

Blended ratio of CSA-DCA	FI, (%)
100%CSA-0%CWA	18.08
90%CSA-10% CWA	21.05
80%CSA-20%CWA	21.99
70%CSA-30%CWA	22.68
60%CSA-40%CWA	23.05
50%CSA-50%CWA	23.92
0%CSA-1005CWA	24.32

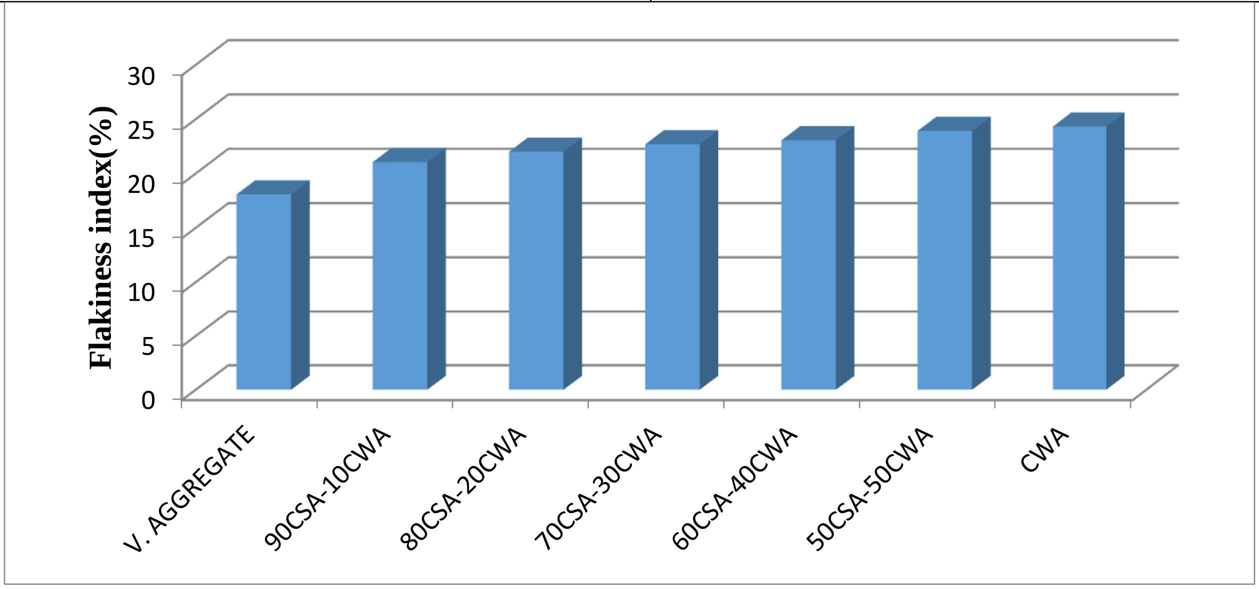

Figure 4.16 Flakiness Index of Different proportion of CWA and CA

As seen in Table 4.8 and fig. 4-8, the results of shape tests, such as the flakiness index, were tabulated and analysed by the graph for various blended proportions of CWA and CA. The graph shows that as the percent of CWAgrows, the flakiness index similarly rises, yet all blends are within the ERA and BS standard specification's recommended maximum FI of 30%. However, the blended aggregate's flakiness index ranged from 18.08% to 24.32 percent, which was within the permitted range.

4.3.5 Aggregate Crushing Value of CSA and CW

According to ERA (BS-812-Part 111, Part 110), CWA and CA mix confirm specification as indicated in Table 4.19. The ACV of the CW and CA blend ranged from 20 to 26%. It implied that they were sturdy enough to withstand stress generated by traffic wheel load and had strong resistance to crushing.

Table 4. 20 Results of aggregate crushing values for RCA and CA blended

Blended ratio of CSA-CWA	ACV, (%)
100%CSA-0%CWA	18.8
90%CSA-10%CWA	20.3
80%CSA-20%CWA	21.8
70%CSA-30%CWA	22.3
60%CSA-40%CWA	22.6
50%CSA-50%CWA	24.9
0%CSA-1005CWA	26.4

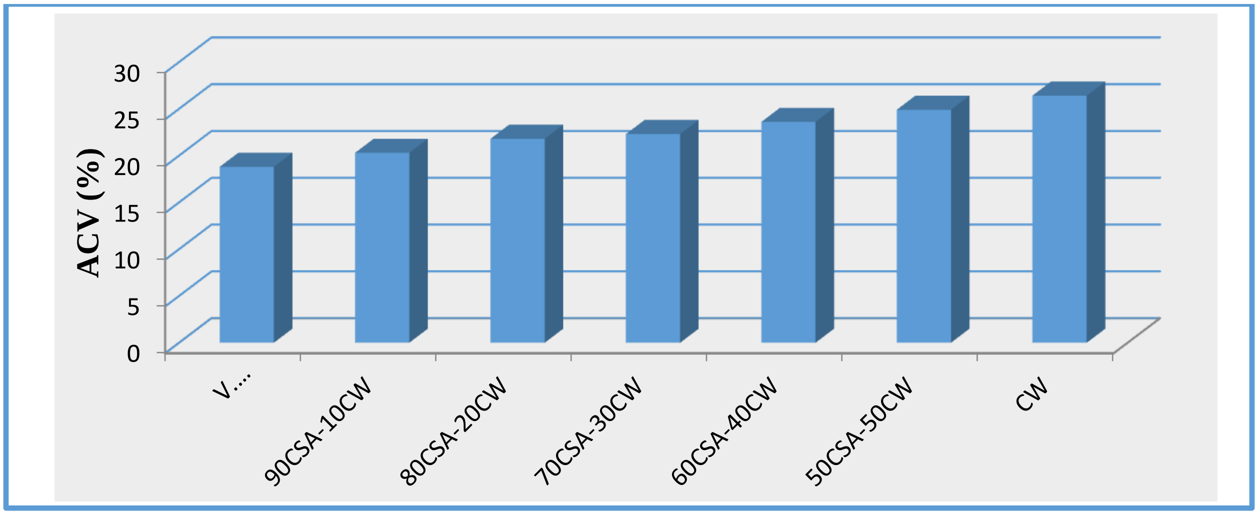

Figure 4. 16 Average ACV of Blended CSA and CW

4.3.6 Aggregate Impact Value of blended CSA and CW

As shown in Table 4.21 according to IS-2386, CWA and CA blend AIV confirm specification.

Table 4. 21 Results of aggregate impact value

Blended ratio of CSA-CWA	AIV	ERA 2013 Governing Specification
100%CSA-0%CWA	17.8	AIV<30
90%CSA-10%CWA	20.2	
80%CSA-20%CWA	21.2	
70%CSA-30%CWA	22.3	
60%CSA-40%CWA	22.8	
50%CSA-50%CWA	23.7	
0%CSA-100%CWA	25.5	

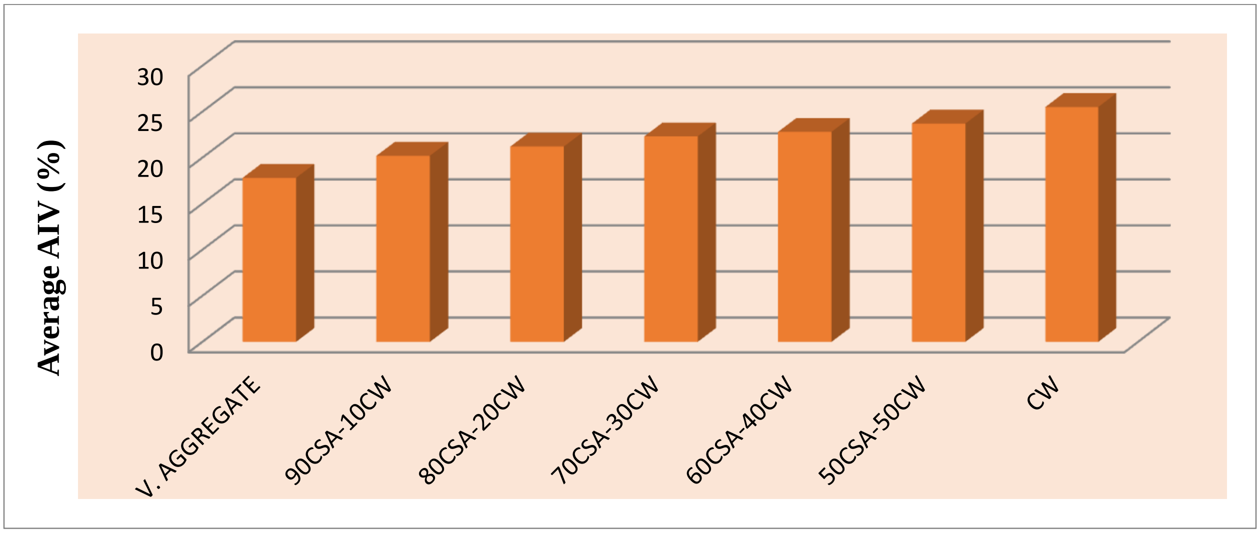

Figure 4. 17 Average AIV of Blended CSA and CW

The effect value for conventional aggregate and ceramic waste was calculated in accordance with BS 812: Part 112:1990, as illustrated in figure 4.14. The findings of this study showed that the inclusion of ceramic waste greatly raised the data of the minimal impact value. One may fairly conclude from the statistics above that as the amount of ceramic waste aggregate in the combination increases, the resistance to impact decreases. The materials in any case satisfy the requirements of the ERA standard specification for basic coarse materials, which suggests an aggregate impact value of less than 30%.

4.3.7 Los Angles Abrasion Value (LAAV) for blended CSA and DCA

Table 4. 22 LAA Test Result of Blended demolished concrete and Conventional Aggregate

Blended ratio of, CSA: DCA	Average LAAV (%)	ERA 2013 Governing Specification
100%CSA-0%CW	11.95	LAAV<45%
90%CSA-10%CW	15.64	
80%CSA-20%CW	16.14	
70%CSA-30%CW	17.01	
60%CSA-40%CW	17.68	
50%CSA-50%CW	18.05	
0%CSA-100%CW	19.39	

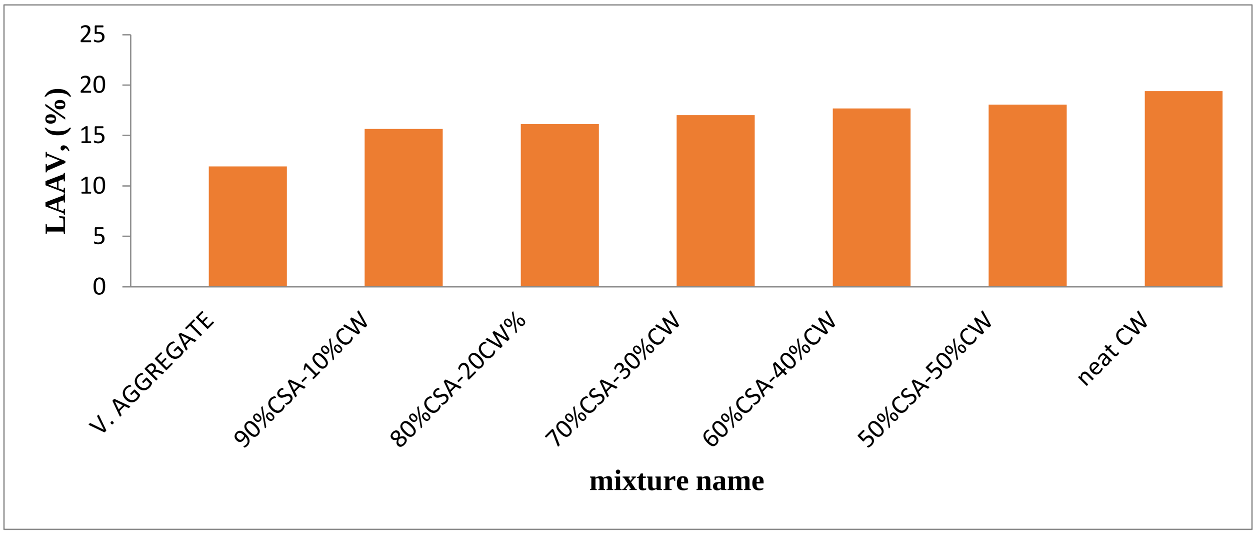

Figure 4. 18 Los Angles Abrasion Test (LAA) Results for blended CSA and CW

The maximum abrasion value of the base course is limited to 45% in accordance with ERA regulations. Figure 4.15 shows that the combination containing ceramic waste has a lower abrasion value than conventional aggregate and that it becomes less resistant to abrasion and impact as the percentage of CW in the mixture increases. The outcome of this test thus suggests that using 100%CW in base course building would not result in any abrasion issues.

4.3.8 Moisture – Density Relationship of blended CWA and CSA

According to AASHTO T180, a compaction test was performed on a combination of varied percentage replacements of CA by CW to determine the ideal and maximum dry density (OMC and MDD). The optimal moisture content and maximum dry density for aggregate mixtures at various mix percentages are shown in Table 4-21.

Table 4. 23 Result of the compaction test for Blended CSA and CWA

Blended ratio of CSA-CWA	OMC,(%)	MDD,(gm/cm3)
100%CSA-0%CWA	6.34	2.19
90%CSA-10%CWA	6.20	1.93
80%CSA-20%CWA	5.94	1.91
70%CSA-30%CWA	5.75	1.88
60%CSA-40%CWA	5.59	1.85
50%CSA-50%CWA	5.36	1.83
0%CSA-100%CWA	5.36	1.72

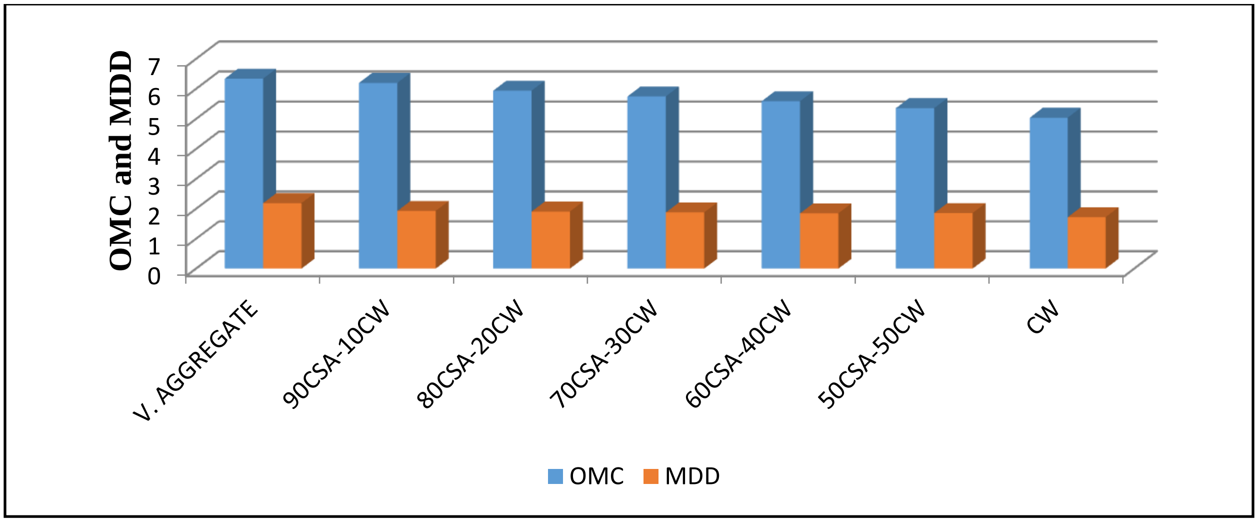

Figure 4. 19 OMC and MDD of ceramic waste and conventional aggregate mixtures test results.

Table 4-22 makes it readily apparent that as the proportion of ceramic waste aggregate in the mixtures increases, the optimum moisture content of the mixtures decreases. The values drop from 6.20% for 10%CWA-90%CA to 5.36% for 50%CW-50%CSA, which was caused by the smoothness and water resistance of the ceramic waste. The maximum dry density of the combination incorporating ceramic waste aggregate is lower than that of neat conventional aggregate, according to the data. Consequently, as the percentage of ceramic waste grew, the maximum dry density dropped.

4.2.9 California Bearing Ratio (CBR)

Table 4. 24 Result of the CBR test for blended CSA and CWA

Aggregate type	CBR at 98%MDD,%	Dry density at 98% MDD,(gm./cm^3)	Swell,(%)
90%CSA-10%CWA	95.6	1.89	0.00
80%CSA-20%CWA	90.4	1.87	0.00
70%CSA-30%CWA	84.3	1.84	0.00
60%CSA-40%CWA	78.14	1.79	0.00
50%CSA-50%CWA	73.8	1.73	0.00

The dry density and moisture content of CBR specimens for CWA and CSA mixed materials are shown in Table 4.23. As can be seen from the values for all blending conditions, it meets the ERA standard specification recommendation, which is >80% for base coarse material of (GB2 and GB3) except 40 and 50%CWA which is <80.

In comparison to the ERA standard specification for GB1 base course materials, the CBR test result for 100%CWA at 98%MDD was 64.35%. As illustrated in Table 4.23, a CBR test was also carried out using CSA and a range of CWA mix proportions (10%CWA to 50%CWA). Based on this, a result that was acceptable up to the range of ceramic west aggregate are (10% to 30%) CWA mix and had a 98%MDD was found to be (95.6% to 84.3%) respectivelly. The conclusion complies with the minimal requirements of the ERA standard specification for base coarse materials. The CBR value of the base coarse material's strength did not satisfy the ERA criterion (>80%) when the CWA employed more than 30% of CWA. The value of swelling was between 0.00 and 0.01; this demonstrates that soaking of aggregate material has little impact on the values of swelling property. For the unbounded base course (GB2 and GB3) materials in pavement construction, the Ceramic waste aggregate can therefore be utilized up to 30% without losing any strength issues.

4.2.10 Effect of CWA on ACV, AIV, LAA, Flakiness Index, and Water Absorption Value of CSA

The physical properties of CSA were tested in the lab, and different percentages of CWA was substituted for the base course material (10%, 20%, 30%, 40%, and 50%), as indicated in Table below. The ACV result demonstrates that substituting CSA with various percentages of CWA were within ERA standard specification requirements for GB1 basic course material, which needs a maximum value of 29%. The ACV for 50 percent CWA was 24.9%, which was confirmed to be within the ERA standard specification limit. The AIV test results of both materials have a significant difference, 25.5 and 17.5, as seen in Table. The resistance to impact (toughness) abrupt load increases with decreasing aggregate impact value. According to the ERA specification, the combined results of both materials demonstrated good resistance under abrupt traffic force in the AIV tests on the combination of CSA at various percentages of CWA (10%, 20%, 30%, 40%, and 50%). Table below also demonstrates the flakiness index for CWA, which was 24.32% and is within the ERA standard specification limit of FI 30%, suggesting that the CWA sample was suitable for use as a base coarse material.

Table 4. 25 Physical properties of CSA and CWA for the study

Tests	CSA: CWA	CSA: CWA	CSA: CWA	CSA: CWA	CSA: CWA	CSA: CWA	CSA: CWA	ERA Specification requirements
	100:0	90:10	80:20	70:30	60:40	50:50	0:100	
Bulk dry S.G	2.57	2.55	2.51	2.48	2.47	2.46		
Bulk SSD S.G	2.61	2.59	2.55	2.52	2.51	2.49		
Apparent S.G	2.69	2.66	2.61	2.58	2.57	2.55	2.54	2.5-3%
Water absorption, %	1.76	1.73	1.62	1.55	1.5	1.43	1.32	<2%
Flakiness Index	18.08	21.05	21.99	22.68	23.05	23.92	24.32	<30%
Los Angeles Abrasion (LAA	11.95	15.64	16.14	17.01	17.68	18.05	19.39	<45%
Aggregate crushing value (ACV), %	18.8	20.3	21.8	22.3	22.6	24.9	26.4	<29%
Aggregate Impact Value (AIV), %	17.8	20.2	21.2	22.3	22.8	23.7	25.5	<30%

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the results obtained in the experimental investigation, the following conclusions have been drawn based on Ethiopian road authority standard specifications.

- According to the findings of the sieve analysis, the gradation of neat CSA, DCA, and CWA as well as blended DCA-CSA and CWA-CSA at various percentages of mix are parallel to a standard specification of ERA. Sand and gravel are present in the material, which is categorised as A-1-a.
- According to the study, the ACV results for neat CSA and DCA are 18.8 and 22.9 percent, respectively. The replacement rates of 10%, 20%, 30%, 40%, and 50% of DCA with its complement of CSA in the DCA-CSA blends aggregate evaluated were 20.1%, 20.9%, 21.3%, 21.5%, and 21.9%, respectively. Similar to this, it was determined that the maximum and minimum values of the test were 12.55% - 14.99% for LAA and 19.6% - 21.9% for AIV. Aditionally, the ACV results for neat CWA is 26.4 percent. The replacement rates of 10%, 20%, 30%, 40%, and 50% of CWA with its complement of CSA in the CWA-CSA blends aggregate evaluated were 20.3%, 21.8%, 22.3%, 22.6%, and 24.9%, respectively. Similar to this, it was determined that the maximum and minimum values of the test were 15.64% - 18.%5 for LAA and 20.2% - 23.7% for AIV.
- Additionally, its CBR test was carried out using CSA and a variable ratio of DCA (10% to 50%). And the result was 105.3%, 97.25%, 90.1%, 82.6%, 78.9% respectively.
- Consequently, 40% for DCA replacement is determined to be an economically viable conclusion. DCA replacement at 98%MDD was 82.6%. Similarly, CBR test was carried out using CSA and a variable ratio of CWA (10% to 50%). And the result was 95.6%, 90.4%, 84.3%, 78.14%, 73.8% respectively, Consequently, 30% for CWA replacement is determined to be an economically viable conclusion. CWA replacement at 98%MDD was 84.3%. This result is chosen as the ideal percentage of replacement since it complies with the ERA standard criterion for base coarse materials.
- Finally, according to the quirement of ERA standered for the base coarse material , the optimum percent of DCA blending with CSA at 40% with the result were 82.6% for

CBR, 21.5% for ACV, 21.2% for AIV and 14.02% for LAA. Additionaly, the optimum percent of CWA blending with CSA is at 30% with the result were 84.3% for CBR, 22.3% for ACV, 22.3% for AIV and 17.01% for LAA

5.2 Recomendation

- Based on the findings of this study, it is advised that improvements and applications of the locally accessible ceramic waste aggregate and demolished concrete material be given due consideration for upcoming road construction projects in the study area or in other locations where marble waste material is available.
- Road construction cannot effectively use ceramic waste aggregate and demolished concerete material as a base coarse material. As a result, it should be blended with convetional aggregate while taking into account ERA standard specifications.
- The use of clean ceramic waste aggregate mixed with conventional aggregate as a substitute for base course construction materials is inappropriate. However, as the obtained CBR value at a 40/ 60 CWA to CSA ratio by percentage is 78.14%>30%. And also, demolished concrete aggregate mixed with convetional aggregate CBR value at a 50/50 DCA to CSA ratio by percent is 78.9%>30%, it was advised to use it as a sub base building material
- Industrial waste materials, such as waste ceramic aggregates and demolished concrete mateial, have a lot of potential to be used as a convetional aggregate material for a variety of road construction, therefore it should be suggested for future construction sectors.
- In order to assess the durability and resilience modulus of pavement structures with full scale road tests, more research should be done on the long-term effects and performance of ceramic waste aggregate and demolished concrete material at base course layer.

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APPENDIX

APPENDIX A: RESULTS OF BLENDED CSA AND DCA

Table A1: Test result of sieve analysis for 90%CSA-10%DCA

Sieve size (mm)	mass of retain on each seive(g)	Percentage of retained	cumulative % of retain	percentage of passing particle	ERA Specification for GB1	
					Lower limit	Upper limit
50	0.00	0.00	0.00	100.00	100	100
37.5	232.56	4.65	4.65	95.35	80	100
20	1189.54	23.80	28.46	71.54	60	80
9.5	912.85	18.27	46.72	53.28	45	65
4.75	792.60	15.86	62.58	37.42	30	50
2.36	612.80	12.26	74.85	25.15	20	40
0.425	628.90	12.58	87.43	12.57	10	25
0.075	354.21	7.09	94.52	5.48	5	15
pan	273.98	5.48	100.00	0.00		

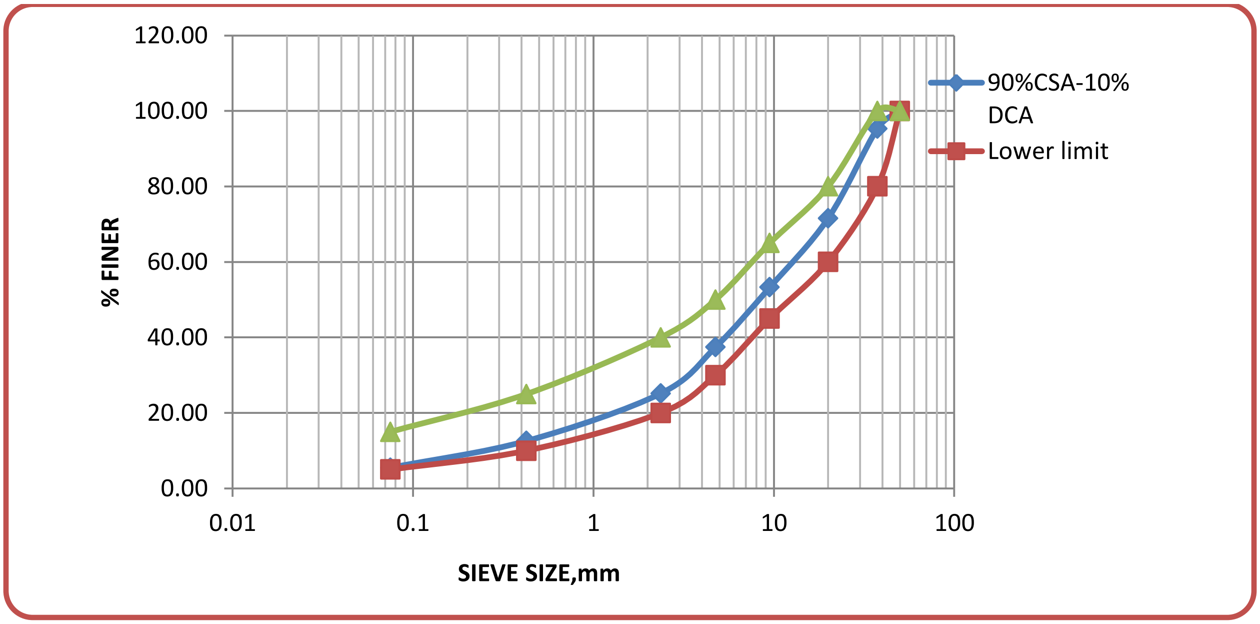


Figure A1: Particle Size Distribution of 90%CSA-10%DCA

Table A2: Result of Sieve Analysis for 80%CSA-20%DCA

Sieve size (mm)	mass of retain on each seive(g)	Percentage of retained	cumulative % of retain	percentage of passing particle	ERA Specification for GB1	
					Lower limit	Upper limit
50	0.00	0.00	0.00	100.00	100	100
37.5	209.61	4.19	4.19	95.81	80	100
20	1069.28	21.39	25.58	74.42	60	80
9.5	983.21	19.67	45.25	54.75	45	65
4.75	847.94	16.96	62.21	37.79	30	50
2.36	715.62	14.31	76.53	23.47	20	40
0.425	614.28	12.29	88.81	11.19	10	25
0.075	336.98	6.74	95.55	4.45	5	15
pan	222.25	4.45	100.00	0.00		

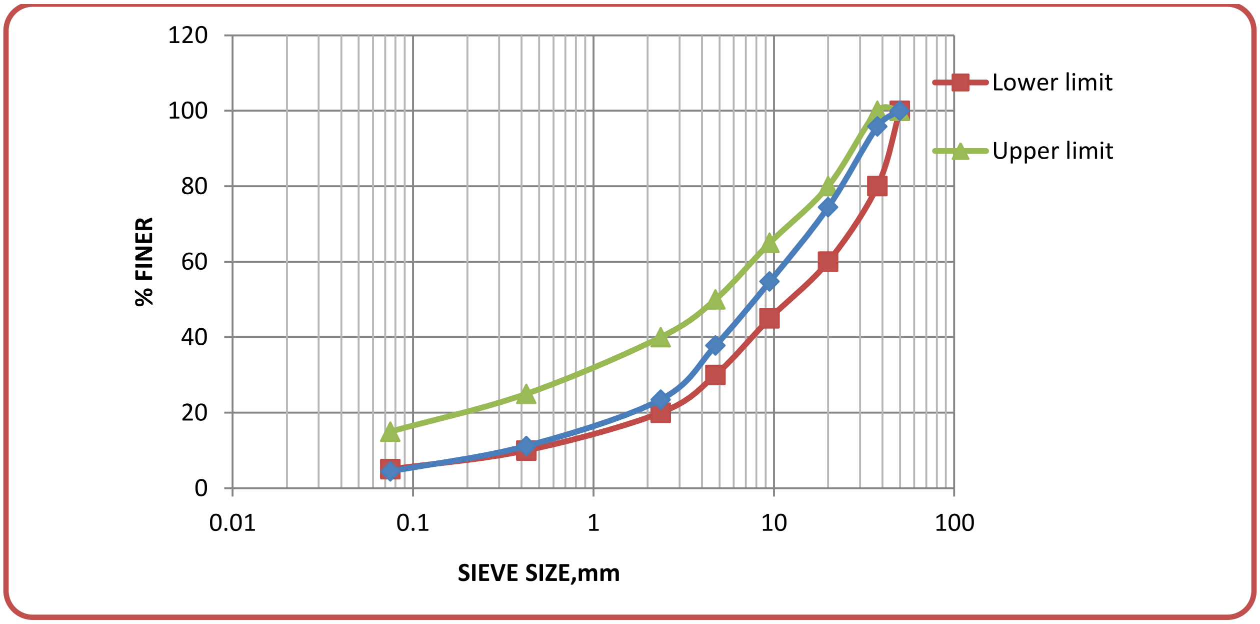


Figure A2: Particle Size Distribution of 80%CSA-20%DCA

Table A3: Result of Sieve Analysis for 70%CSA-30%DCA

Sieve size (mm)	mass of retain on each seive(g)	Percentage of retained	cumulative % of retain	percentage of passing particle	ERA Specification for GB1	
					Lower limit	Upper limit
50	0	0.00	0.00	100.00	100	100
37.5	142.6	2.86	2.86	97.14	80	100
20	1089.6	21.82	24.67	75.33	60	80
9.5	1129.30	22.61	47.29	52.71	45	65
4.75	839.60	16.81	64.10	35.90	30	50
2.36	719.52	14.41	78.50	21.50	20	40
0.425	530.20	10.62	89.12	10.88	10	25
0.075	280.21	5.61	94.73	5.27	5	15
pan	263.14	5.27	100.00	0.00		

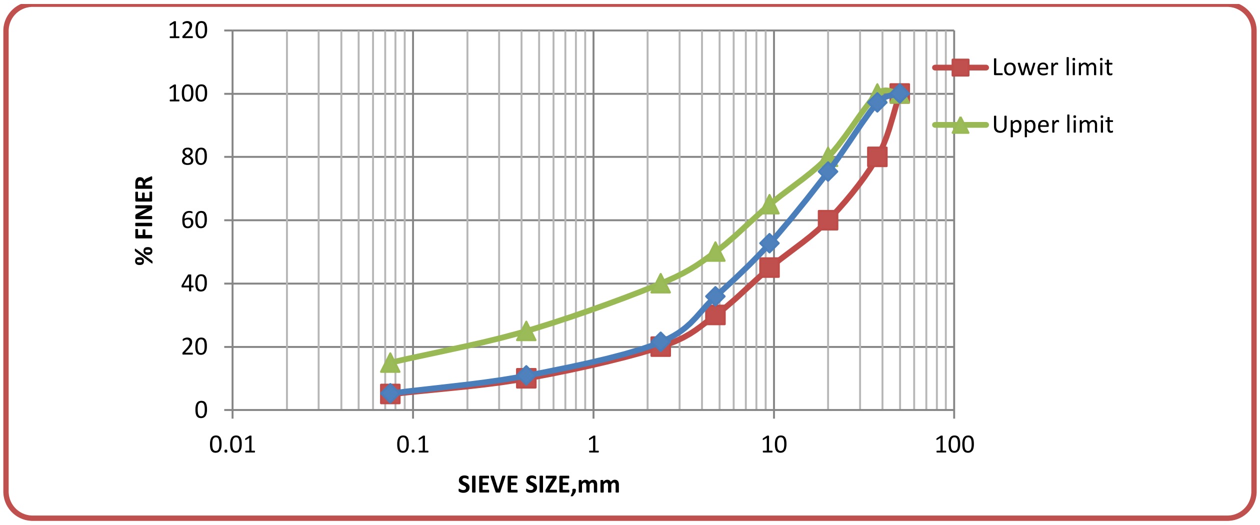


Figure A3: Particle Size Distribution of 70%CSA-30%DCA

Table A4: Result of Sieve Analysis for 60%CSA-40%DCA

Sieve size (mm)	mass of retain on each seive(g)	Percentage of retained	cumulative % of retain	percentage of passing particle	ERA Specification for GB1	
					Lower limit	Upper limit
50	0	0.00	0.00	100.00	100	100
37.5	102.6	2.05	2.05	97.95	80	100
20	1157.6	23.16	25.21	74.79	60	80
9.5	1219.50	24.40	49.61	50.39	45	65
4.75	689.40	13.79	63.41	36.59	30	50
2.36	694.59	13.90	77.31	22.69	20	40
0.425	479.58	9.60	86.90	13.10	10	25
0.075	342.60	6.85	93.76	6.24	5	15
pan	312.10	6.24	100.00	0.00		

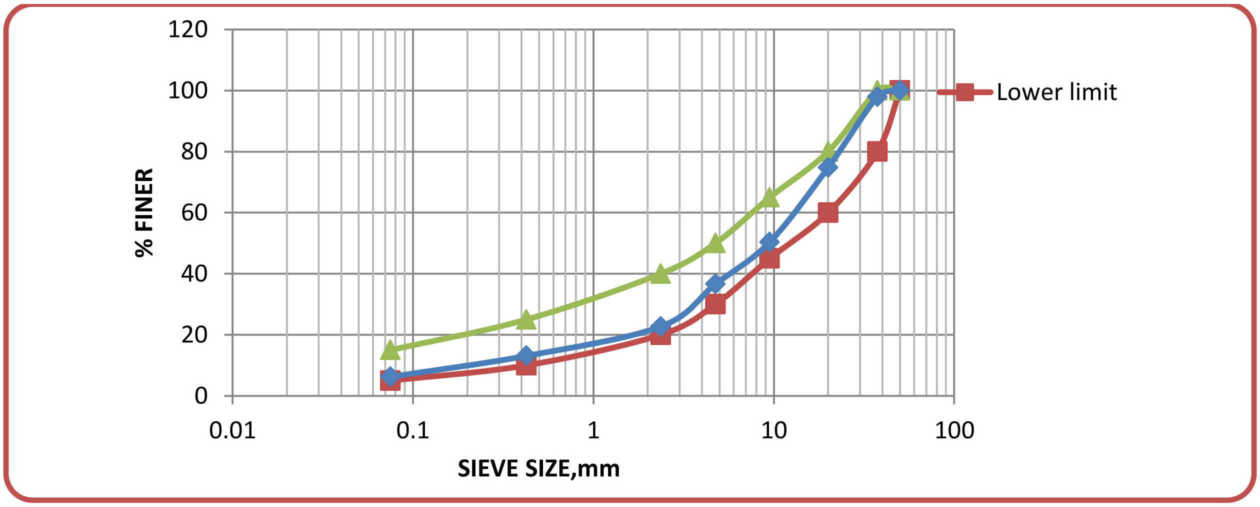


Figure A4: Particle Size Distribution of 60%CSA-40%DCA

Table A5: Result of Sieve Analysis for 50%CSA-50%DCA

Sieve size (mm)	mass of retain on each seive(g)	Percentage of retained soil	cumulative % of retain soil	percentage of passing particle	ERA Specification for GB1	
					Lower limit	Upper limit
50	0.00	0.00	0.00	100.00	100	100
37.5	172.31	3.45	3.45	96.55	80	100
20	1068.63	21.39	24.84	75.16	60	80
9.5	1027.30	20.56	45.40	54.60	45	65
4.75	884.79	17.71	63.11	36.89	30	50
2.36	614.21	12.29	75.40	24.60	20	40
0.425	543.25	10.87	86.28	13.72	10	25
0.075	397.89	7.96	94.24	5.76	5	15
pan	287.65	5.76	100.00	0.00		

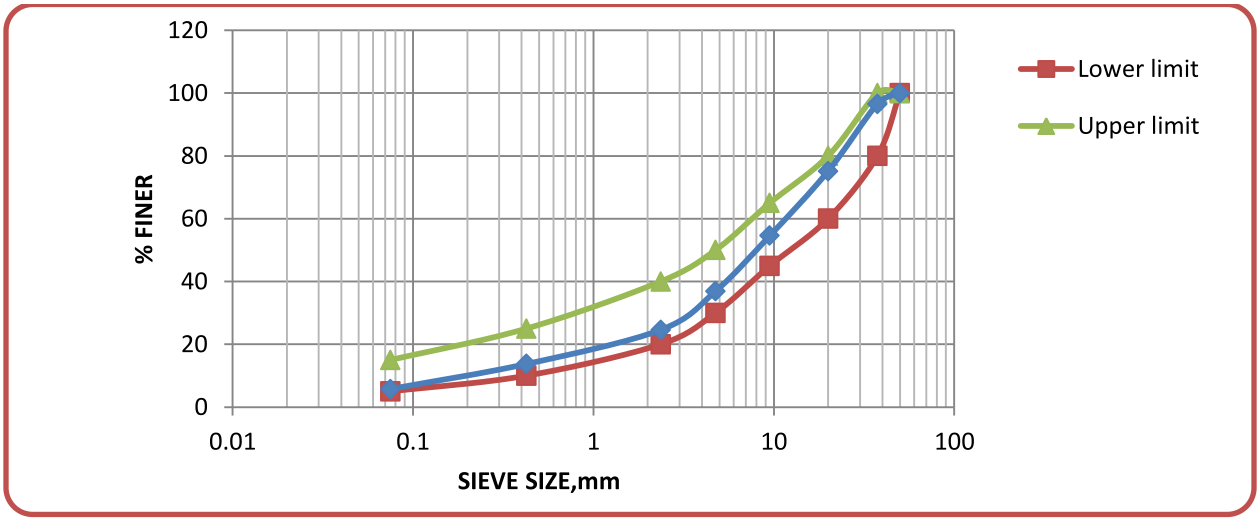


Figure A5: Particle Size Distribution of 50%CSA-50%DCA

A-2: Specific Gravity and Water Absorption

Table A-6 result of Specific gravity & water absorption of 90% CSA -10%DCA blended

SPECIFIC GRAVITY AND WATER ABSORPTION		
Trial	1	2
Weight of sample , g	2500	2500
Weight of vessel + sample + water (A), g	2260.1	2260.5
Weight of vessel + water (B), g	664.1	664.1
Weight of SSD sample (C) ,g	2617.2	2617.5
Weight of oven dry sample (D),g	2571.2	2570.9
Bulk Specific gravity(SSD basis) = C/(C-(A-B))	2.56	2.56
Average bulk specific gravity(SSD basis)	2.56	
Bulk Specific gravity(dry basis) = D/(C-(A-B))	2.52	2.52
Average bulk specific gravity(dry basis)	2.52	
Apparent specific gravity = D/(D-(A-B))	2.64	2.64
average Apparent specific gravity	2.64	
water absorption, percentage dry weight (C-D)/D*100	1.79	1.81
average water absorption	1.80	

Table A-7 result of Specific gravity & water absorption of 80% CSA -20%DCA blended

SPECIFIC GRAVITY AND WATER ABSORPTION		
Trial	1	2
Weight of sample , g	2500	2500
Weight of vessel + sample + water (A), g	2242.1	2242.17
Weight of vessel + water (B), g	663.6	663.6
Weight of SSD sample (C) ,g	2608.1	2608.25
Weight of oven dry sample (D),g	2560.1	2560.24
Bulk Specific gravity(SSD basis) = C/(C-(A-B))	2.53	2.53
Average Bulk specific gravity(SSD basis)	2.53	
Bulk Specific gravity(dry basis) = D/(C-(A-B))	2.49	2.49
Average bulk specific gravity(dry basis)	2.49	
Apparent specific gravity = D/(D-(A-B))	2.61	2.61
Average apparent specific gravity	2.61	
water absorption, percentage dry weight (C-D)/D*100	1.87	1.88
average water absorption	1.88	

Table A-8 result of Specific gravity & water absorption of 70% CSA -30%DCA blended

SPECIFIC GRAVITY AND WATER ABSORPTION		
Trial	1	2
Weight of sample , g	2500	2500
Weight of vessel + sample + water (A), g	2230	2230.5
Weight of vessel + water (B), g	663.6	663.6
Weight of SSD sample (C) ,g	2601.2	2601.41
Weight of oven dry sample (D),g	2552.4	2552.1
Bulk Specific gravity(SSD basis) = C/(C-(A-B))	2.51	2.51
Average bulk specific gravity(SSD basis	2.51	
Bulk Specific gravity(dry basis) = D/(C-(A-B))	2.47	2.47
Average specific gravity(dry basis)	2.47	
Apparent specific gravity = D/(D-(A-B))	2.59	2.59
average Apparent specific gravity	2.59	
water absorption, percentage dry weight (C-D)/D*100	1.91	1.93
average water absorption	1.92	

Table A-9 result of Specific gravity & water absorption of 60% CSA -40%DCA blended

SPECIFIC GRAVITY AND WATER ABSORPTION		
Trial	1	2
Weight of sample , g	2500	2500
Weight of vessel + sample + water (A), g	2218.1	2218.3
Weight of vessel + water (B), g	663.6	663.6
Weight of SSD sample (C) ,g	2597.1	2596.8
Weight of oven dry sample (D),g	2546.8	2546.6
Bulk Specific gravity(SSD basis) = C/(C-(A-B))	2.49	2.49
Average Bulk specific gravity(SSD basis	2.49	
Bulk Specific gravity(dry basis) = D/(C-(A-B))	2.44	2.44
average bulk specific gravity(dry basis	2.44	
Apparent specific gravity = D/(D-(A-B))	2.57	2.57
average Apparent specific gravity	2.57	
water absorption, percentage dry weight (C-D)/D*100	1.98	1.97
average water absorption	1.97	

Table A-10 result of Specific gravity & water absorption of 50% CSA -50%DCA blended

SPECIFIC GRAVITY AND WATER ABSORPTION		
Trial	1	2
Weight of sample , g	2500	2500
Weight of vessel + sample + water (A), g	2225.6	2225
Weight of vessel + water (B), g	663.6	663.6
Weight of SSD sample (C) ,g	2625.1	2624.8
Weight of oven dry sample (D),g	2571.2	2570.2
Bulk Specific gravity(SSD basis) = C/(C-(A-B))	2.47	2.47
Average bulk specific gravity(SSD basis)	2.47	
Bulk Specific gravity(dry basis) = D/(C-(A-B))	2.42	2.42
Average bulk specific gravity(dry basis)	2.42	
Apparent specific gravity = D/(D-(A-B))	2.55	2.55
Average Apparent specific gravity	2.55	
water absorption, percentage dry weight (C-D)/D*100	2.10	2.12
Average water absorption	2.11	

A-3: Flakiness Index

Table A-11 result of flakiness index of 90%CSA-10%DCA

Sieve size(mm)	Wt. Retained	5% check	Wt. after gauging(**A**)	Wt. pass(**B**)	Wt. retained(**C**)
37.5	0	0	0	0	0
28	1333.50	20.79	724.90	78.50	646.40
20	1224.60	19.09	1087.20	179.40	907.80
14	1211.30	18.89	1089.50	314.64	774.86
10	1524.30	23.77	715.20	147.21	567.99
6.3	1119.60	17.46	255.30	29.80	225.50
Total	6413.30	100.00	**3872.10**	**749.55**	3122.55
FI=B/A*100			19.36		

Table A-12 result of flakiness index of 80%CSA-20%DCA

Sieve size(mm)	Wt. Retained	5% check	Wt. after gauging(**A**)	Wt. pass(**B**)	Wt. retained(**C**)
37.5	0	0	0	0	0
28	1295.74	20.69	779.30	81.21	698.09
20	1235.67	19.73	1110.80	198.97	911.83
14	1121.57	17.91	1043.40	312.46	730.94
10	1521.35	24.29	689.70	143.62	546.08
6.3	1088.28	17.38	247.59	42.85	204.74
Total	6262.61	100.00	**3870.79**	**779.11**	3091.68
FI=B/A*100			20.13		

Table A-13 result of flakiness index of 70%CSA-30%DCA

Sieve size(mm)	Wt. Retained	5% check	Wt. after gauging(**A**)	Wt. pass(**B**)	Wt. retained(**C**)
37.5	0	0	0	0	0
28	1279.94	19.78	655.30	97.29	558.01
20	1198.31	18.52	1125.92	242.60	883.32
14	1210.10	18.70	1049.31	274.49	774.82
10	1632.69	25.23	709.82	135.25	574.57
6.3	1149.94	17.77	264.87	59.89	204.98
Total	6470.98	100.00	**3805.22**	**809.52**	2995.70
FI=B/A*100			21.27		

Table A-14 result of flakiness index of 60%CSA-40%DCA

Sieve size(mm)	Wt. Retained	5% check	Wt. after gauging(**A**)	Wt. pass(**B**)	Wt. retained(**C**)
37.5	0	0	0	0	0
28	1410.26	21.66	705.31	67.89	637.42
20	1176.29	18.07	1112.30	195.97	916.33
14	1210.95	18.60	1102.64	335.47	767.17
10	1634.38	25.11	512.30	132.10	380.20
6.3	1078.29	16.56	245.30	62.12	183.18
Total	6510.17	100.00	**3677.85**	**793.55**	2884.30
FI=B/A*100			21.58		

Table A-15 result of flakiness index of 50%CSA-50%DCA

Sieve size(mm)	Wt. Retained	5% check	Wt. after gauging(**A**)	Wt. pass(**B**)	Wt. retained(**C**)
37.5	0	0	0	0	0
28	1379.56	21.41	626.42	79.23	547.19
20	1183.74	18.37	1151.25	215.36	935.89
14	1215.36	18.86	1025.60	299.69	725.91
10	1465.85	22.75	667.90	165.26	502.64
6.3	1198.29	18.60	225.70	52.49	173.21
Total	6442.80	100.00	**3696.87**	**812.03**	2884.84
FI=B/A*100			21.97		

A-4 Aggregate crushing value

Table 16 result of aggregate crushing value of 90%CSA-10%DCA

Test No	Mass of sample (A)	Mass of Portion Passing B.S 2.36 mm Sieve (B) gm after crushing	Aggregate Crushing Value ACV %	
			individual, (B/A×100)%	Average %
1	2466.2	492.64	19.98	**20.1**
2	2468.8	500.36	20.27	

Table 17 result of aggregate crushing value of 80%CSA-20%DCA

Test No	Mass of sample (A)	Mass of Portion Passing B.S 2.36 mm Sieve (B) gm after crushing	Aggregate Crushing Value, ACV %	
			individual, (B/A×100)%	Average %
1	2478.26	515.6	20.80	**20.9**
2	2475.28	519.7	21.00	

Table 18 result of aggregate crushing value of 70%CSA-30%DCA

Test No	Mass of sample (A)	Mass of Portion Passing	Aggregate Crushing Value,ACV %	
		B.S 2.36 mm Sieve (B) gm after crushing	individual, (B/A×100)%	Average %
1	2465.91	525.6	21.31	**21.3**
2	2461.29	522.6	21.23	

Table 19 result of aggregate crushing value of 60%CSA-40%DCA

Test No	Mass of sample (A)	Mass of Portion Passing B.S 2.36 mm Sieve (B) gm after crushing	Aggregate Crushing Value ACV %	
			individual, (B/A×100)%	Average %
1	2477.6	532.6	21.50	**21.5**
2	2480.6	535.6	21.59	

Table 20 result of aggregate crushing value of 50%CSA-50%DCA

Test No	Mass of sample (A)	Mass of Portion Passing B.S 2.36 mm Sieve (B) gm after crushing	Aggregate Crushing Value, ACV %	
			individual, (B/A×100)%	Average %
1	2467.69	542.96	22.00	**21.9**
2	2465.21	539.6	21.89	

A-5 Aggregate impact value

Table 21 result of aggregate impact value of 90%CSA-10%DCA

Test No	Mass of sample (A)	Mass of Portion Passing B.S 2.36 mm Sieve (B) gm	**Aggregate Impact Value(AIV) %**	
			individual, (B/A×100)%	Average %
1	643.21	124.65	19.38	**19.6**
2	641.84	127.19	19.82	

Table 22 result of aggregate impact value of 80%CSA-20%DCA

Test No	Mass of sample (A)	Mass of Portion Passing B.S 2.36 mm Sieve (B) gm	**Aggregate Impact Value(AIV) %**	
			individual, (B/A×100)%	Average %
1	657	132.5	20.17	**20.0**
2	654.5	129.31	19.76	

Table 23 result of aggregate impact value of 70%CSA-30%DCA

Test No	Mass of sample (A)	Mass of Portion Passing B.S 2.36 mm Sieve (B) gm	**Aggregate Impact Value(AIV) %**	
			individual, (B/A×100)%	Average %
1	646.5	135.71	20.99	**21.2**
2	641.5	137.17	21.38	

Table 24 result of aggregate impact value of 60%CSA-40%DCA

Test No	Mass of sample (A)	Mass of Portion Passing B.S 2.36 mm Sieve (B) gm	**Aggregate Impact Value(AIV) %**	
			individual, (B/A×100)%	Average %
1	664.8	142.12	21.38	**21.5**
2	672.3	145.62	21.66	

Table 25 result of aggregate impact value of 50%CSA-50%DCA

Test No	Mass of sample (A)	Mass of Portion Passing B.S 2.36 mm Sieve (B) gm	**Aggregate Impact Value(AIV) %**	
			individual, (B/A×100)%	Average %
1	633.5	137.21	21.66	**21.9**
2	637	140.7	22.09	

A-6 Los Angeles abrasion value

Table 26 Los Angeles test result for 90%CSA-10%DCA

Grading of a test sample	sample passing through is a sieve	sample retained on is sieve mm	weight of sample taken gm.	total weight of sample taken from two sieves (A)gm.	number of charges	weight retained on 1.7mm IS sieve after test(B)gm.	loss Angeles Abrasion value=(A-B)/A%	Average LAAA%
B	19	12.5	2500	5000	11	4375.29	12.49	12.55
	12.5	9.5	2500					
	19	12.5	2500	5000	11	4369.54	12.61	
	12.5	9.5	2500					

Table 27 los Angeles test result for 80%CSA-20%DCA

Grading of a test sample	sample passing through is sieve	sample retained on is sieve mm	weight of sample taken gm.	total weight of sample taken from two sieves (A)gm.	number of charges	weight retained on 1.7mm IS sieve after test(B)gm.	loss Angeles Abrasion value=(A-B)/A%	Average LAAA%
B	19	12.5	2500	5000	11	4349.61	13.01	13.13
	12.5	9.5	2500					
	19	12.5	2500	5000	11	4337.41	13.25	
	12.5	9.5	2500					

Table 28 Los Angeles test result for 70%CSA-30%DCA

Grading of a test sample	sample passing through is sieve	sample retained on is sieve mm	weight of sample taken gm.	total weight of sample taken from two sieves (A)gm.	number of charges	weight retained on 1.7mm IS sieve after test(B)gm.	loss Angeles Abrasion value=(A-B)/A%	Average LAAA%
B	19	12.5	2500	5000	11	4325.74	13.49	13.59
	12.5	9.5	2500					
	19	12.5	2500	5000	11	4315.26	13.69	
	12.5	9.5	2500					

Table 29 Los Angeles test result for 60%CSA-40%DCA

Grading of a test sample	sample passing through is sieve	sample retained on is sieve mm	weight of sample taken gm.	total weight of sample taken from two sieves (A)gm.	number of charges	weight retained on 1.7mm IS sieve after test(B)gm.	loss Angeles Abrasion value=(A-B)/A%	Average LAAA%
B	19	12.5	2500	5000	11	4295.6	14.09	14.02
	12.5	9.5	2500					
	19	12.5	2500	5000	11	4302.52	13.95	
	12.5	9.5	2500					

Table 30 Los Angeles test result for 50%CSA-50%DCA

Grading of a test sample	sample passing through is sieve	sample retained on is sieve mm	weight of sample taken gm.	total weight of sample taken from two sieves (A)gm.	number of charges	weight retained on 1.7mm IS sieve after test(B)gm.	loss Angeles Abrasion value=(A-B)/A%	Average LAAA%
B	19	12.5	2500	5000	11	4259.21	14.82	14.99
	12.5	9.5	2500					
	19	12.5	2500	5000	11	4241.98	15.16	
	12.5	9.5	2500					

A-7 Moisture-density relation test result

Table 31 moisture–density relation test result of 90% CSA-10%DCA

Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4500	4500	4500	4500
Mass of Mold +Wet soil (gm.) (A)	10489.2	10652.6	10574.9	10498.2
Mass of Mold (gm.)(B)	6148.8	6148.8	6148.8	6148.8
Mass of Wet Soil(gm.)A-B=C	4340.4	4503.8	4426.1	4349.4
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm./cm^3 C/D=(E)	2.04	2.12	2.08	2.05
Moisture Content Determination				
Container Code .	A	2	P3	G19
Mass of Wet soil + Container(gm.)(F)	241.77	230.6	200.54	211.35
Mass of dry soil +container(gm.).(G)	231.2	217.32	184.1	189.1
Mass of container(gm.)(H)	32.79	34.84	32.68	34.75
Mass of moisture(gm.)F-G=(I)	10.57	13.28	16.44	22.25
Mass of Dry soil(gm.)G-H=(J)	198.41	182.48	151.42	154.35
Moisture content % (I/J)*100=K	**5.33**	**7.28**	**10.86**	**14.42**
Dry Density gm./cm^3 E/(100+K)*100	**1.94**	**1.98**	**1.88**	**1.79**

Table 32 moisture–density relation test result of 80% CSA-20%DCA

Density Determination				
Test No.	1	2	3	
Mass of sample (gm.)	4500	4500	4500	4500
Mass of Mold +Wet soil(gm.)(A)	10416.1	10612.3	10525.6	10472.1
Mass of Mold(gm.)(B)	6155.6	6155.6	6155.6	6155.6
Mass of Wet Soil(gm.)A-B=C	4260.5	4456.7	4370	4316.5
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm./cm^3 C/D=(E)	2.01	2.10	2.06	2.03
Moisture Content Determination				
Container Code .	A	2	P3	G19
Mass of Wet soil +Container(gm.)(F)	235.77	225.6	201.45	219.35
Mass of dry soil +container(gm.)(G)	222.9	212.1	184	195.3
Mass of container(gm.)(H)	32.79	34.84	32.68	34.75
Mass of moisture(gm.)F-G=(I)	12.87	13.5	17.45	24.05
Mass of Dry soil(gm.)G-H=(J)	190.11	177.26	151.32	160.55
Moisture content % (I/J)*100=K	**6.77**	**7.62**	**11.53**	**14.98**
Dry Density gm./cm^3 E/(100+K)*100	**1.88**	**1.95**	**1.84**	**1.77**

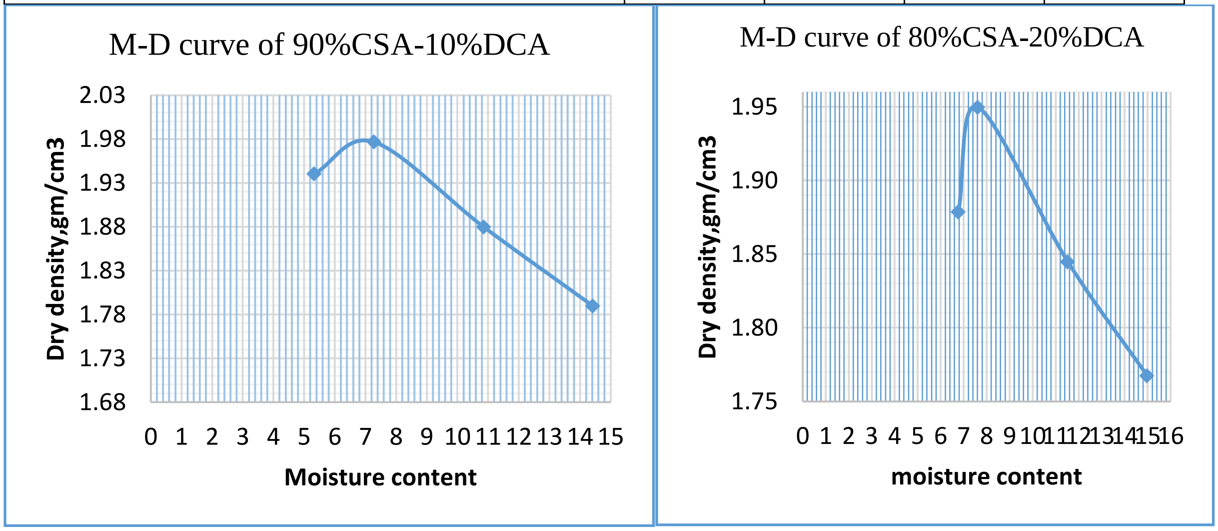


Figure A6: moisture- density relation curve of blended 90%CSA-10%DCA and 80%CSA-20%DCA

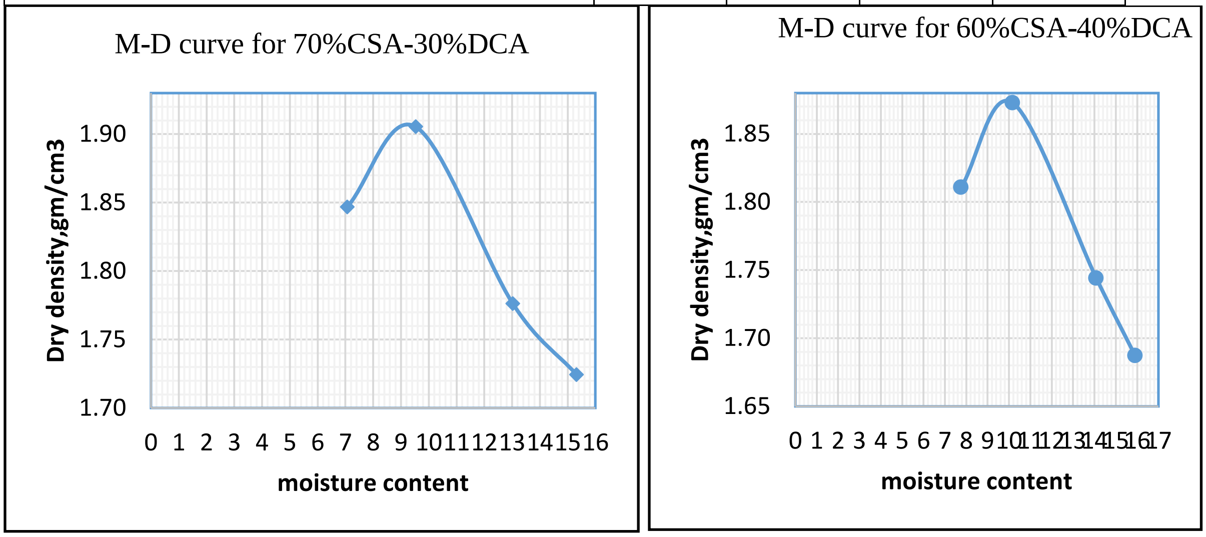
Table 33 moisture–density relation test result of 70% CSA-30%DCA

Density Determination				
Test No.	1	2	3	4
Mass of sample (gm.)	5000	5000	5000	5000
Mass of Mold +Wet soil(gm.)(A)	9664.2	9897.2	9728.6	9688.3
Mass of Mold(gm.)(B)	5464.5	5464.5	5464.5	5464.5
Mass of Wet Soil(gm.)A-B=C	4199.7	4432.7	4264.1	4223.8
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm./cm^3 C/D=(E)	1.98	2.09	2.01	1.99
Moisture Content Determination				
Container Code .	A	2	P3	G53
Mass of Wet soil +Container(gm.)(F)	225.83	142.35	132.95	141.3
Mass of dry soil +container(gm.)(G)	212.6	131.5	119.6	124.9
Mass of container(gm.)(H)	25.38	17.7	17.11	17.89
Mass of moisture(gm.)F-G=(I)	13.23	10.85	13.35	16.4
Mass of Dry soil(gm.)G-H=(J)	187.22	113.8	102.49	107.01
Moisture content % (I/J)*100=K	**7.07**	**9.53**	**13.03**	**15.33**
Dry Density gm./cm^3 E/(100+K)*100	**1.85**	**1.91**	**1.78**	**1.72**

Table 34 moisture–density relation test result of 60% CSA-40%DCA

Density Determination				
Test No.	1	2	3	4
Mass of sample (gm.)	5000	5000	5000	5000
Mass of Mold +Wet soil(gm.)(A)	10349.5	10587.2	10431.2	10358.4
Mass of Mold(gm.)(B)	6204.8	6204.8	6204.8	6204.8
Mass of Wet Soil(gm.)A-B=C	4144.7	4382.4	4226.4	4153.6
Volume of Mold cm^3(D)	2124	2124	2124	2124

Bulk Density gm./cm^3 C/D=(E)	1.95	2.06	1.99	1.96
Moisture Content Determination				
Container Code .	P15	P65	E-12	K23
Mass of Wet soil +Container(gm.)(F)	247.57	246	233.6	214.63
Mass of dry soil +container(gm.)(G)	232.1	226.8	208.8	190.1
Mass of container(gm.)(H)	32.8	37.96	32.74	35.9
Mass of moisture(gm.)F-G=(I)	15.47	19.2	24.8	24.53
Mass of Dry soil(gm.)G-H=(J)	199.3	188.84	176.06	154.2
Moisture content % (I/J)*100=K	**7.76**	**10.17**	**14.09**	**15.91**
Dry Density gm./cm^3 E/(100+K)*100	**1.81**	**1.87**	**1.74**	**1.69**


M-D curve for 70%CSA-30%DCA

M-D curve for 60%CSA-40%DCA

Figure A7: moisture- density relation curve of blended 70%CSA-30%DCA and 60%CSA-40%DCA

Table 35 moisture–density relation test result of 50% CSA-50%DCA

Density Determination				
Test No.	1	2	3	4
Mass of sample (gm.)	5000	5000	5000	5000
Mass of Mold +Wet soil(gm.)(A)	10321.2	10541.2	10379.6	10312.1
Mass of Mold(gm.)(B)	6204.8	6204.8	6204.8	6204.8
Mass of Wet Soil(gm.)A-B=C	4116.4	4336.4	4174.8	4107.3
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm./cm^3 C/D=(E)	1.94	2.04	1.97	1.93

Moisture Content Determination				
Container Code .	P15	P65	E-12	K23
Mass of Wet soil +Container(gm.)(F)	247.57	246	233.6	214.63
Mass of dry soil +container(gm.)(G)	231.6	225.4	207.1	189.21
Mass of container(gm.)(H)	32.8	37.96	32.74	35.9
Mass of moisture(gm.)F-G=(I)	15.97	20.6	26.5	25.42
Mass of Dry soil(gm.)G-H=(J)	198.8	187.44	174.36	153.31
Moisture content % (I/J)*100=K	**8.03**	**10.99**	**15.20**	**16.58**
Dry Density gm./cm^3 E/(100+K)*100	**1.79**	**1.84**	**1.71**	**1.66**

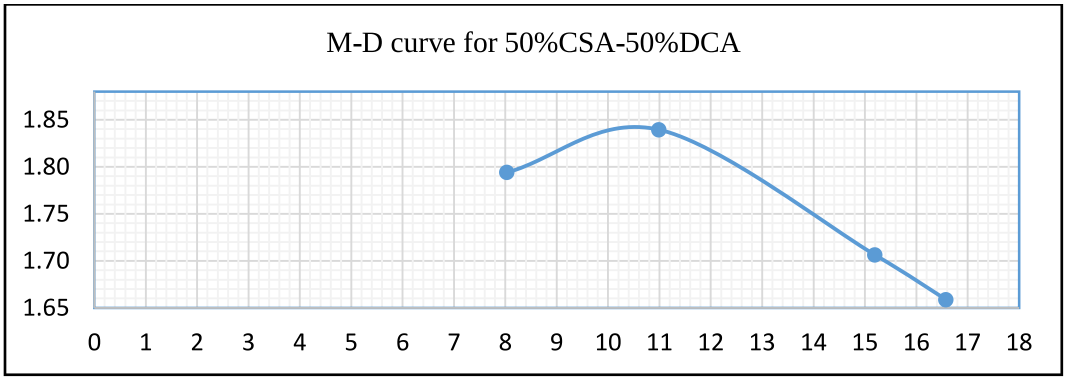


Figure A8: moisture- density relation curve of blended 50%CSA-50%DCA

A-8: CBR test result

Table 36 CBR test result of 90% CSA-10%DCA

Compaction Determination						
COMPACTION DATA	**65 Blows**		**30 Blows**		**10 Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.	T4	T4	N13	N13	N9	N9
Mass of wet soil + Mould g	11458.7	11683.7	11151.4	10903	10890.7	10664.3
Mass Mould g	6950.3	6950.3	6968.6	6968.6	6943.5	6943.5
Mass of Soil g	4508.4	4733.4	4182.8	3934.4	3947.2	3720.8
Volume of Mould g	2124	2124	2124	2124	2124	2124
Wet density of soil g/cc	2.123	2.229	1.969	1.852	1.858	1.752
Dry density of soil g/cc	1.98	2.14	1.83	1.75	1.72	1.65
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 soil + Container g	195.17	187.34	181.78	173.85	140.10	188.19
Mass of dry soil + Container g	184.38	181.10	170.66	166.30	132.44	179.10
Mass of container g	37.1	36.9	25.2	33.3	34.7	37.5
Mass of water g	10.8	6.2	11.1	7.5	7.7	9.1
Mass of drysoil g	147.3	144.2	145.5	133.0	97.8	141.6
Moisture content %	7.3	4.3	7.6	5.7	7.8	6.4

CBR Penetration Determination

Penetration after 96 hrs Soaking Period	Surcharge Weight:-4.55 KG

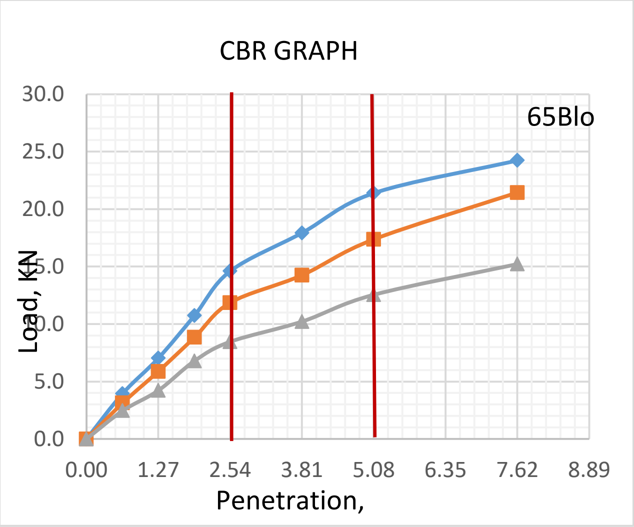
65 Blows				**30 Blows**				**10 Blows**			
Pen.mm	**Load, KN**		**CBR %**	**Pen. mm**	**Load, KN**		**CBR %**	**Pen. mm**	**Load, KN**		**CBR %**
0.00	0.0			0.00	0.0			0.00	0.00		
0.64	3.954			0.64	3.128			0.64	2.456		
1.27	7.023			1.27	5.876			1.27	4.213		
1.91	10.734			1.91	8.834			1.91	6.789		
2.54	14.593		110.55	2.54	11.853		89.80	2.54	8.456		64.06
3.81	17.921			3.81	14.245			3.81	10.212		
5.08	21.385		106.93	5.08	17.365		86.83	5.08	12.543		62.72
7.62	24.231			7.62	21.435			7.62	15.212		

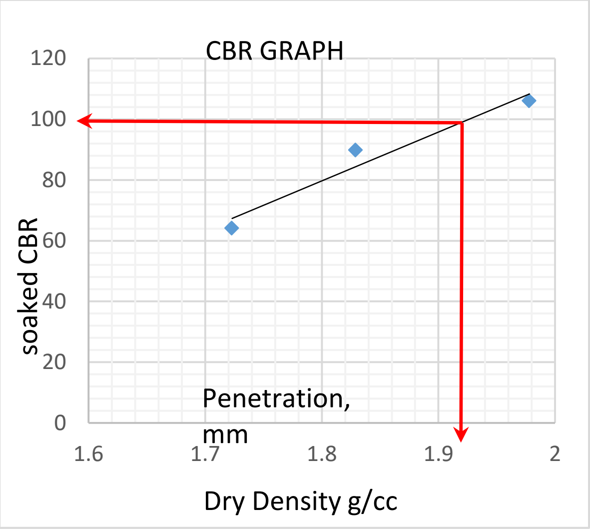
Modified Max.Dry Density g/cc	**1.98**	OMC %	**7.28**

Swell Determination

Date		10 Blows		30 Blows		65 Blows	
		Gauge rdg	Swell in %	Gauge rdg	Swell in %	Gauge rdg	Swell in %
		mm		mm		mm	

15/2/2021	Initial	0.00	0.00	0	0.00	0.00	0.00
19/2/2021	Final	0.00		0.00		0.00	





No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	7.8	1.723	64.1	87	
30	7.6	1.829	89.8	92	
65	7.3	1.978	110.6	100	
CBR (%) @ 98 % MDD			**105.3**	**% Swell**	**0.00**

Table 37 CBR test result of 80% CSA-20%DCA

Compaction Determination							
COMPACTION DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		65B	65B	30B	30B	N7	N7
Mass of wet soil + Mould	g	11298.7	11356.2	10983.7	11204.6	10790.7	10964.3
Mass Mould	g	6915.5	6915.5	7018.7	7018.7	6943.2	6943.2
Mass of Soil	g	4383.2	4440.7	3965	4185.9	3847.5	4021.1
Volume of Mould	g	2124	2124	2124	2124	2124	2124
Wet density of soil	g/cc	2.064	2.091	1.867	1.971	1.811	1.893

Dry density of soil g/cc	1.94	2.00	1.78	1.87	1.69	1.78

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 soil + Container g	193.07	187.34	181.78	173.85	140.10	188.19
Mass of dry soil + Container g	183.88	181.10	174.96	166.30	132.44	179.10
Mass of container g	34.8	36.0	37.7	28.3	26.6	33.0
Mass of water g	9.2	6.2	6.8	7.5	7.7	9.1
Mass of drysoil g	149.1	145.1	137.2	138.0	105.8	146.1
Moisture content %	6.2	4.3	5.0	5.5	7.2	6.2

CBR Penetration Determination

Penetration after 96 hrs Soaking Period

Surcharge Weight:-4.55 KG

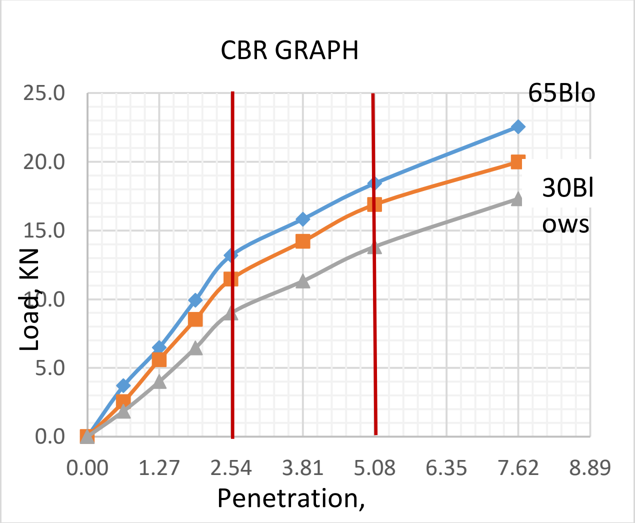
65 Blows				30 Blows				10 Blows			
Pen.mm	**Load, KN**		**CBR %**	**Pen. mm**	**Load, KN**		**CBR %**	**Pen. mm**	**Load, KN**		**CBR %**
0.00	0.0			0.00	0.0			0.00	0.00		
0.64	3.7			0.64	2.5			0.64	1.86		
1.27	6.5			1.27	5.6			1.27	4.01		
1.91	9.9			1.91	8.5			1.91	6.45		
2.54	13.2		99.85	2.54	11.5		86.80	2.54	8.99		68.10
3.81	15.8			3.81	14.2			3.81	11.32		
5.08	18.4		92.14	5.08	16.9		84.44	5.08	13.83		69.13
7.62	22.6			7.62	20.0			7.62	17.31		

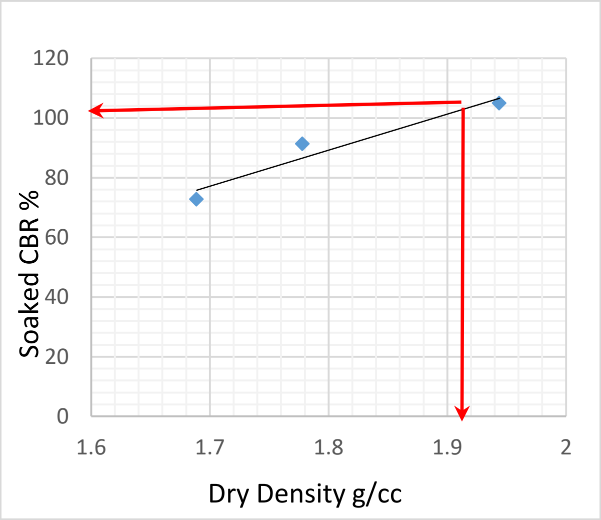
Modified Max.Dry Density g/cc	**1.95**	OMC %	**7.62**

Swell Determination

Date		10 Blows	30 Blows	65 Blows

		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
15/2/2021	Initial	0.00	0.00	0	0.00	0.00	0.00
19/2/2021	Final	0.00		0.00		0.00	





No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	7.2	1.689	69.1	87	
30	5.0	1.778	86.8	91	
65	6.2	1.944	99.9	100	
CBR (%) @ 98 % MDD			**97.3**	**% Swell**	**0.00**

Table 38 CBR test result of 70% CSA-30%DCA

Compaction Determination							
COMPACTION DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		N13	N13	N12	N12	J8	J8
Mass of wet soil + Mould	g	11176.5	11323.9	10974.5	11142.5	10753.1	10932.1
Mass Mould	g	6976.3	6976.3	6941.5	6941.5	7001.6	7001.6

Mass of Soil	g	4200.2	4347.6	4033	4201	3751.5	3930.5
Volume of Mould	g	2124	2124	2124	2124	2124	2124
Wet density of soil	g/cc	1.977	2.047	1.899	1.978	1.766	1.851
Dry density of soil	g/cc	1.88	1.95	1.75	1.87	1.62	1.75

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.		0-2	P3	A2	T1	2	G3T3
Mass of wet soil + Container	g	187.60	175.60	207.40	142.38	212.10	206.30
Mass of dry soil + Container	g	179.55	168.05	193.30	136.24	197.57	197.25
Mass of container	g	28.34	18.00	25.33	25.33	32.89	37.71
Mass of water	g	8.0	7.5	14.1	6.1	14.5	9.1
Mass of drysoil	g	151.2	150.1	168.0	110.9	164.7	159.5
Moisture content	%	5.3	5.0	8.4	5.5	8.8	5.7

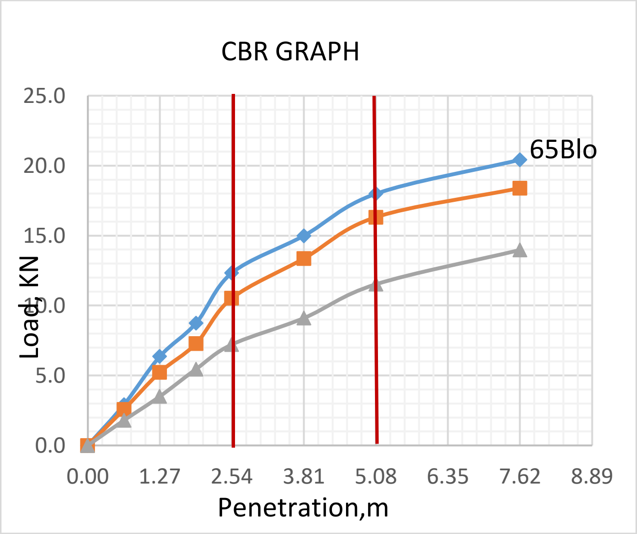
CBR Penetration Determination

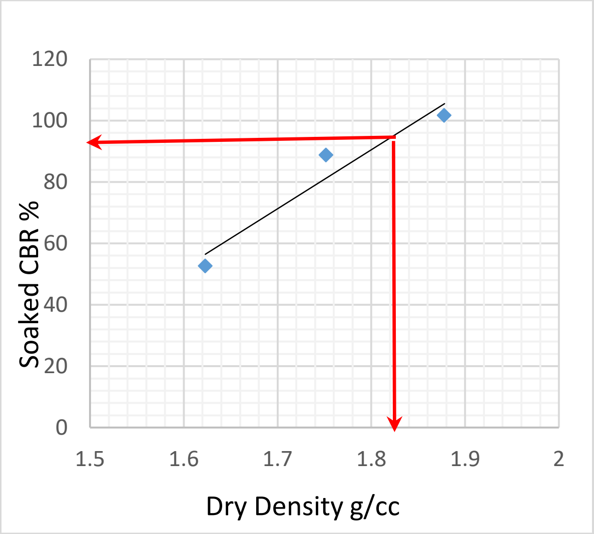
Penetration after 96 hrs Soaking Period	Surcharge Weight:-4.55 KG

65 Blows				30 Blows				10 Blows			
Pen.mm	**Load, KN**		**CBR %**	**Pen. mm**	**Load, KN**		**CBR %**	**Pen. mm**	**Load, KN**		**CBR %**
0.00	0.0			0.00	0.0			0.00	0.00		
0.64	2.9			0.64	2.6			0.64	1.80		
1.27	6.4			1.27	5.2			1.27	3.50		
1.91	8.7			1.91	7.3			1.91	5.46		
2.54	12.3		93.40	2.54	10.5		79.69	2.54	7.22		54.66
3.81	15.0			3.81	13.4			3.81	9.10		
5.08	18.0		89.94	5.08	16.3		81.58	5.08	11.52		57.60
7.62	20.4			7.62	18.4			7.62	13.97		

Modified Max.Dry Density g/cc	**1.88**	OMC %	**5.75**

Swell Determination							
Date		10 Blows		30 Blows		65 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
15/2/2021	Initial	0.00	0.00	0	0.00	0.00	0.00
19/2/2021	Final	0.00		0.00		0.00	





No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	8.8	1.623	57.6	86	
30	8.4	1.752	81.6	93	
65	5.3	1.878	93.4	100	
CBR (%) @ 98 % MDD			**90.1**	**% Swell**	**0.00**

Table 39 CBR test result of 60% CSA-40%DCA

Compaction Determination						
COMPACTION DATA	**65 Blows**		**30 Blows**		**10 Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.	N4	N4	N2	N2	A1	A1

Mass of wet soil + Mould	g	11290.1	11423.5	11008.9	11246	10789.1	10977.2
Mass Mould	g	7016.6	7016.6	6960.6	6960.6	6969.6	6969.6
Mass of Soil	g	4273.5	4406.9	4048.3	4285.4	3819.5	4007.6
Volume of Mould	g	2124	2124	2124	2124	2124	2124
Wet density of soil	g/cc	2.012	2.075	1.906	2.018	1.798	1.887
Dry density of soil	g/cc	1.87	1.88	1.72	1.79	1.58	1.66

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 soil + Container	g	221.3	199.4	209.0	187.7	221.5	234.5
Mass of dry soil + 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 drysoil	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

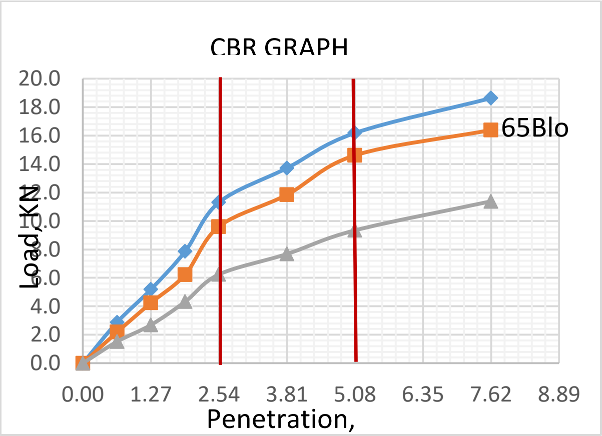
CBR Penetration Determination

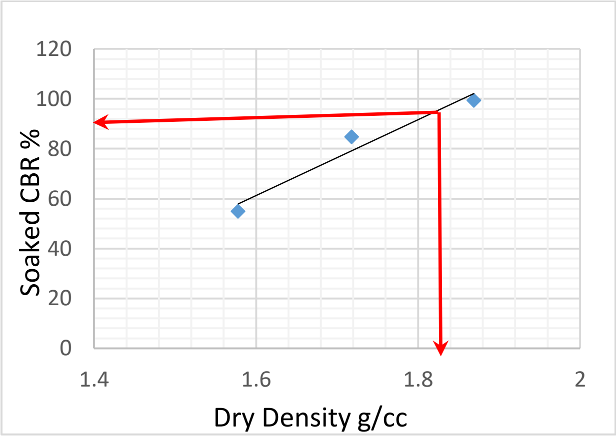
Penetration after 96 hrs Soaking Period				Surcharge Weight:-4.55 KG							
65 Blows				**30 Blows**				**10 Blows**			
Pen.mm	**Load, KN**		**CBR %**	**Pen. mm**	**Load, KN**		**CBR %**	**Pen. mm**	**Load, KN**		**CBR %**
0.00	0.0			0.00	0.0			0.00	0.00		
0.64	2.9			0.64	2.2			0.64	1.52		
1.27	5.2			1.27	4.2			1.27	2.69		
1.91	7.9			1.91	6.2			1.91	4.33		
2.54	11.3		85.62	2.54	9.6		72.77	2.54	6.24		47.27
3.81	13.7			3.81	11.8			3.81	7.68		
5.08	16.2		80.90	5.08	14.6		73.06	5.08	9.34		46.70
7.62	18.6			7.62	16.4			7.62	11.38		

Modified Max.Dry Density g/cc	**1.87**	OMC %	**10.17**

Swell Determination

Date		10 Blows		30 Blows		65 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
15/2/2021	Initial	0.00	0.00	0	0.00	0.00	0.00
19/2/2021	Final	0.00		0.00		0.00	





No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	13.9	1.578	47.3	84	
30	11.0	1.718	73.1	92	
65	7.7	1.869	85.6	100	
CBR (%) @ 98 % MDD			**82.6**	**% Swell**	**0.00**

Table 40 CBR test result of 50% CSA-50%DCA

Compaction Determination

COMPACTION DATA	**65 Blows**		**30 Blows**		**10 Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.	N-12	N-12	N9	N9	M-30	M-30

Mass of wet soil + Mould	g	11156.6	11234.5	10802.5	10949.6	10532.5	10842.3
Mass Mould	g	6965.5	6965.5	6944	6944	6962.5	6962.5
Mass of Soil	g	4191.1	4269	3858.5	4005.6	3570	3879.8
Volume of Mould	g	2124	2124	2124	2124	2124	2124
Wet density of soil	g/cc	1.973	2.010	1.817	1.886	1.681	1.827
Dry density of soil	g/cc	1.85	1.93	1.69	1.78	1.56	1.72

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.		2	G19	A	J41	A16	G61
Mass of wet soil + Container	g	193.07	187.34	181.78	173.85	140.10	188.19
Mass of dry soil + Container	g	183.18	181.10	171.96	166.30	132.44	179.10
Mass of container	g	33.5	32.9	36.6	37.0	36.1	34.8
Mass of water	g	9.9	6.2	9.8	7.5	7.7	9.1
Mass of drysoil	g	149.7	148.2	135.3	129.3	96.4	144.4
Moisture content	%	6.6	4.2	7.3	5.8	8.0	6.3

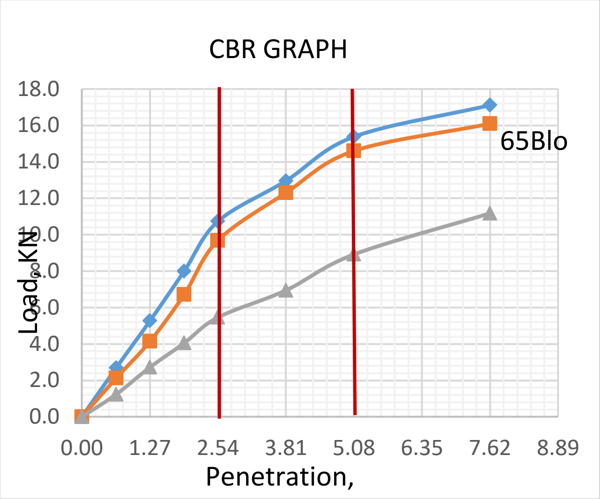
CBR Penetration Determination

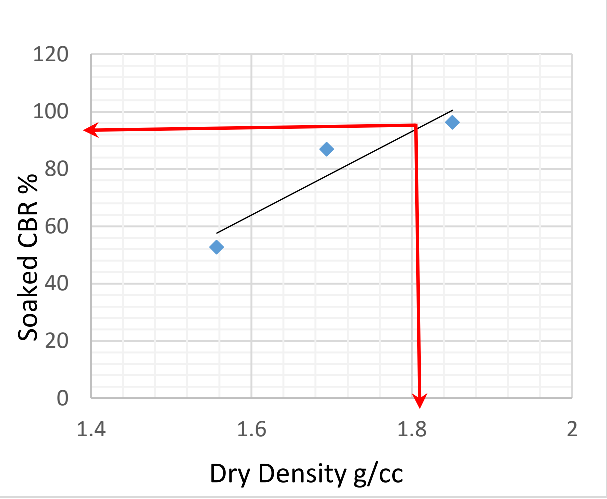
Penetration after 96 hrs Soaking Period				Surcharge Weight:-4.55 KG							
65 Blows				**30 Blows**				**10 Blows**			
Pen.mm	**Load, KN**		**CBR %**	**Pen. mm**	**Load, KN**		**CBR %**	**Pen. mm**	**Load, KN**		**CBR %**
0.00	0.0			0.00	0.0			0.00	0.00		
0.64	2.7			0.64	2.1			0.64	1.23		
1.27	5.3			1.27	4.1			1.27	2.72		
1.91	8.0			1.91	6.7			1.91	4.05		
2.54	10.7		81.32	2.54	9.7		73.37	2.54	5.46		41.36
3.81	13.0			3.81	12.3			3.81	6.94		
5.08	15.4		76.89	5.08	14.6		73.00	5.08	8.92		44.58
7.62	17.1			7.62	16.1			7.62	11.17		

Modified Max.Dry Density g/cc	**1.84**	OMC %	**10.99**

Swell Determination

Date		10 Blows		30 Blows		65 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
15/2/2021	Initial	0.00	0.00	0	0.00	0.00	0.00
19/2/2021	Final	0.00		0.00		0.00	





No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	8.0	1.557	44.6	85	
30	7.3	1.694	73.4	92	
65	6.6	1.851	81.3	101	
CBR (%) @ 98 % MDD			**78.9**	**% Swell**	**0.00**

APPENDIX B: RESULTS OF BLENDED CSA AND CWA

Table B-1 Test result of sieve analysis for 90%CSA-10%CWA

Sieve size (mm)	mass of retain on each seive(g)	Percentage of retained soil	cumulative % of retain soil	percentage of passing particle	ERA Specification for GB1	
					Lower limit	Upper limit
50	0	0.00	0.00	100.00	100	100
37.5	183.1	3.66	3.66	96.34	95	100
20	321.5	6.43	10.09	89.91	80	100
9.5	1513.50	30.27	40.36	59.64	40	60
4.75	1024.53	20.49	60.85	39.15	25	40
2.36	662.10	13.24	74.09	25.91	15	30
0.425	777.80	15.56	89.65	10.35	7	19
0.075	228.50	4.57	94.22	5.78	5	12
pan	288.97	5.78	100.00	0.00		
sum	5000.0	100.00				

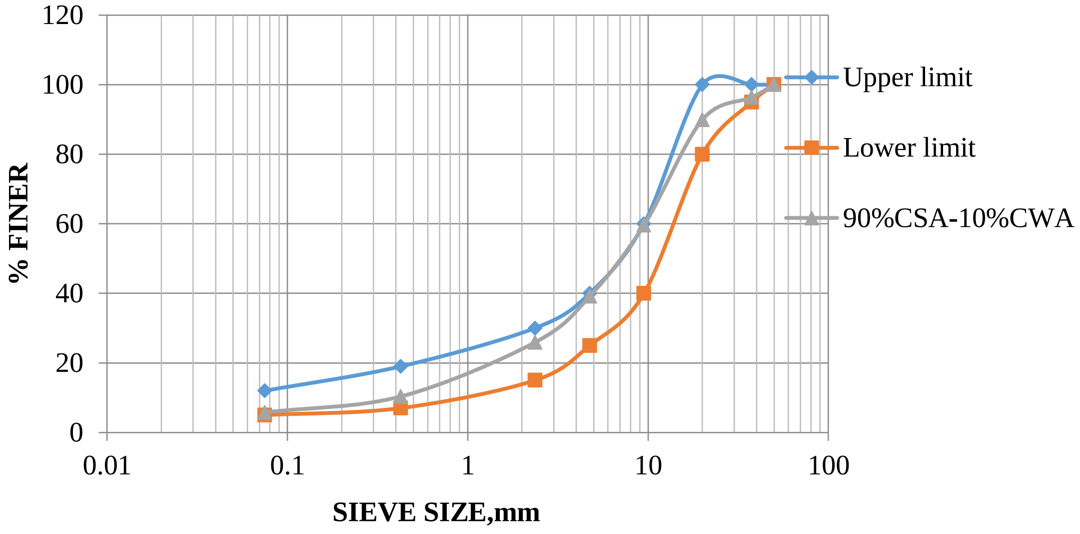


Figure B-1: Particle Size Distribution of 90%CSA-10%CWA

Table B-2 Test result of sieve analysis for 80%CSA-20%CWA

Sieve size (mm)	mass of retain on each seive(g)	Percentage of retained soil	cumulative % of retain soil	percentage of passing particle	ERA Specification for GB1	
					Lower limit	Upper limit
50	0	0.00	0.00	100.00	100	100
37.5	120.6	2.41	2.41	97.59	95	100
20	721.58	14.43	16.84	83.16	80	100
9.5	1466.50	29.33	46.17	53.83	40	60
4.75	889.50	17.79	63.96	36.04	25	40
2.36	395.60	7.91	71.88	28.12	15	30
0.425	561.23	11.22	83.10	16.90	7	19
0.075	385.16	7.70	90.80	9.20	5	12
pan	459.83	9.20	100.00	0.00		
sum	5000.0	100.00				

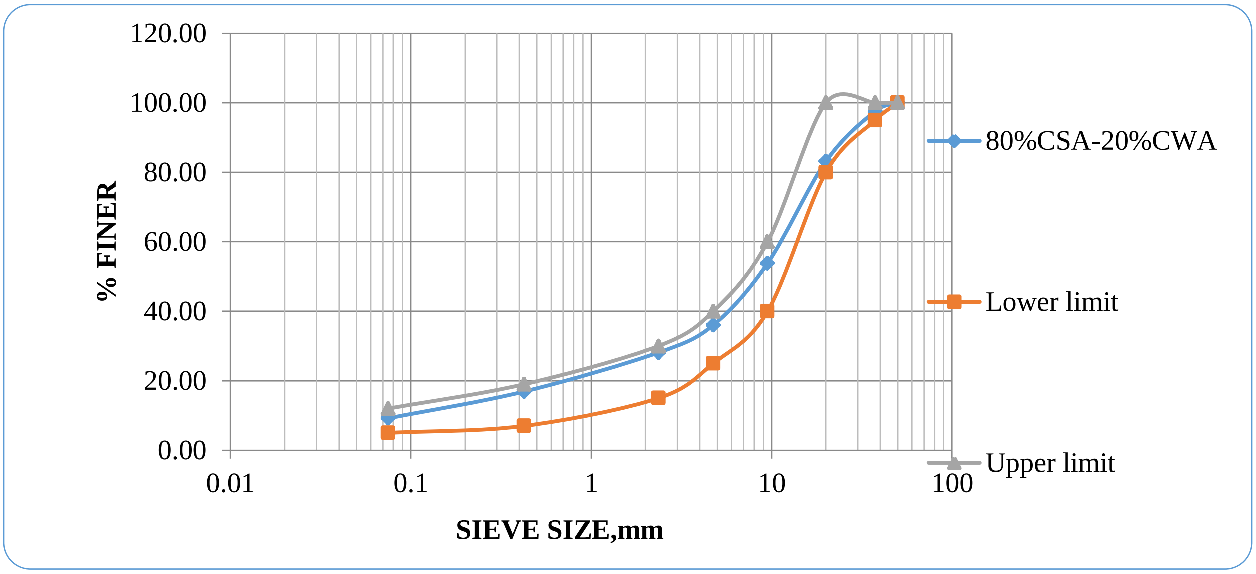


Figure B-2: Particle Size Distribution of 80%CSA-20%CWA

Table B-3 Test result of sieve analysis for 70%CSA-30%CWA

Sieve size (mm)	mass of retain on each seive(g)	Percentage of retained soil	cumulative % of retain soil	percentage of passing particle	ERA Specification for GB1	
					Lower limit	Upper limit
50	0	0.00	0.00	100.00	100	100
37.5	0	0.00	0.00	100.00	95	100
20	259.36	5.19	5.19	94.81	80	100
9.5	1926.30	38.53	43.71	56.29	40	60
4.75	884.50	17.69	61.40	38.60	25	40
2.36	498.94	9.98	71.38	28.62	15	30
0.425	576.35	11.53	82.91	17.09	7	19
0.075	312.25	6.25	89.15	10.85	5	12
pan	542.3	10.85	100.00	0.00		
sum	5000.0	100.00				

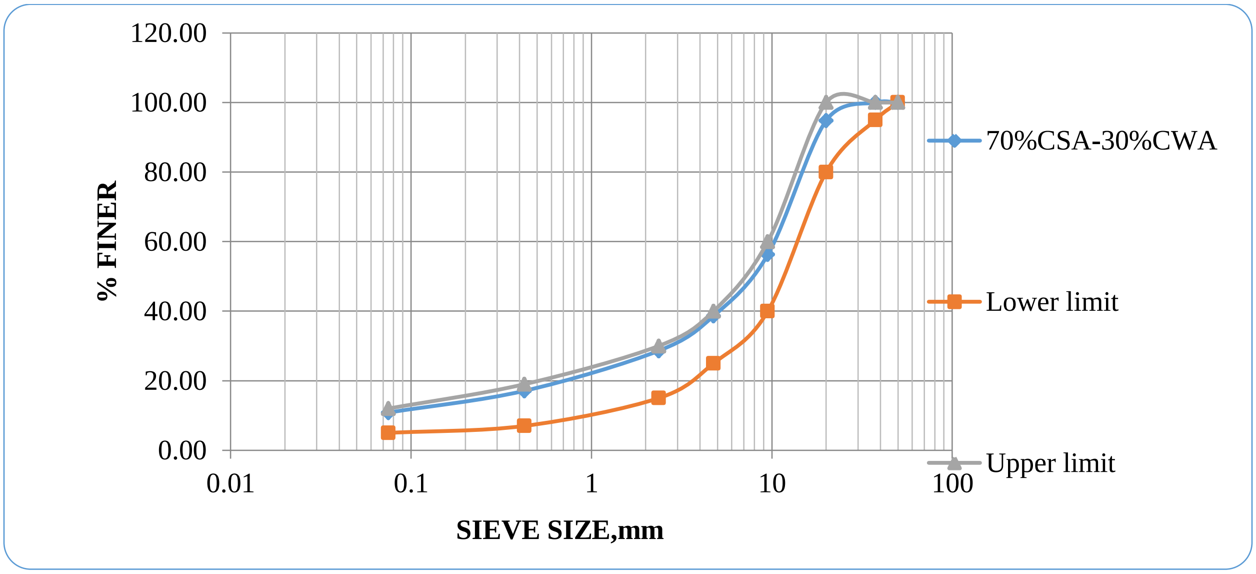


Figure B-3: Particle Size Distribution of 70%CSA-30%CWA

Table B-4 Test result of sieve analysis for 60%CSA-40%CWA

Sieve size (mm)	mass of retain on each seive(g)	Percentage of retained soil	cumulative % of retain soil	percentage of passing particle	ERA Specification for GB1	
					Lower limit	Upper limit
50	0	0.00	0.00	100.00	100	100
37.5	0	0.00	0.00	100.00	95	100
20	150.5	3.01	3.01	96.99	80	100
9.5	1906.50	38.13	41.14	58.86	40	60
4.75	1235.03	24.70	65.84	34.16	25	40
2.36	603.50	12.07	77.91	22.09	15	30
0.425	256.67	5.13	83.04	16.96	7	19
0.075	283.05	5.66	88.71	11.30	5	12
pan	564.75	11.30	100.00	0.00		
sum	5000.0	100.00				

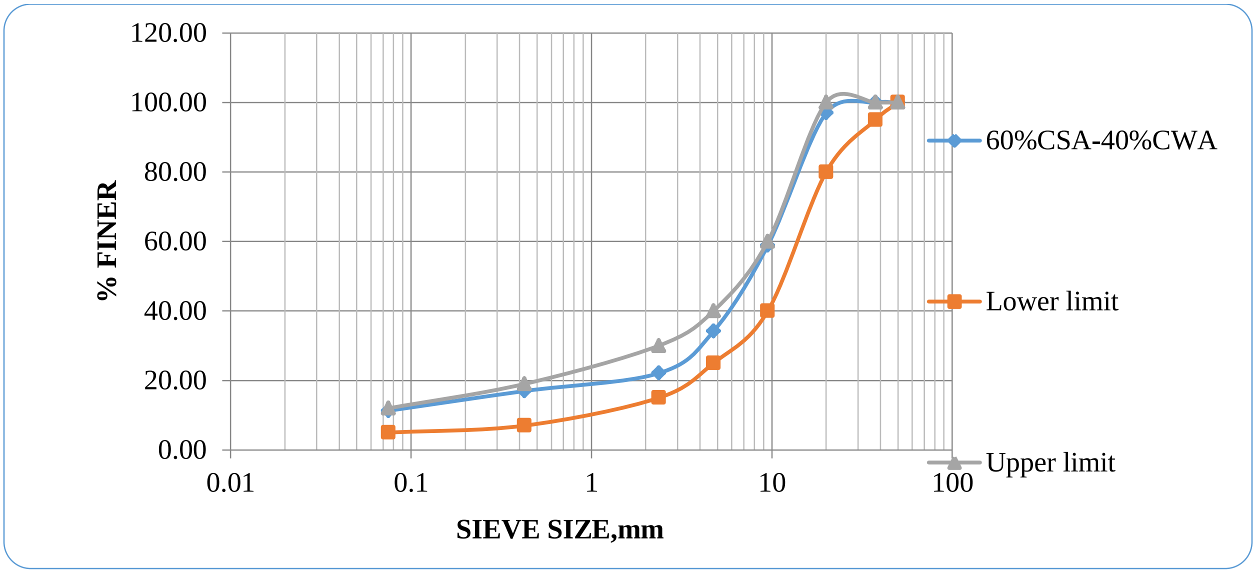


Figure B-4: Particle Size Distribution of 60%CSA-40%CWA

Table B-5 Test result of sieve analysis for 50%CSA-50%CWA

Sieve size (mm)	mass of retain on each seive(g)	Percentage of retained soil	cumulative % of retain soil	percentage of passing particle	ERA Specification for GB1	
					Lower limit	Upper limit
50	0	0.00	0.00	100.00	100	100
37.5	0	0.00	0.00	100.00	95	100
20	335	6.70	6.70	93.30	80	100
9.5	1805.50	36.11	42.81	57.19	40	60
4.75	1159.85	23.20	66.01	33.99	25	40
2.36	454.50	9.09	75.10	24.90	15	30
0.425	425.61	8.51	83.61	16.39	7	19
0.075	223.63	4.47	88.08	11.92	5	12
pan	595.91	11.92	100.00	0.00		
sum	5000.0	100.00				

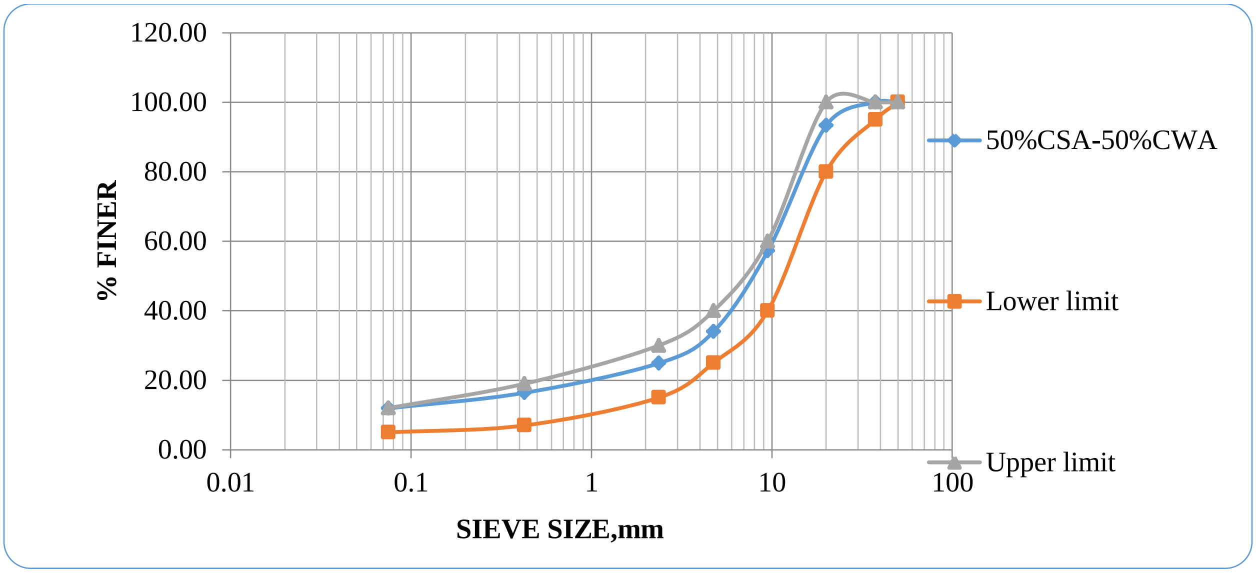


Figure B-5: Particle Size Distribution of 50%CSA-50%CWA

B-2 Specific Gravity and Water Absorption

Table B-6 result of specific gravity and water absorption of 90%CSA-10%CWA

SPECIFIC GRAVITY AND WATER ABSORPTION		
Trial	1	2
Weight of sample , g	3000	3000
Weight of vessel + sample + water (A), g	2525.6	2523.9
Weight of vessel + water (B), g	663.6	663.6
Weight of SSD sample (C) ,g	3032.1	3032.6
Weight of oven dry sample (D),g	2980.5	2981
Bulk Specfic gravity(SSD basis) = C/(C-(A-B))	2.59	2.59
Bulk Specfic gravity(dry basis) = D/(C-(A-B))	2.55	2.54
Apparent specfic gtravity = D/(D-(A-B))	2.66	2.66
water absorption, percentage dry weight (C-D)/D*100	1.73	1.73
average	1.73	

Table B-7 result of specific gravity and water absorption of 80%CSA-20%CWA

SPECIFIC GRAVITY AND WATER ABSORPTION		
Trial	1	2
Weight of sample , g	3000	3000
Weight of vessel + sample + water (A), g	2505.7	2506.1
Weight of vessel + water (B), g	663.6	663.6
Weight of SSD sample (C) ,g	3031.5	3032
Weight of oven dry sample (D),g	2983.6	2983.5
Bulk Specfic gravity(SSD basis) = C/(C-(A-B))	2.55	2.55
Bulk Specfic gravity(dry basis) = D/(C-(A-B))	2.51	2.51
Apparent specfic gtravity = D/(D-(A-B))	2.61	2.61
water absorption, percentage dry weight (C-D)/D*100	1.61	1.63
average	1.62	

Table B-8 result of specific gravity and water absorption of 70%CSA-30%CWA

SPECIFIC GRAVITY AND WATER ABSORPTION		
Trial	1	2
Weight of sample , g	3000	3000
Weight of vessel + sample + water (A), g	2483.1	2484.5
Weight of vessel + water (B), g	663.6	663.6
Weight of SSD sample (C) ,g	3019.6	3019.6
Weight of oven dry sample (D),g	2973.6	2973.6
Bulk Specfic gravity(SSD basis) = C/(C-(A-B))	2.52	2.52
Bulk Specfic gravity(dry basis) = D/(C-(A-B))	2.48	2.48
Apparent specfic gtravity = D/(D-(A-B))	2.58	2.58
water absorption, percentage dry weight (C-D)/D*100	1.55	1.55
Average	1.55	

Table B-9 result of specific gravity and water absorption of 60%CSA-40%CWA

SPECIFIC GRAVITY AND WATER ABSORPTION		
Trial	1	2
Weight of sample , g	3000	3000
Weight of vessel + sample + water (A), g	2472.1	2472.5
Weight of vessel + water (B), g	663.6	663.6
Weight of SSD sample (C) ,g	3017.9	3017.7
Weight of oven dry sample (D),g	2974.5	2974.5
Bulk Specfic gravity(SSD basis) = C/(C-(A-B))	2.50	2.50
Bulk Specfic gravity(dry basis) = D/(C-(A-B))	2.46	2.46
Apparent specfic gtravity = D/(D-(A-B))	2.55	2.55
water absorption, percentage dry weight (C-D)/D*100	1.46	1.45
AVERAGE	1.46	

Table B-10 result of specific gravity and water absorption of 50%CSA-50%CWA

SPECIFIC GRAVITY AND WATER ABSORPTION		
Trial	1	2
Weight of sample , g	3000	3000
Weight of vessel + sample + water (A), g	2465.9	2465.6
Weight of vessel + water (B), g	663.6	663.6
Weight of SSD sample (C) ,g	3015.6	3015
Weight of oven dry sample (D),g	2974.1	2974.1
Bulk Specfic gravity(SSD basis) = C/(C-(A-B))	2.49	2.49
Bulk Specfic gravity(dry basis) = D/(C-(A-B))	2.45	2.45
Apparent specfic gtravity = D/(D-(A-B))	2.54	2.54
water absorption, percentage dry weight (C-D)/D*100	1.40	1.38
Average	1.39	

B-3 Flakiness Index

Table B-11 results of flakiness index of 90%CSA-10%CWA

Sieve size(mm)	Wt. Retained	5% check	Wt. after gauging(**A**)	Wt. pass(**B**)	Wt. retained(**C**)
37.5	0	0	0	0	0
28	1256.53	19.34	732.63	87.67	644.96
20	1263.58	19.45	1089.67	183.65	906.02
14	1326.56	20.42	1024.00	295.76	728.24
10	1524.56	23.47	804.20	227.36	576.84
6.3	1125.65	17.33	270.00	30.74	239.26
Total	6496.88	100.00	3920.50	825.18	3095.32
FI=B/A*100			21.05		

Table B-12 results of flakiness index of 80%CSA-20%CWA

Sieve size(mm)	Wt. Retained	5% check	Wt. after gauging(**A**)	Wt. pass(**B**)	Wt. retained(**C**)
37.5	0	0	0	0	0
28	1249.71	19.23	735.23	94.59	640.64
20	1273.54	19.59	1078.67	187.37	891.30
14	1324.60	20.38	1030.60	304.67	725.93
10	1534.70	23.61	799.72	238.60	561.12
6.3	1116.97	17.19	273.20	36.21	236.99
Total	6499.52	100.00	3917.42	861.44	3055.98
FI=B/A*100			21.99		

Table B-13 results of flakiness index of 70%CSA-30%CWA

Sieve size(mm)	Wt. Retained	5% check	Wt. after gauging(**A**)	Wt. pass(**B**)	Wt. retained(**C**)
37.5	0	0	0	0	0
28	1243.67	19.15	753.67	102.79	650.88
20	1283.27	19.76	1087.21	189.57	897.64
14	1317.60	20.29	1020.57	312.80	707.77
10	1539.30	23.71	790.27	245.78	544.49
6.3	1109.60	17.09	269.31	38.21	231.10
Total	6493.44	100.00	**3921.03**	**889.15**	3031.88
FI=B/A*100			**22.68**		

Table B-14 results of flakiness index of 60%CSA-40%CWA

Sieve size(mm)	Wt. Retained	5% check	Wt. after gauging(**A**)	Wt. pass(**B**)	Wt. retained(**C**)
37.5	0	0	0	0	0
28	1253.67	19.30	747.28	109.32	637.96
20	1272.60	19.59	1097.52	202.43	895.09
14	1325.25	20.40	1032.90	304.28	728.62
10	1531.21	23.58	778.24	252.71	525.53
6.3	1112.21	17.12	275.60	37.31	238.29
Total	6494.94	100.00	**3931.54**	**906.05**	3025.49
FI=B/A*100			**23.05**		

Table B-15 results of flakiness index of 50%CSA-50%CWA

Sieve size(mm)	Wt. Retained	5% check	Wt. after gauging(**A**)	Wt. pass(**B**)	Wt. retained(**C**)
37.5	0	0	0	0	0
28	1262.24	19.43	752.27	115.63	636.64
20	1266.36	19.50	1090.21	210.41	879.80
14	1329.57	20.47	1042.56	315.26	727.30
10	1527.50	23.52	783.25	260.45	522.80
6.3	1109.54	17.08	270.21	40.53	229.68
Total	6495.21	100.00	**3938.50**	**942.28**	2996.22
FI=B/A*100			**23.92**		

B-4 Aggregate crushing value

Table B-16 result of aggregate crushing value of 90%CSA-105CWA

Test No	Mass of sample (A)	Mass of Portion Passing	Aggregate Crushing Value,ACV %	
		B.S 2.36 mm Sieve (B) gm after crushing	individual, (B/A×100)%	Average %
1	2438.9	489.36	20.06	**20.3**
2	2441.95	500.1	20.48	

Table B-17 result of aggregate crushing value of 80%CSA-20%CWA

Test No	Mass of sample (A)	Mass of Portion Passing	Aggregate Crushing Value,ACV %	
		B.S 2.36 mm Sieve (B) gm after crushing	individual, (B/A×100)%	Average %
1	2462.1	535.36	21.74	**21.8**
2	2463.5	536.7	21.79	

Table B-18 result of aggregate crushing value of 70%CSA-30%CWA

Test No	Mass of sample (A)	Mass of Portion Passing	Aggregate Crushing Value,ACV %	
		B.S 2.36 mm Sieve (B) gm after crushing	individual, (B/A×100)%	Average %
1	2439.21	544.6	22.33	**22.3**
2	2437.68	545.29	22.37	

Table B-19 result of aggregate crushing value of 60%CSA-40%CW

Test No	Mass of sample (A)	Mass of Portion Passing	Aggregate Crushing Value,ACV %	
		B.S 2.36 mm Sieve (B) gm after crushing	individual, (B/A×100)%	Average %
1	2429.85	575.9	23.70	**23.6**
2	2431.29	573.41	23.58	

Table B-20 result of aggregate crushing value of 50%CSA-505CW

Test No	Mass of sample (A)	Mass of Portion Passing	Aggregate Crushing Value,ACV %	
		B.S 2.36 mm Sieve (B) gm after crushing	individual, (B/A×100)%	Average %
1	2426.21	605.62	24.96	**24.9**
2	2424.36	603.47	24.89	

B-5 Aggregate impact value

Table B-21 result of aggregate impact value of 90%CSA-10%CWA

Test No	Mass of sample (A)	Mass of Portion Passing	**Aggregate Impact Value(AIV) %**	
		B.S 2.36 mm Sieve (B) gm	individual, (B/A×100)%	Average %
1	672.8	134.54	20.00	**20.2**
2	678.5	138.47	20.41	

Table B-22 result of aggregate impact value of 80%CSA-20%CWA

Test No	Mass of sample (A)	Mass of Portion Passing	**Aggregate Impact Value(AIV) %**	
		B.S 2.36 mm Sieve (B) gm	individual, (B/A×100)%	Average %
1	664.8	143.21	21.54	**21.2**
2	672.3	140.31	20.87	

Table B-23 result of aggregate impact value of 70%CSA-30%CWA

Test No	Mass of sample (A)	Mass of Portion Passing	**Aggregate Impact Value(AIV) %**	
		B.S 2.36 mm Sieve (B) gm	individual, (B/A×100)%	Average %
1	663.54	147.12	22.17	**22.3**
2	665.28	149.48	22.47	

Table B-24 result of aggregate impact value of 60%CSA-40%CWA

Test No	Mass of sample (A)	Mass of Portion Passing	**Aggregate Impact Value(AIV) %**	
		B.S 2.36 mm Sieve (B) gm	individual, (B/A×100)%	Average %
1	657.58	150.31	22.86	**22.8**
2	653.5	147.97	22.64	

Table B-25 result of aggregate impact value of 50%CSA-50%CWA

Test No	Mass of sample (A)	Mass of Portion Passing	**Aggregate Impact Value(AIV) %**	
		B.S 2.36 mm Sieve (B) gm	individual, (B/A×100)%	Average %
1	649.65	155.6	23.95	**23.7**
2	651.5	153.2	23.51	

B-6 Los Angeles abrasion value

Table B-26 Los Angeles test result for 90%CSA-10%CWA

Grading of Test Sample	Fraction and Mass		Total Mass used (g)	Number of Spheres (390-445) g	Mass of Sample Retained on 1.70 mm Sieve (dry) (g)	Loss through 1.70 mm Sieve(g)	los angeles abration value (C/A)	average LAAV
	Fraction	Mass(g)	(A) g		(B) g	(A - B) = C		
B	- 19.0 + 12.5	2500 ± 10	5000	11	4213.43	786.57	15.73	15.64
	- 12.5 + 9.5	2500 ± 10						
	19.0 +12.5	2500 + 10	5000	11	4222.98	777.02	15.54	
	- 12.5 + 9.5	2500 ± 10						

Table B-27 los Angeles test result for 80%CSA-20%CWA

Grading of Test Sample	Fraction and Mass		Total Mass used (g)	Number of Spheres (390-445) g	Mass of Sample Retained on 1.70 mm Sieve (dry) (g)	Loss through 1.70 mm Sieve(g)	los angeles abratio n value (C/A)	average LAAV
	Fraction	Mass(g)	(A) g		(B) g	(A - B) = C		
B	- 19.0 + 12.5	2500 ± 10	5000	11	4198.36	801.64	16.03	16.14
	- 12.5 + 9.5	2500 ± 10						
	19.0 +12.5	2500 + 10	5000	11	4187.31	812.69	16.25	
	- 12.5 + 9.5	2500 ± 10						

Table B-28 Los Angeles test result for 70%CSA-30%CWA

Grading of Test Sample	Fraction and Mass		Total Mass used (g)	Number of Spheres (390-445) g	Mass of Sample Retained on 1.70 mm Sieve (dry) (g)	Loss through 1.70 mm Sieve(g)	los angeles abration value (C/A)	average LAAV
	Fraction	Mass(g)	(A) g		(B) g	(A - B) = C		
B	- 19.0 + 12.5	2500 ± 10	5000	11	4152.37	847.63	16.95	17.01
	- 12.5 + 9.5	2500 ± 10						
	19.0 +12.5	2500 + 10	5000	11	4146.59	853.41	17.07	
	- 12.5 + 9.5	2500 ± 10						

Table B-29 Los Angeles test result for 60%CSA-40%CWA

Grading of Test Sample	Fraction and Mass		Total Mass used (g)	Number of Spheres (390-445) g	Mass of Sample Retained on 1.70 mm Sieve (dry) (g)	Loss through 1.70 mm Sieve(g)	los angeles abration value (C/A)	average LAAV
	Fraction	Mass(g)	(A) g		(B) g	(A - B) = C		
B	- 19.0 + 12.5	2500 ± 10	5000	11	4119.29	880.71	17.61	17.68
	- 12.5 + 9.5	2500 ± 10						
	19.0 +12.5	2500 + 10	5000	11	4112.38	887.62	17.75	
	- 12.5 + 9.5	2500 ± 10						

Table B-30 Los Angeles test result for50%CSA-50%CW

Grading of Test Sample	Fraction and Mass		Total Mass used (g)	Number of Spheres (390-445) g	Mass of Sample Retained on 1.70 mm Sieve (dry) (g)	Loss through 1.70 mm Sieve(g)	los angeles abration value (C/A)	average LAAV
	Fraction	Mass(g)	(A) g		(B) g	(A - B) = C		
B	- 19.0 + 12.5	2500 ± 10	5000	11	4101.23	898.77	17.98	18.01
	- 12.5 + 9.5	2500 ± 10						
	19.0 +12.5	2500 + 10	5000	11	4097.53	902.47	18.05	
	- 12.5 + 9.5	2500 ± 10						

B-7 Moisture-density relation test result

Table B-31 moisture–density relation test result of 90CSA-10CWA

Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	5000	5000	5000	5000
Mass of Mold+Wet soil(gm)(A)	10664.9	10983.6	10926.8	10721.5
Mass of Mold(gm)(B)	6148.8	6148.8	6148.8	6148.8
Mass of Wet Soil(gm)A-B=C	4516.1	4834.8	4778	4572.7
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	2.13	2.28	2.25	2.15
Moisture Content Determination				
Container Code .	A5	B13	CH2	G21
Mass of Wet soil+Container(gm)(F)	142.05	143.87	170.56	159.45
Mass of dry soil+container(gm)(G)	135.52	136.76	158.87	145.42
Mass of container(gm)(H)	33.54	37.95	37.78	34.58
Mass of moisture(gm)F-G=(I)	6.53	7.11	11.69	14.03
Mass of Dry soil(gm)G-H=(J)	101.98	98.81	121.09	110.84
Moisture content % (I/J)*100=K	6.40	7.20	9.65	12.66
Dry Density gm/cm^3 E/(100+K)*100	2.00	2.12	2.05	1.91

Table B-32 moisture–density relation test result of 80CSA-20CWA

Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	5000	5000	5000	5000
Mass of Mold+Wet soil(gm)(A)	10540.9	10843.5	10826.8	10701.5
Mass of Mold(gm)(B)	6148.8	6148.8	6148.8	6148.8
Mass of Wet Soil(gm)A-B=C	4392.1	4694.7	4678	4552.7
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	2.07	2.21	2.20	2.14
Moisture Content Determination				
Container Code .	F12	B3	NH12	C4
Mass of Wet soil+Container(gm)(F)	138.43	138.24	153.25	128.35
Mass of dry soil+container(gm)(G)	133.27	131.52	143.56	118.46
Mass of container(gm)(H)	33.54	37.95	37.78	34.58
Mass of moisture(gm)F-G=(I)	5.16	6.72	9.69	9.89
Mass of Dry soil(gm)G-H=(J)	99.73	93.57	105.78	83.88
Moisture content % (I/J)*100=K	5.17	7.18	9.16	11.79
Dry Density gm/cm^3 E/(100+K)*100	1.97	2.06	2.02	1.92

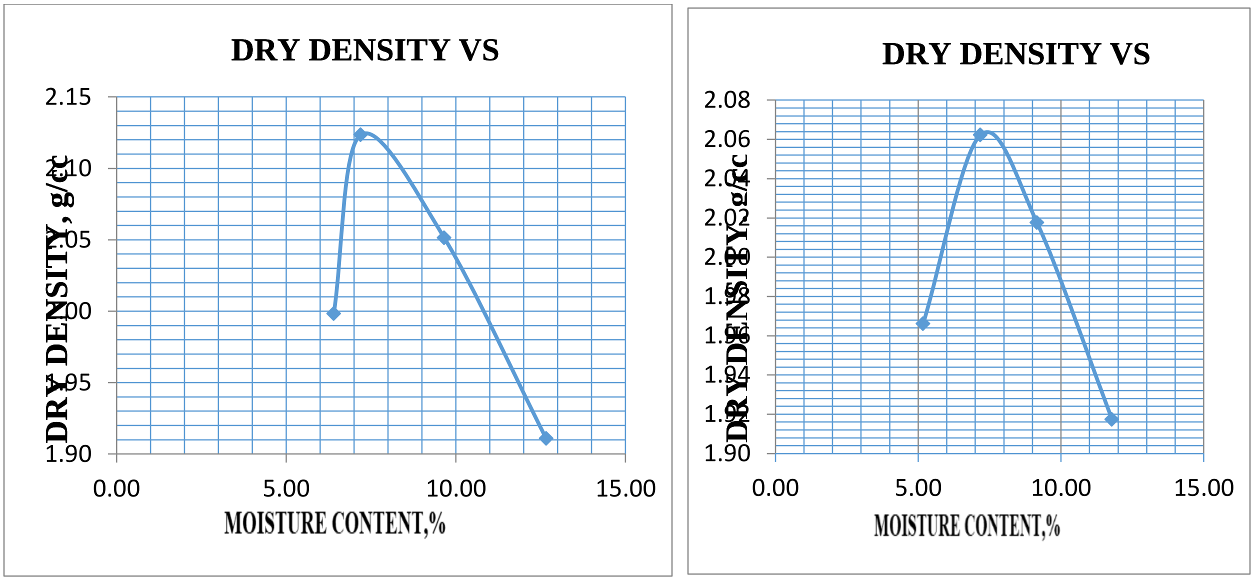


Figure B-6: moisture- density relation curve of blended 90CSA-10CWA and 80CSA-20CWA

Table B-33 moisture–density relation test result of 70% CSA-30%CWA

Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	5000	5000	5000	5000
Mass of Mold+Wet soil(gm)(A)	10440.9	10613.6	10524.3	10401.5
Mass of Mold(gm)(B)	6148.8	6148.8	6148.8	6148.8
Mass of Wet Soil(gm)A-B=C	4292.1	4464.8	4375.5	4252.7
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	2.02	2.10	2.06	2.00
Moisture Content Determination				
Container Code .	P65	A5	C3	NH12
Mass of Wet soil+Container(gm)(F)	142.05	128.06	156.25	154.56
Mass of dry soil+container(gm)(G)	136.22	122.17	146.54	142.87
Mass of container(gm)(H)	33.54	37.95	37.78	34.58
Mass of moisture(gm)F-G=(I)	5.83	5.89	9.71	11.69
Mass of Dry soil(gm)G-H=(J)	102.68	84.22	108.76	108.29
Moisture content % (I/J)*100=K	5.68	6.99	8.93	10.80
Dry Density gm/cm^3 E/(100+K)*100	1.91	1.96	1.89	1.81

Table B-34 moisture–density relation test result of 60% CSA-40%CWA

Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	5000	5000	5000	5000
Mass of Mold+Wet soil(gm)(A)	10216.48	10386.4	10264.86	10186.53
Mass of Mold(gm)(B)	6148.8	6148.8	6148.8	6148.8
Mass of Wet Soil(gm)A-B=C	4067.68	4237.6	4116.06	4037.73
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.92	2.00	1.94	1.90
Moisture Content Determination				
Container Code .	A17	P67	C4	B3
Mass of Wet soil+Container(gm)(F)	140.56	142.69	169.65	143.26
Mass of dry soil+container(gm)(G)	135.52	136.08	157.56	131.58
Mass of container(gm)(H)	33.54	37.95	37.78	34.58
Mass of moisture(gm)F-G=(I)	5.04	6.61	12.09	11.68
Mass of Dry soil(gm)G-H=(J)	101.98	98.13	119.78	97
Moisture content % (I/J)*100=K	4.94	6.74	10.09	12.04
Dry Density gm/cm^3 E/(100+K)*100	1.82	1.87	1.76	1.70

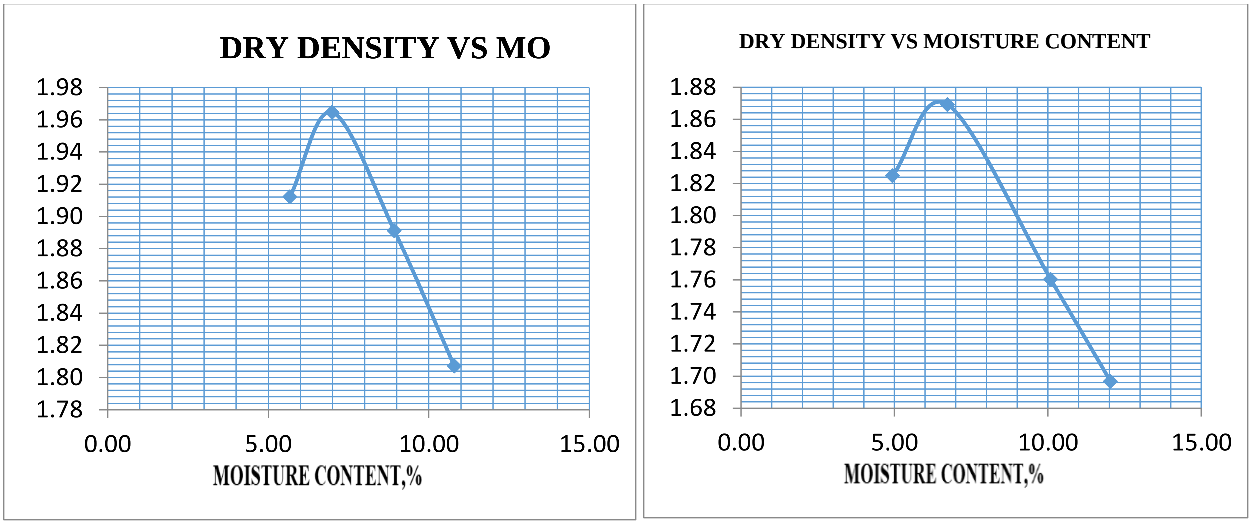


Figure B7: moisture- density relation curve of blended 70%CSA-30%CWA and 60%CSA-40%CWA

Table B-35 moisture–density relation test result of 50% CSA-50%CWA

Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	5000	5000	5000	5000
Mass of Mold+Wet soil(gm)(A)	10134.6	10325.8	10213.4	10137.56
Mass of Mold(gm)(B)	6175.5	6148.8	6148.8	6148.8
Mass of Wet Soil(gm)A-B=C	3959.1	4177	4064.6	3988.76
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.86	1.97	1.91	1.88
Moisture Content Determination				
Container Code .	NH12	P65	P4	B12
Mass of Wet soil+Container(gm)(F)	118.42	165.83	138.46	125.62
Mass of dry soil+container(gm)(G)	114.85	157.44	129.43	116.42
Mass of container(gm)(H)	37.58	33.64	34.67	33.57
Mass of moisture(gm)F-G=(I)	3.57	8.39	9.03	9.2
Mass of Dry soil(gm)G-H=(J)	77.27	123.8	94.76	82.85
Moisture content % (I/J)*100=K	4.62	6.78	9.53	11.10
Dry Density gm/cm^3 E/(100+K)*100	1.78	1.84	1.75	1.69

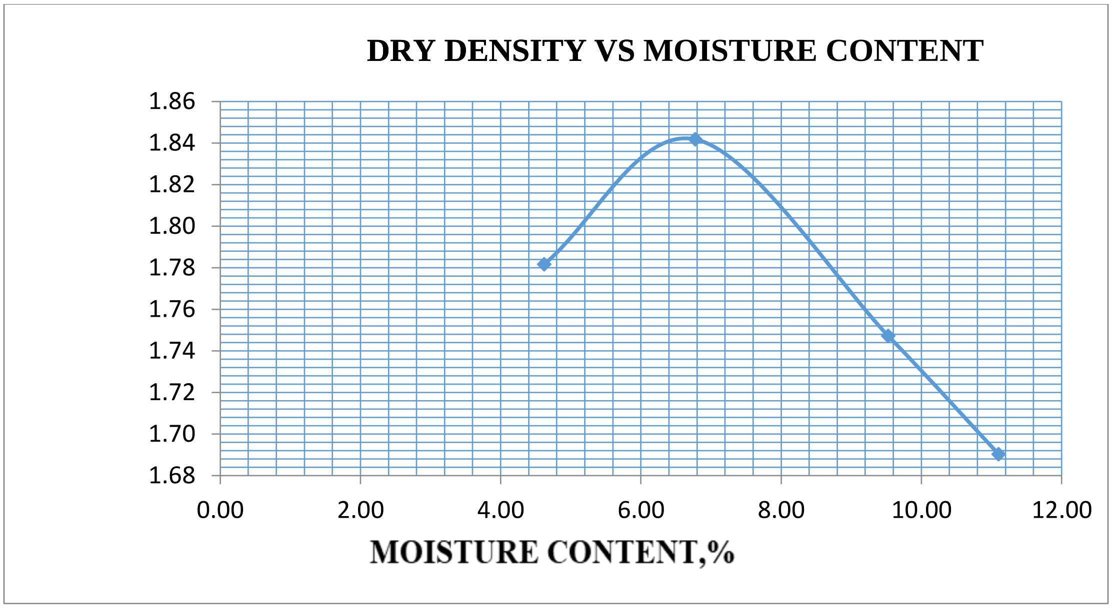


Figure B-8: moisture- density relation curve of blended 50%A-50%C

B-8: CBR test result of CSA and CWA blended

Table B-36: CBR test result for 90%CSA-10%CWA

Compaction Determination						
COMPACTION DATA	**65 Blows**		**30 Blows**		**10 Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.	65B	65B	30B	30B	N7	N7
Mass of wet soil + Mould g	11298.6	11383.7	10996.43	11023.1	10690.7	10864.3
Mass Mould g	6915.5	6915.5	7018.7	7018.7	6943.2	6943.2
Mass of Soil g	4383.1	4468.2	3977.73	4004.4	3747.5	3921.1
Volume of Mould g	2124	2124	2124	2124	2124	2124
Wet density of soil g/cc	2.064	2.104	1.873	1.885	1.764	1.846
Dry density of soil g/cc	1.96	2.02	1.76	1.78	1.65	1.74
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.	2	G19	A	J41	A16	G61
Mass of wet soil + Container g	195.07	187.34	181.78	173.85	140.10	188.19

Mass of dry soil + Container	g	187.38	181.10	172.96	166.30	132.44	179.10
Mass of container	g	34.64	36.10	32.94	32.91	17.66	25.38
Mass of water	g	7.7	6.2	8.8	7.5	7.7	9.1
Mass of drysoil	g	152.7	145.0	140.0	133.4	114.8	153.7
Moisture content	%	5.0	4.3	6.3	5.7	6.7	5.9

CBR Penetration Determination

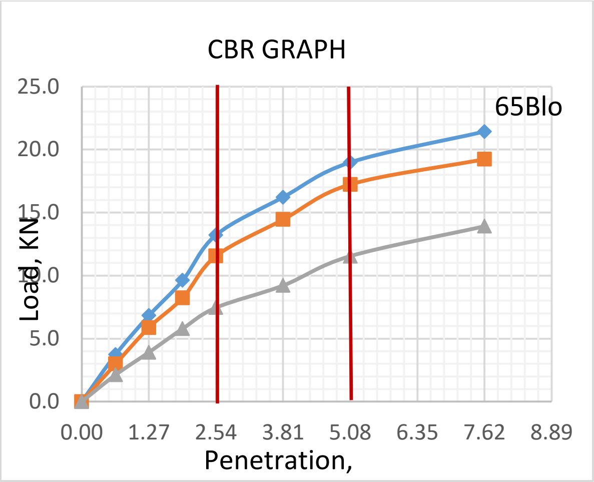
Penetration after 96 hrs Soaking Period — Surcharge Weight:-4.55 KG

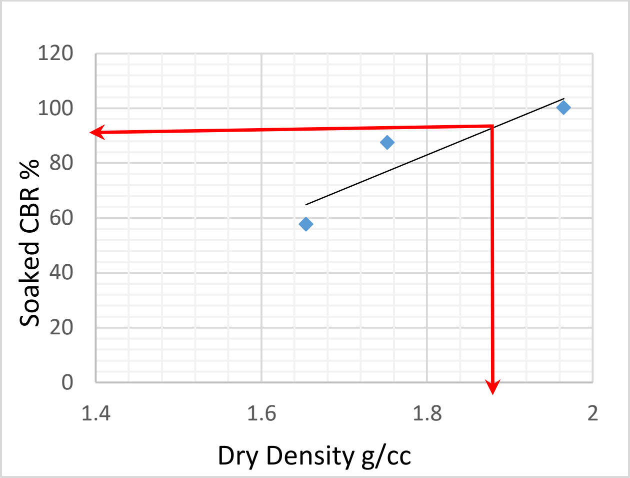
65 Blows				**30 Blows**				**10 Blows**			
Pen.mm	**Load, KN**		**CBR %**	**Pen. mm**	**Load, KN**		**CBR %**	**Pen. mm**	**Load, KN**		**CBR %**
0.00	0.0			0.00	0.0			0.00	0.00		
0.64	3.732			0.64	2.987			0.64	2.123		
1.27	6.821			1.27	5.876			1.27	3.913		
1.91	9.623			1.91	8.234			1.91	5.789		
2.54	13.223		100.17	2.54	11.553		87.52	2.54	7.456		56.48
3.81	16.221			3.81	14.445			3.81	9.212		
5.08	18.985		94.93	5.08	17.231		86.16	5.08	11.543		57.72
7.62	21.431			7.62	19.234			7.62	13.912		

Modified Max.Dry Density g/cc	**1.93**	OMC %	**6.20**

Swell Determination

Date		10 Blows		30 Blows		65 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
15/2/2021	Initial	0.00	0.00	0	0.00	0.00	0.00
19/2/2021	Final	0.00		0.00		0.00	





No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	6.7	1.654	57.7	86	
30	6.3	1.762	87.5	91	
65	5.0	1.965	100.2	102	
CBR (%) @ 98 % MDD			**95.6**	**% Swell**	**0.00**

Table B-37: CBR test result for 80%CSA-20%CWA

Compaction Determination						
COMPACTION DATA	**65 Blows**		**30 Blows**		**10 Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.	N4	N4	N2	N2	A1	A1
Mass of wet soil + Mould g	11320.5	11469.5	11008.5	11221.5	10813.5	10987.6
Mass Mould g	7003.6	7003.6	7004	7004	6913.4	6913.4
Mass of Soil g	4316.9	4465.9	4004.5	4217.5	3900.1	4074.2
Volume of Mould g	2124	2124	2124	2124	2124	2124
Wet density of soil g/cc	2.032	2.103	1.885	1.986	1.836	1.918
Dry density of soil g/cc	1.90	1.96	1.78	1.88	1.70	1.80
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 soil + g	200.87	189.24	181.78	173.85	140.10	188.19

Container							
Mass of dry soil + Container	g	190.38	179.10	172.96	166.30	132.44	179.10
Mass of container	g	37.1	36.9	25.2	33.3	34.7	37.5
Mass of water	g	10.5	10.1	8.8	7.5	7.7	9.1
Mass of drysoil	g	153.3	142.2	147.8	133.0	97.8	141.6
Moisture content	%	6.8	7.1	6.0	5.7	7.8	6.4

CBR Penetration Determination

Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
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	3.9		0.64	2.728		0.64	1.292	
1.27	6.7		1.27	5.463		1.27	2.878	
1.91	9.4		1.91	7.679		1.91	5.263	
2.54	12.4	94.20	2.54	10.409	78.86	2.54	6.961	52.74
3.81	14.8		3.81	12.931		3.81	8.974	
5.08	17.9	89.50	5.08	15.049	75.25	5.08	10.280	51.40
7.62	20.6		7.62	17.533		7.62	11.917	

Modified Max.Dry Density g/cc	**1.91**	OMC %	**5.94**

Swell Determination

Date		10 Blows		30 Blows		65 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
15/2/2021	Initial	0.00	0.00	0	0.00	0.00	0.00
19/2/2021	Final	0.00		0.00		0.00	

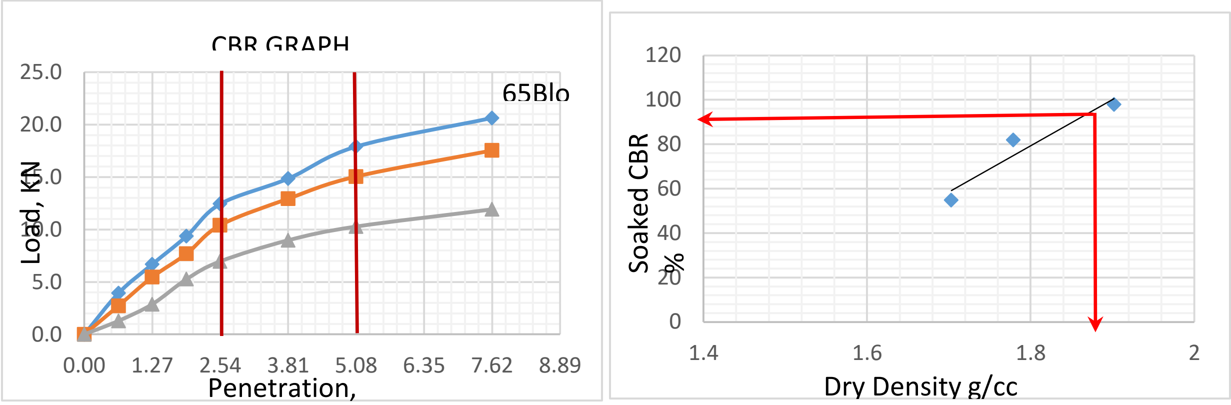


Figure B10: load vs. penetration and CBR vs. dry density of 80%CSA-20%DCA

No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	7.8	1.703	52.7	89	
30	6.0	1.779	78.9	93	
65	6.8	1.902	94.2	100	
CBR (%) @ 98 % MDD			**90.4**	**% Swell**	**0.00**

Table B-38: CBR test result for 70%CSA-30%CWA

COMPACTION DATA	**65 Blows**		**30 Blows**		**10 Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.	N-12	N-12	N9	N9	M-30	M-30
Mass of wet soil + Mould g	11226.6	11334.5	10802	10949.6	10532.5	10842.3
Mass Mould g	6965.5	6965.5	6944	6944	6962.5	6962.5
Mass of Soil g	4261.1	4369	3858	4005.6	3570	3879.8
Volume of Mould g	2124	2124	2124	2124	2124	2124
Wet density of soil g/cc	2.006	2.057	1.816	1.886	1.681	1.827
Dry density of soil g/cc	1.90	1.93	1.72	1.75	1.57	1.63
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 soil + Container g	221.3	197.7	223.7	201.2	223.7	196.5

Mass of dry soil + Container g	211.5	187.2	213.3	189.5	211.3	179.3
Mass of container g	33.5	32.9	36.6	37.0	36.1	34.8
Mass of water g	9.8	10.4	10.3	11.8	12.3	17.2
Mass of drysoil g	178.0	154.3	176.7	152.4	175.3	144.6
Moisture content %	5.5	6.8	5.8	7.7	7.0	11.9

CBR Penetration Determination

Penetration after 96 hrs Soaking Period	Surcharge Weight:-4.55 KG

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	3.2		0.64	2.513		0.64	1.785	
1.27	6.3		1.27	5.371		1.27	2.954	
1.91	8.5		1.91	7.749		1.91	4.483	
2.54	11.5	87.15	2.54	10.325	78.22	2.54	6.112	46.30
3.81	14.2		3.81	12.790		3.81	8.028	
5.08	16.7	83.71	5.08	14.410	72.05	5.08	9.416	47.08
7.62	19.3		7.62	17.062		7.62	11.896	

Modified Max.Dry Density g/cc	**1.88**	OMC %	**5.75**

Swell Determination

Date		10 Blows		30 Blows		65 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
15/2/2021	Initial	0.00	0.00	0	0.00	0.00	0.00
19/2/2021	Final	0.00		0.00		0.00	

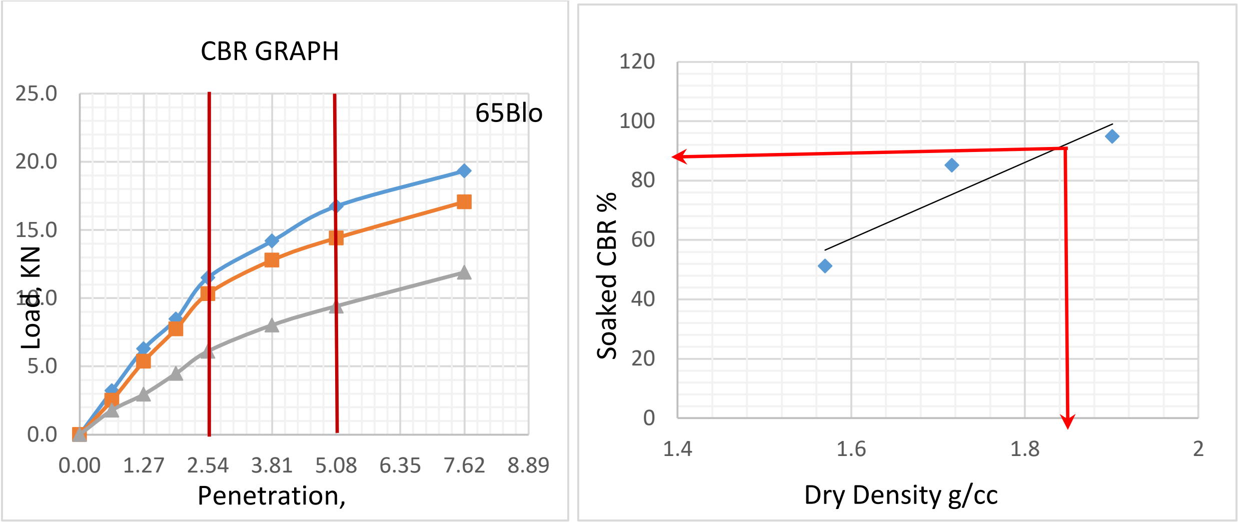


Figure B-11: load vs. penetration and CBR vs. dry density of 70%CSA-30%DCA

No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	7.0	1.570	47.1	84	
30	5.8	1.716	78.2	91	
65	5.5	1.901	87.2	101	
CBR (%) @ 98 % MDD			**84.3**	**% Swell**	**0.00**

Table B-39: CBR test result for 60%CSA-40%CWA

COMPACTION DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		T4	T4	N13	N13	N9	N9
Mass of wet soil + Mould	g	11193.4	11345.6	10987.6	10771.5	10683	10856.7
Mass Mould	g	6950.3	6950.3	6968.6	6968.6	6943.5	6943.5
Mass of Soil	g	4243.1	4395.3	4019	3802.9	3739.5	3913.2
Volume of Mould	g	2124	2124	2124	2124	2124	2124
Wet density of soil	g/cc	1.998	2.069	1.892	1.790	1.761	1.842
Dry density of soil	g/cc	1.84	1.92	1.73	1.63	1.59	1.57
Moisture Determination							
MOISTURE CONTENT		**65 Blows**		**30 Blows**		**10 Blows**	

DATA		**Before soak**	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.		A	P3	A2	T1	2	G3T3
Mass of wet soil + Container	g	221.3	176.5	208.8	187.2	213.4	240.4
Mass of dry soil + Container	g	206.9	166.2	192.8	173.8	196.5	210.0
Mass of container	g	37.1	36.9	25.2	33.3	34.7	37.5
Mass of water	g	14.5	10.3	15.9	13.4	16.9	30.4
Mass of drysoil	g	169.7	129.4	167.6	140.5	161.8	172.5
Moisture content	%	8.5	8.0	9.5	9.5	10.4	17.6

CBR Penetration Determination

Penetration after 96 hrs Soaking Period	Surcharge Weight:-4.55 KG

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	3.6		0.64	2.477		0.64	1.435	
1.27	6.1		1.27	4.960		1.27	2.613	
1.91	8.5		1.91	6.971		1.91	4.757	
2.54	10.7	80.89	2.54	9.800	74.24	2.54	6.670	50.53
3.81	13.5		3.81	12.614		3.81	8.564	
5.08	16.0	79.94	5.08	14.275	71.37	5.08	10.207	51.04
7.62	18.7		7.62	16.792		7.62	12.567	

Modified Max.Dry Density g/cc	**1.83**	OMC %	**5.36**

Swell Determination

Date		10 Blows		30 Blows		65 Blows	
		Gauge rdg	Swell in %	Gauge rdg	Swell in %	Gauge rdg	Swell in %

		mm		mm		mm	
15/2/2021	Initial	0.00	0.00	0	0.00	0.00	0.00
19/2/2021	Final	0.00		0.00		0.00	

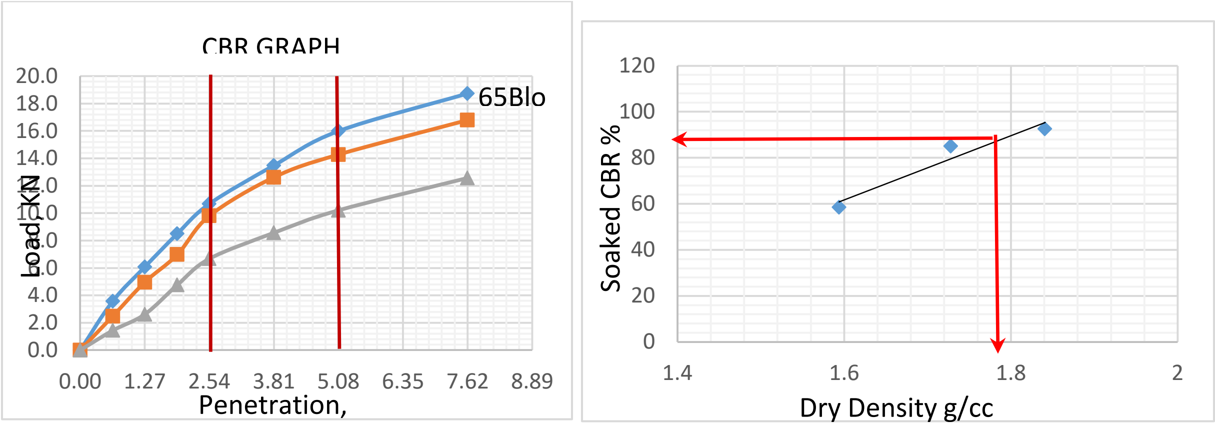


Figure B12: load vs. penetration and CBR vs. dry density of 60%CSA-40%CWA

No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	10.4	1.594	51.0	87	
30	9.5	1.728	74.2	94	
65	8.5	1.841	80.9	101	
CBR (%) @ 98 % MDD			**78.1**	**% Swell**	**0.00**

Table B-40: CBR test result for 50%CSA-50%CWA

COMPACTION DATA	**65 Blows**		**30 Blows**		**10 Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.	M10	M10	N4	N4	I65	I65
Mass of wet soil + Mould g	11093.8	11118.8	10892.1	11040.1	10793.6	10826.5
Mass Mould g	6948.1	6948.1	7015.1	7015.1	6979.1	6979.1
Mass of Soil g	4145.7	4170.7	3877	4025	3814.5	3847.4

Volume of Mould	g	2124	2124	2124	2124	2124	2124
Wet density of soil	g/cc	1.952	1.964	1.825	1.895	1.796	1.811
Dry density of soil	g/cc	1.80	1.78	1.67	1.67	1.63	1.56

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 soil + Container	g	221.3	176.5	208.8	187.2	213.4	240.4
Mass of dry soil + Container	g	206.9	163.2	192.8	168.8	196.5	212.0
Mass of container	g	37.1	36.9	25.2	33.3	34.7	37.5
Mass of water	g	14.5	13.3	15.9	18.4	16.9	28.4
Mass of drysoil	g	169.7	126.4	167.6	135.5	161.8	174.5
Moisture content	%	8.5	10.5	9.5	13.6	10.4	16.3

CBR Penetration Determination

Penetration after 96 hrs Soaking Period	Surcharge Weight:-4.55 KG

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	3.0		0.64	1.926		0.64	1.243	
1.27	5.4		1.27	4.175		1.27	2.491	
1.91	8.0		1.91	6.750		1.91	4.204	
2.54	10.6	80.43	2.54	8.821	66.82	2.54	5.732	43.42
3.81	12.9		3.81	11.133		3.81	7.529	
5.08	15.4	76.88	5.08	12.652	63.26	5.08	8.831	44.15
7.62	17.8		7.62	15.139		7.62	11.156	

Modified Max.Dry Density g/cc	**1.77**	OMC %	**4.71**

Swell Determination

Date		10 Blows		30 Blows		65 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
15/2/2021	Initial	0.00	0.00	0	0.00	0.00	0.00
19/2/2021	Final	0.00		0.00		0.00	

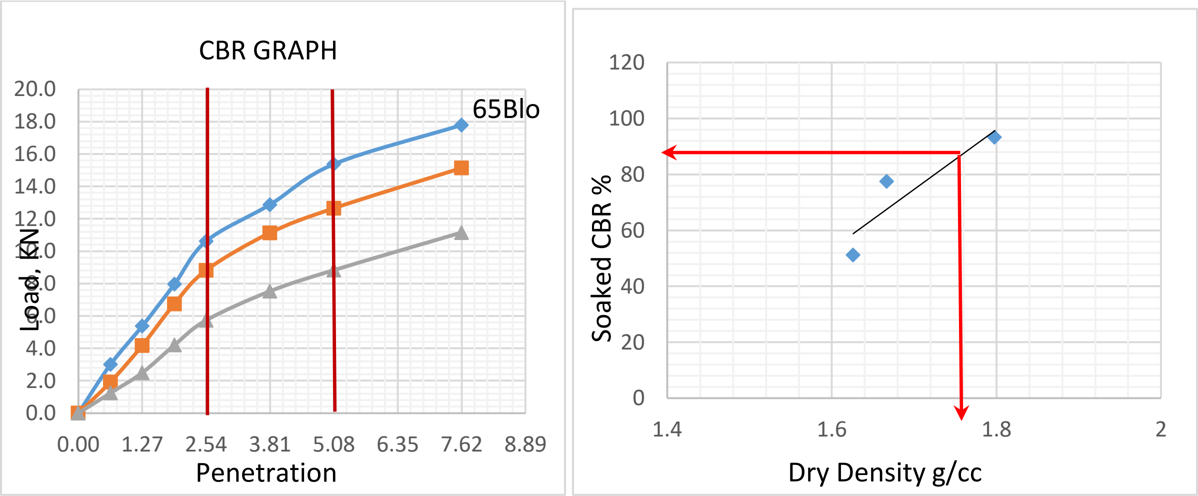


Figure B-13: load vs. penetration and CBR vs. dry density of 50%CSA-50%CWA

No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	10.4	1.626	44.2	92	
30	9.5	1.667	66.8	94	
65	8.5	1.798	80.4	102	
CBR (%) @ 98 % MDD			**73.8**	**% Swell**	**0.00**