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

SUITABILITY OF RECYCLED CONCRETE AND MARBLE WASTES AS CONVENTIONAL AGGREGATES FOR BASE COURSE MATERIAL

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

by

Daniel Gizachew Melese

February 2021
Jimma, Ethiopia

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DECLARATION

I, the undersigned, declare that this thesis entitled:**"Suitability of Recycled Concrete and Marble Wastes as Conventional Aggregates for Base Course Material"**is my original work, and has not been presented by any other person for an award of a degree in this or any other university, and all sources of material used for this thesis have to be duly acknowledged.

Candidate:

Mr. Daniel Gizachew

______________ ___________

Signature Date

As Master's Research Advisors, I hereby certify that I have read and evaluated this MSc Thesis prepared under my guidance by **Mr. Daniel Gizachew** entitled: **"Suitability of Recycled Concrete and Marble Wastes as Conventional Aggregates for Base Course Material**."

Dr.-Inj. FekaduFufa (PhD) ______________ ______________

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Engr. Abel Tesfaye (MSc.) ______________ ______________

(Co-advisor) Signature Date

ABSTRACT

The rate of consumption of natural aggregate increase as the demand for highway construction materials increase and landfills fill up, interest in recycling solid wastes such as demolished concrete and marble waste as conventional aggregate. Using wastes are important to reduce natural aggregate consumption rate and to minimize pollution. Solid wastes that have been considered as aggregate for base course include mineral wastes from mining and mineral processing known as marble waste aggregate and municipal wastes include commercial or household known as recycled concrete aggregate. Using these wastes also enhance some properties of the pavement, hence the aim of this study is to evaluate the suitability of recycled concrete and marble wastes as conventional aggregates for base course material. Sampling population were recycled concrete, marble wastes and suchlike solid wastes materials. Samples of recycled concrete and marble waste were collected from Addis Ababa city, demolished Samsung building and Ethiopian Marble Processing Enterprise, respectively. Purposive sampling techniques and experimental sampling design were used in this study. Laboratory tests were conducted to determine engineering properties such as gradation, specific gravity and water absorption, California bearing ratio (CBR), aggregate crushing value (ACV), aggregate impact value (AIV), loss Angeles abrasion value (LAV), plasticity, angularity, flakiness and elongation index of recycled concrete and marble wastes. To achieve these blend (0:100, 20:80, 50:50, 80:20 and 100:0)RCA and CA as well blend (0:100, 20:80, 50:50, 80:20, and 100:20) MWA and CA were conducted. Blend 80:20 RCA and CA engineering properties obtained are Gs, W, FI, EI, ACV, AIV,LAA and CBR with corresponding values of 2.21, 9.3%, 26.3, 21.8, 22.9, 15.9, and 15.5, 106% respectively with well graded gradation. Blend 80:20 MWA and CA engineering properties obtained are Gs, W, FI, EI, ACV, AIV,LAA and CBR with corresponding values of 2.68, 0.57%, 22.4, 17.4, 24.9, 16.2, and 19.7, 99%, respectively with well graded gradation. The finding of the study shows that both materials can be as conventional aggregates for base course. However, further research has needed particularly on long term field performance of both materials.

Keywords: *recycled concrete aggregate, marble waste aggregate, CBR.*

ACKNOWLEDGEMENT

Foremost my deepest gratitude goes to my advisor Dr.-Inj. Fekadu Fufa (PhD), for his genuine and valuable assist, professional guidance, valuable advice, endless encouragement, and contribution throughout the progress of this research starting from the topic, development of the writing of this thesis paper. Next, I express my thanks to my co-advisor Engr. Abel Tesfaye (MSc.) for his effort in guiding me through the preparation of this research.

I am also thankful for all workers of the Jimma Institute of Technology Highway Material laboratory for permitting me to conducted my laboratory work effectively.

Above all, thanks to Almighty God for his limitless support through my study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BSI	British Standard Institute
CA	Conventional Aggregate
DOT	Department of Transportation
EMA	Ethiopian Map Agency
ERA	Ethiopian Road Authority
FHWA	Federal Highway Administration
FRAP	Fractionated Recycled Asphalt Pavement
FRG	Fine Recycled Glass
HD	Highway Design
IS	Indian Standard
IRC	Indian Road Corporation
MWA	Marble Waste Aggregate
NA	Natural Aggregate
NMPS	Nominal Maximum Particle Size
RCA	Recycled Concrete Aggregate
RPDG	Road Pavement Design Guide

CHAPTER ONE

INTRODUCTION

1.1 Background

The construction sector is characterized by a significant demand for both energy and raw materials with aim of reducing the demand for natural sources and minimizing pollution (Pepe, 2015). In this regard, several studies have been recently proposed from abroad for understanding the behavior of construction made with different types of recycled aggregates(Meyer, 2009). Among them a clear focus was placed on using aggregates derived from the demolition of concrete members and structures, generally referred to as Recycled Concrete Aggregates(Neil, 2013). In fact, huge volumes of waste concrete can be derived from construction demolition and rehabilitation projects, concrete testing laboratories, and from constructions damaged or collapsed as a result of human- induced actions or natural disasters, such as earthquakes (EDCW, 2014).

Many countries and international establishments have been working for new regulations on how to minimize and reuse the generated waste. 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(Huseyin, 2007).Currently, there are more than fourteen marble processing plants in Ethiopia located in different towns most of them around Addis Ababa (Yager, 2013). Particularly in the construction sector, the usages of marble commodities are increased. As the production in the marble factories increases, its waste could not be stored due to huge volume, thus pollute the environment. So, recycling and re use of waste material have become crucial in terms of protection of the environment and the human health (Tahmoorian, 2018). Marble waste is one of the materials which can be reused for the pavement construction purpose (Abed, 2016).

The findings from the study show that the recycled concrete and marble wastes may be useful for construction of transportation infrastructure such as pavements in different parts of world. Many African countries like Egypt also giving infrastructural laws for increasing the use of recycled aggregate (Wagih, 2013).

Using of demolished concrete and marble waste as a recycled material is not yet known in Ethiopia. This may be due to availability of natural aggregate nowadays, or it may be due to unavailability of enough research done on recycling.The rate of consumption of natural aggregate is increasing as the demand for different construction industries is increasing and landfills fill up, it is wise recycling solid wastes such as demolished concrete and marble waste as conventional aggregate. Using wastes are important to reduce natural aggregate consumption rate and to minimize pollution.

Conventional aggregate is expensive; hence, the use of demolished concrete and marble waste aggregate, when there are locally available and close to the highway project they can be used as partial replacement of conventional aggregate. Using wastes for road construction should be encouraged due to the following reason, exploitation of natural resources can be minimized, transportation costs of aggregate from quarries to site can be minimized, construction and demolition wastes to be dumped in landfill can be reduced thus reducing the demand for land, reduce cost of crushing and processing the material. Further, if the material can be process on site, fuel consumption and related transportation costs are reduced (Surya, 2013).

Generally, recycling and re use of waste materials are often less expensive than the virgin materials they replace and use these waste makes good economic sense for project owners and contractors. Putting industrial waste materials such as marble waste aggregate, ceramic waste aggregates to use in construction projects will solve several environmental problems, on one hand avoiding the extraction of large quantities of raw materials from the earth and by reducing the landfill areas that would be occupied by these wastes. Therefore, it is important to see an alternative mineral aggregate material in order to save the environment (Arabian, 2017).

Using these wastes reduce natural aggregate consumption rate and minimize pollution and also enhance some properties of the pavement. Hence, this study is to investigate the suitability of recycled concrete and marble waste aggregates which are derived from construction demolition and marble industries during the marble processing, respectively as conventional aggregates for base course material.

Therefore, the aim of this study is to investigate engineering properties recycled concrete and marble of wastes as conventional aggregate for base course materials. Hence, various engineering properties of recycled concrete aggregate and marble waste aggregate were discussed and compared with ERA standard specification.

1.2 Statement of Research Problem

The rate of consumption of natural aggregates is increasing as the demand for different construction industries is increasing (Behiry, 2013). Huge volumes of waste concrete can be derived from construction demolition and rehabilitation projects, concrete testing laboratories, and from constructions damaged in many parts of the country including Addis Ababa are uneconomical and environmentally unfriendly. Therefore, it is essential to recycle concrete waste for road construction due to construction and demolition wastes to be dumped in landfill can be reduced thus reducing the demand for land, reduce cost of crushing and processing the material.

Besides, the waste generated from the marble industries during the process of cutting and polishing was increasing day by day all over the world(Huseyin, 2007).In Ethiopia 409,374.00, 572,421.00, 613,820.00, 770,000.00 and 1,000,000.00 m^2 of marble commodities were produced in the year 2009, 2010, 2011, 2012 and 2013 respectively (Yager, 2013).Disposal of this massive waste materials cause pollution of environment. So, recycling and re use of these waste materials has become crucial in terms of the protection of the environment and human health (Tahmoorian, 2018).

This demand for dumping land and transportation cost is uneconomical and environmentally unfriendly. The increasing price of land in recent years has led to high dumping costs at landfill sites, particularly in Addis Ababa city, Ethiopia where most of construction works and marble processing plants are located. Considering all the aforementioned problems, this aims study to evaluate the suitability of using recycled concrete and marble wastes as conventional aggregates for base coarse material.

1.3 Research Questions

1. What are the engineering properties of recycled concrete and marble waste of solid wastes?
2. What is the strength of recycled concrete and marble waste as conventional aggregate base course material?
3. How much recycled concrete and marble waste deviate from ERA standard specification base course?

1.4 Objectives

1.4.1 General Objective

The general objective of the study was to evaluate the suitability of recycled concrete and marble wastes as conventional aggregates for base course material.

1.4.2 Specific objectives

The specific objectives were:

- to determine the engineering properties of recycled concrete and marble waste of solid wastes;
- to analyze the strength of recycled concrete and marble waste as conventional aggregates base course; and
- to evaluate the suitability of recycled concrete and marble waste by comparing with ERA standard specification base course.

1.5 Scope and Limitations of the study

This study was limited to evaluate the suitability of recycled concrete and marble waste as conventional aggregate for base coarse material. The engineering properties of these materials as base layer of pavements were compared based on different standards including of ERA, AASHTO, IS, ASTM and BS standards.

Engineering properties used to evaluate the suitability of recycled concrete and marble waste as conventional aggregate are gradation, specific gravity and water absorption, California bearing ratio (CBR), aggregate crushing value (ACV),ten percent fines value (TFV), aggregate impact value (AIV), Loss Angeles abrasion value (LAV), plasticity, angularity, flakiness and elongation index.

1.6 Significance of the study

The finding of this study would be essential to urban area of Ethiopia particular Addis Ababa city which is the capital city of Ethiopia where high construction works done and marble processing plant to improve the management of solid waste disposal problem. This study would be used to reduce natural aggregate consumption rate and to minimize pollution. Large amount of waste concrete and marble are disposed of in our country every day. But, it is not considered for any value rather than it is disposed as garbage, but it is a good source for road construction industry as secondary material. ERA would be benefited in particular to upgrade the highway construction materials in Ethiopia. This study would be help to reveal for researchers to know this waste material can be reused for pavement construction purpose.

CHAPTER TWO

LITERATURE REVIEW

2.1 Highway Pavements Design

Highway pavements are divided into two main categories: rigid and flexible. The wearing surface of a rigid pavement usually is constructed of Portland cement concrete such that it act like bridge over any irregularities in the underlying supporting material. The wearing surface of flexible pavements, on the other hand, usually is constructed of bituminous materials such that they remain in contact with the underlying material even when minor irregularities occur. Flexible pavements usually consist of a bituminous surface under laid with a layer of granular material and a layer of a suitable mixture of coarse and fine materials. Traffic loads are transferred by the wearing surface to the underlying supporting materials through the interlocking of aggregates, the frictional effect of granular materials, and cohesion of fine materials (Tutumluer, 2013).

The essential difference between two types of pavements is the manner in which they distribute load over the sub grade. The strength of the rigid pavement is contributed mainly by concrete slab unlike flexible pavements where successive layers of the pavement contributed cumulatively. Also in flexible pavement, the strength of sub grade soil would have a direct bearing on the total thickness of the pavement as shown in Figure2.1(Mathew, 2009). According to highway design manual no sub-base is required if the sub grade is composed of hard rock or of a granular material with a CBR of at least 30%, in this case the base course improve the load carry capacity of the sub grade by distributing the load over a large area.

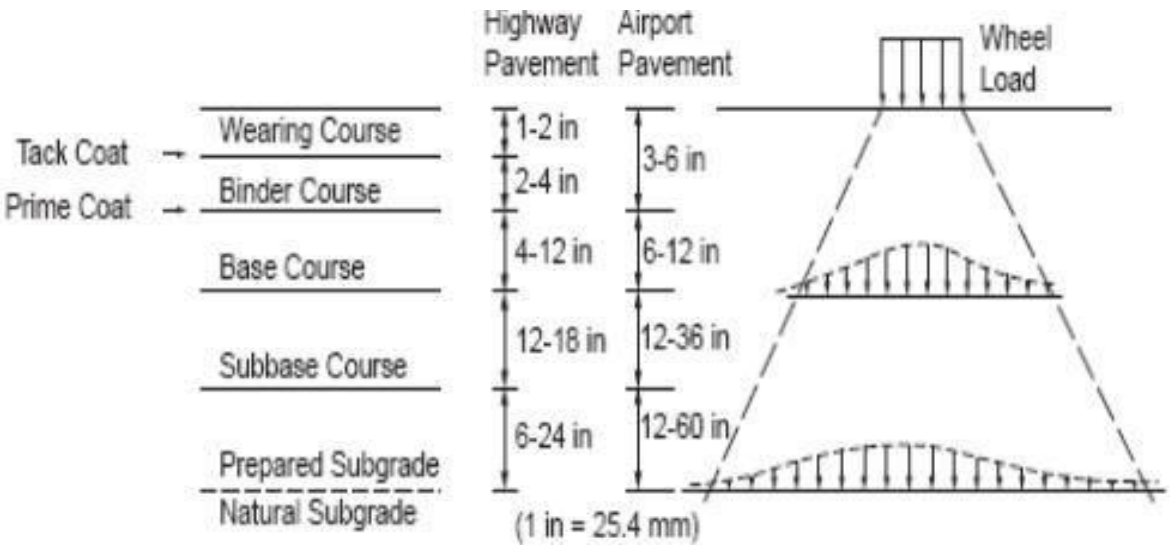


Figure 2.1 Load transfer mechanism of flexible pavement(Source: RPDG)

2.2 Aggregate and their property

2.2.1 Aggregate

"Aggregate" is a glossary of base course terms sand, crushed block of marble, crushed demolition concrete and suchlike solid wastes materials(ERA, 2013). Aggregates can either be natural, manufactured or recycled. Recycled aggregates are generally recycled from solid wastes materials through crusher in similar situation as natural aggregate.

Aggregates take up the major portion of base course and prime materials used. Aggregate for base course shall consist of hard, durable particles or fragments of crushed stone, crushed slag or crushed or natural gravel and filler of natural or crushed sand or other finely divided mineral matter. The material shall be of such nature that it can be compacted readily to form a firm, stable base. The suitability of base course material for use depends primarily on the design traffic level of the pavement and climate. For higher class of traffic base course can be bituminous and material stabilized with cement or lime may also be considered(DPWH, 2004).

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 considerable significance to the highway engineers.

2.2.2 Properties of Aggregate

Strength:-the aggregates to be used in road construction should be sufficiently strong to withstand the stresses due to traffic wheel loads. The aggregates which are to be used in top layer of the pavements, particularly in the wearing course have to be capable of withstanding high stresses in addition to wear and tear; hence they should possess sufficient strength and resistance to crushing (ERA, 2013).

Hardness:-the aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving traffic. They should be hard enough to resist the wear due to abrasive action of traffic.

Toughness:-aggregates in the pavements are also subjected to impact due to moving wheel loads. Jumping of the steel tyre wheels from one stone to another at different levels cause severe impact on the stones. The magnitude of impact would increase with the roughness of the road surface, the speed of the vehicle and other vehicular characteristics. The resistance to impact or toughness is hence another desirable property of aggregates (ERA, 2013).

Durability:-the stone used in the pavement construction should be durable and should resist disintegration due to the action of weather. The property of the stones to withstand the adverse action of weather may be called soundness. The aggregates are subjected to the physical and chemical action of rain and ground water, the impurities there-in and that of atmosphere. Hence it is desirable that the road stones used in the construction should be sound enough to withstand the weathering action (EDCW, 2014).

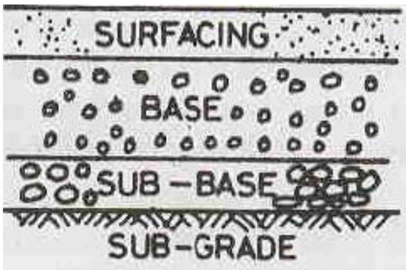
Shape of aggregates:-the size of the aggregates is first qualified by the size of square sieve opening through which an aggregate may pass, and not by shape. Aggregates which happen to fall in a particular size range may have rounded cubical, angular flaky or elongated shape of particles. It is evident that the flaky and elongated particles will have less strength and durability when compared with cubical, angular or rounded particles of the same stone. Hence too flaky and too much elongated aggregates should be avoided as far as possible. The voids present in a compacted mix of coarse aggregates depend on the shape factors. Highly angular, flaky and elongated aggregates have more voids in comparison with rounded aggregates. The shape of aggregates is generally described in terms of its shape factors such as flakiness index, elongation index and angularity number. Many researches also show that, recycled concrete aggregates have good angularity (Mark, 2016).The types of tests and required properties of road aggregates are shown in Table 2.1.

Table 2.1 Tests on Road Aggregates and Properties Evaluated

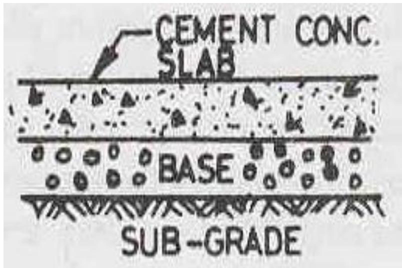
SL No.	Type of test	Required property
1	Aggregate impact test	Toughness or resistance to impact
2	Los Angeles Abrasion Test	Hardness or resistance to abrasion
3	Aggregate Crushing Test	Strength or resistance to crushing
4	Soundness/Durability/Accelerated weathering test	Durability or resistance to weathering
5	Shape test: Flakiness Index, Elongation Index and Angularity Number	Assessment of suitable shape or shape factors of coarse aggregates
6	Specific gravity Test	To measure the quality or strength of material
7	Water absorption Test	To measure the porosity

2.3 Structural Components of Flexible and Rigid Pavements

As Figure 2.2 (a) shows the components of flexible pavements are: the sub grade or prepared roadbed, the sub-base, the base, and the wearing surface. The performance of the pavement depends on the satisfactory performance of each component, which requires proper evaluation of the properties of each component separately. As the concrete layer is quite strong in rigid pavement which is made of cement concrete, the sub-base may not be required as shown in Figure 2.2 (b). The strength of the pavement is contributed mainly by concrete slab because of its rigidity and high modulus of elasticity(Arora, 2003).



(a)



(b)

Figure 2.2 (a) Flexible Pavement(Source: ARORA)(b) Rigid Pavement(Source: ARORA)

2.3.1 Base Course

The function of base course varies according to the types of pavement. In rigid pavement, the base course increase foundation support and reduces stresses and deflection tolerance, and improves joint load transfer. Therefore, cracking and faulting potential are reduced(Hall, 2005). Mindess (2003) note that base course is used to minimize the damaging effects of frost action, prevent pumping of fine-grained soils at joints, cracks and edges of the rigid pavement and to provide a working plat form for construction equipment. In flexible pavement, base course is an important load spreading layer. It spread the wheel loads to the sub-base and enables traffic stresses to be reduced to acceptable levels in the sub grade so that improve the load supporting capacity of the sub grade by distributing the load over a large area (Reta, 2018). Besides this other functions of base course include resistance to the built-up of permanent deformation within each layer so that the underlying materials are not overstressed(Mathew, 2009).

2.4 History of Recycled Concrete Aggregate and Marble Processing

In the 1990, the necessity of preserving natural resources and increasing landfill space, inclined Australian authorities to start the technology of using RCA in lightly traffic road construction. In 2004 and 2005, South Australia was generating around 1.5 million tons of construction and demolished waste which just 70% of this waste was recovered. In recent years, over 500 million kg of RCA are produced annually in South Australia mostly from building demolition waste, and a significant proportion of this is used in pavement construction (Gabr, 2012). In Europe, from 1945 to 2000, around 600×10^6 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 was used in base and sub-base layers of Finland's road construction (Gabr, 2012). 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(FHWA, 2004). Thereafter, in United States, over 130×10^6 tons of construction and demolition (C&D) waste is produced each year which around 70% of RCA produced is used in pavement construction and particularly as a granular material in base layers(Gabr,2012).

According to the Ethiopian Marble industry profile, Italian investors primarily established marble processing industry called "Ethiopian Marble Processing Enterprise" established many years back. It was during the time of Italian occupation, a man known as Signore Loliva Cesare, who set up the first marble processing plant in Gullelie area, with the name of "Ethio Marble" the pioneer of the processing plant started producing Marble for the purpose of monuments, tiles and window sills. In 1961 E.C the raw materials for Marble products were supplied from Asmara, Mekele and Harar quarries(Negesse, 2018).

Currently, there are more than fourteen marble processing plants in Ethiopia located indifferent towns most of them around Addis Ababa. Namely, Ethiopian marble industry, Debay granite and marble industry, Three M marble and terrazzo industry, Yayhaa marble industry, City marble industry, Souriish marble PLC, Firdows marble company, Alisha marble company, Gelan marble, AL Marge marble and granite, Tsegaye marble products and processing plant, Edel granite and marble, Halal tiles and marble, Samo marble industry, Weri marble industry, FMG fabrica marble and granite, Bekele Berhane Wondim, Berta Construction PLC, Ethiopian Marble processing Enterprise, Rift valley Gemstones Import and Export, Saba Dimensional Stones PLC, Tis Abay International PLC, Anteneh Worku Hiruy, Kara Marble Processing Enterprise. Assaes Marble PLC, D.M.C Marble Plc, Ethiopian Marble Industry, Negat United Construction, and Sam Marble Industry (Yager, 2013).

In Ethiopia, 3,365,615 metric squares of marble commodities were produced from the year 2009 to 2013(Yager, 2013). This implies that the amount of marble waste increase as more marble processing companies produce more amount of marble block. From the history here in Ethiopia, there is not practice to reuse the waste concrete and marble.

2.5 Advantages of Using Recycled Concrete Aggregate and marble waste

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 FHWA(2004), recycled concrete aggregate (RCA) have the following advantages.

2.5.1 Angularity

RCA have good angularity and this in turn helps to increased structural strength in the base, resulting in improved load carrying capacity; building pads (residual cementation), provides a strong, durable platform for which to build upon and better control over gradation, in this RCA is able to meet gradation and angularity requirements.

2.5.2 Resource Conservation

Reduced land disposal and dumping: The use of recycled concrete pavement eliminates the development of waste stockpiles of concrete. Also, since recycled material can be used within the same metropolitan area, this can lead to a decrease in energy consumption from hauling and producing aggregate, and can help improve air quality through reduced transportation source emissions.

Conservation of virgin aggregate: Using recycled aggregates substituting the virgin materials. The use of recycled aggregate serve as an environmentally friendly and economically viable solution. Many European countries have placed a tax on the use of virgin aggregates. This process is being used as an incentive to recycle aggregates. It is noted that several states have high tipping fees for disposal of RCA this is done to control landfill usage thus increasing the reuse of RCA.

Reduce impacts to the landscape: The reuse of concrete demolition debris reduces unsightly stockpiles of concrete rubble, animal infestation of stockpiles, and an overall environmental improvement when re-used.

Metal recovery: The removal of metal, steel reinforcement is an important step in the recycling process and can take place in several stages. Contractors usually remove continuous reinforcement on the grade, whereas dowel and tie bar removal is typically done at the plant. Most crushing plants have an electromagnet to catch steel moving along the conveyor belt between the primary and secondary crushers. Salvaged steel usually becomes the property of the crushing plant and is sold as scrap metal. Wire mesh steel generally found in reinforced concrete pipe retains a large quantity of bonded concrete and usually becomes waste.

2.5.3 Economic advantage

Limit haul distance: Recycled concrete is crushed and the entire aggregate product can be used as a base material according to specifications, therefore generating no waste. This can be done on the project site or at nearby recycling plants, eliminating the transportation to distant disposal sites and the hauling in of virgin aggregate. In an urban environment, concrete debris is hauled to a crushing site that is generally closer to the center of the urban area then the virgin aggregate quarry. In some cases, the two operations cohabitate. Industry comments were that the RCA stockpile is usually closer to the job sites in an urban environment, thus less haul distance is less fuel burnt in delivery. Production of virgin aggregate can use more fuel to crush due to larger initial size of rock needing to be crushed to desired grade.

Reduce disposal costs: Disposal of concrete rubble and other waste construction materials by dumping or burial is a less attractive and more expensive option. Reconstruction of urban streets and expressways results in an enormous amount of waste concrete being generated and creating a massive disposal problem. Recycling can therefore alleviate some of these problems and offer savings to the owner agencies in terms of material acquisition and disposal costs.

Overall project savings: There may be considerable project savings by using a less amount of virgin aggregate. This saving is increased by the reduction of transportation and disposal costs. Another economic benefit is the recovery of steel from the recycling process. This material usually becomes property of the contractor, who can sell as scrap metal. There is also potential for cost savings in many areas where aggregates are not locally available, and have to be hauled long distances, often 50 miles or more. Environmental impacts reduction and extending available life of landfills is also a long-term benefit that can be experienced by local governments due to increased recycling of RCA.

2.5.4 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 (FHWA, 2007).

Alexandru(2019) in study mentioned that reconstruction of urban streets and expressways results in an enormous waste concrete, creating a massive disposal problem. 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 (Huseyin, 2007). Massive disposal of this waste material will cause pollution of environment such as water logging, reduces the porosity of soils, and increases in alkalinity of soils, which results in soil fertility and other health problem (Arabian, 2017). Therefore, it is essential to recycle concrete and marble waste for road construction.

2.6 Studies and Findings on Recycled Concrete and Marble Waste

A final research report prepared by APT(2011) state that, when held to the same specifications as natural aggregates, CCA (Crushed Concrete Aggregate) can perform very well as a base material and can be used without design adjustments. The report also indicates that CCA exhibits highly angular properties, which contribute to a strong and stable base. According to this report, untreated CCA bases can even behave like cement-treated bases due to the hydration of un reacted cement exposed during CCA processing.

Mahony(1990)observes that the use of recycled aggregate in highway construction would produce two major benefits, it would supplement the supply of natural aggregates so extending the life expectancy of existing quarries and delaying the need to open new quarries and the rate of consumption of landfill space and the dumping of demolition material on common or derelict land may be reduced.

From this research, it can be understood that the use of clean, graded brick or concrete aggregate in the construction of a road sub-base appears to be accepted in several European countries including Belgium, Germany and The Netherlands. This is particularly true in Holland which has poor reserves of natural aggregate and so has become dependent on recycled material for the construction of unbound aggregate road layers. Recycling is subsidized by the government with the aggregate having to pass certain specifications before it can be used as a sub-base aggregate. Therefore, due to this necessity the recycling of demolition waste has become an important source of aggregate for the Dutch construction industry.

Arulrajah(2012) consider a comprehensive laboratory evaluation of the geotechnical properties of five predominant types of construction and demolition (C&D) wastes materials. The C&D materials tested were recycled concrete aggregate (RCA), crushed brick (CB), Waste Rock (WR), Reclaimed asphalt pavement (RAP), and Fine Recycled Glass (FRG). The geotechnical assessment included particle size distribution, particle density, water absorption, compaction, Los Angeles abrasion, post-compaction sieve analysis, flakiness index, hydraulic conductivity, and California bearing ratio (CBR) tests. Shear strength properties of the materials were studied through a series of tri axial tests. In terms of usage in pavement sub-bases, RCA and WR were found to have geotechnical engineering properties equivalent or superior to that of typical natural granular sub-base materials. CB at the lower target moisture contents of 70% of the OMC was also found to meet the requirements of typical quarry granular sub-base materials. The properties of CB, RAP, and FRG, however, may be further enhanced with additives or mixed in blends with high quality aggregates to enable their usage in pavement sub-bases(Arisha, 2016).

Arulrajah(2012) investigate the recycled crushed brick when blended with recycled concrete aggregate and crushed rock for pavement sub-base applications and observe that the Los Angeles abrasion loss of RCA is durable &CBR values were found to satisfy road authority requirements for sub-base material. Fabiana(2011) in study mention that CBR of crushed concrete was similar to that of natural aggregate. Conversely, demolition debris presented a fairly decrease in its CBR.

Water absorption capacity of RCA varies depending on the amount of cement paste attached to the surface of the aggregate particles (Pepe, 2015). As a consequence the higher water absorption capacity of RCA results higher porosity of RCA. Surya(2013) prove that water absorption capacity of RCA is 6.5 times higher than that of NA. Park(2001)observe the physical and compaction properties of two different recycled aggregates obtained from a housing redevelopment site (RCA1) and a concrete pavement rehabilitation project (RCA2). The bulk specific gravity and water absorption values were 2.53 and 2.54 and 1.43 and 1.77% for RCA1 and RCA2, respectively. The optimum moisture contents were found to be 9, and 12.8%, and the corresponding dry densities were 2.21 $t/m^3$and 1.81 t/m^3 for RCA1 and RCA2, respectively. (Park, 2001)in the study mentioned that optimum moisture content increased with an increase in water absorption of the aggregates.

According to Ahmed(2015), the RCA materials has higher CBR and resilient modulus than the regular GAB materials due to presence of higher CaO content. Based on the results obtained from the performance tests carried out on recycled concrete aggregate (RCA) for use as a base or sub-base material under hot mix asphalt pavements and as an aggregate in Portland cement concrete pavements. Chini(2001) observes that the mechanical properties of RCA concrete decrease as the ratio of coarse RCA to virgin aggregate (VA) increase in the mix. Compared to VA concrete, the 100% RCA concrete was about 82% in compressive strength, 96% in tensile strength, 81% in flexural strength and 86% in modulus of elasticity for lab prepared samples. Despite having lower compressive strength than VA concrete, 100% RCA concrete had a 28-day compressive strength of 35 MPa, which is well above the target strength of 25 MPa.

Park(2001)conclude that RCA has satisfactory mechanical properties and can be a valuable alternative material for use in highway base or sub-base construction. In fact, different authors report that the RCA is suitable for a premium base course product where high stress applications are required (Leek, 2010). Herrador(2011) in study from the experimental investigation verifying the possibility of exploiting construction waste as material for the base in road construction.

Bairagi(1990) study the properties of recycled aggregates obtained by crushing M15 grade natural aggregate concrete and concluded that the grading curve of the recycled coarse aggregate as well as of the natural coarse aggregate do not differ appreciably except that former type of aggregate possess lower specific gravity, higher water absorption capacity and significantly low resistance to mechanical action such as impact and crushing.

Amnon(2003)investigate the properties of the recycled aggregates made from crushed concrete and report that the properties of the recycled aggregates crushed at different ages were quite similar. It was also reported that the size distribution of the recycled aggregates was same for the various ages of crushing, as well as other properties such as water absorption, bulk specific gravity, bulk density, cement content and crushing value.

Besides, different types of marble waste are generated during the processing of marble and categorized as dressing waste, cutting waste and polishing waste. There are also waste marbles generated during Quarrying of marble including overburden, side burden, inter burden, ungraded material and undersize material(Mamta,2013). The waste generated during marble processing and quarrying are used by different researchers as a material for construction both in road and building construction by replacing conventional construction materials.

According to Huseyin(2007),waste aggregates produced from marble during quarrying and processing could be used as construction material in low-traffic asphalt pavement layers. Helena(2011)in study mentioned that the marble quarry waste resulting from marble rock show good characteristics to be used as aggregate in sub-base, particularly if mixed with a traditional aggregate in an 80/20 proportion in weight. The physical properties of marble quarry waste for a mixture of 80/20 obtained from laboratory test are Relative density (26.5kN/m^3), Absorption (1.1%), LAA (38-39%), Maximum dry density (2.29%), Optimum moisture content (5.5%) and Sand equivalent (51%). Therefore, the use of marble quarry may be of local importance, both in replacing traditional aggregates and decreasing the environmental impact linked with the multiple places where the waste is dumped.

According to Kinde(2017), using marble waste in paving mixes may give a solution to the marble waste utilization and disposal problems and also give the means to make the environment safe and clean plus in their study mention that mixtures containing marble waste powder have higher film thickness around aggregate particles than mixes containing Portland cement and have high durability.According to Kofteci(2014),100% marble waste aggregate can be used as fine aggregates in hot mix asphalt as a binder layer.

Generally, Using wastes such as concrete waste generated by demolition and marble waste generated from marble processing can be reused for the pavement construction purpose.

2.6.1 General Properties of Recycled Concrete Aggregate

Table 2.2 shows that the typical properties of RCA. Chlorides have been found in RCA due to corrosion of embedded steel and set times. However, chlorides and other chemicals present in RCA should not cause problems when it is unbound base layers (ACPA, 2009). Alkali-silica reactivity is a result of an undesirable chemical reaction between alkalis in cement paste and reactive siliceous components of susceptible aggregate. The product of the reaction is a gel that expands significantly in the presence of moisture, destroying the integrity of the weakened aggregate particle and the surrounding cement paste. However, the alkalinity rapidly decreases with time, and is not considered a major concern although some vegetation may be destroyed where runoff is discharged directly from RCA base (Hiller, 2011).

Freeze- thaw durability refers to the resistance of the hardened concrete to repeated freeze-thaw cycles while in a saturated state (Van Dam, 2009). The freeze-thaw durability of RCA is dependent on a number of factors, including the characteristics of the original aggregate source and the entrained air-system in the concrete (Ryu, 2009).

Absorption capacity is a measure of the amount of water that an aggregate can absorb. RCA generally have higher absorption capacity than natural materials, primarily due to the porous nature of the cement paste fraction in the reclaimed concrete (MDOT, 2012). Specific gravity is a measure of the density of an aggregate relative of water. RCA particles generally have low specific to the reclaimed mortar bound to the RCA particles, which is less dense than most natural aggregates due to its porosity and entrained air strucure (MDOT, 2012).

Table 2.2 Typical RCA properties(ACPA, 2009)

Property	RCA
Particle shape and Texture	Angular with rough surface
Absorption capacity (%)	3.7-8.7
Specific gravity	2.1-2.4
LAA Abrasion (%)	20-45
Sodium sulfate (%)	18-59
Magnesium sulfate (%)	1-9
Chloride content (kg/m^3)	0.6-7.1

2.6.2 Properties of Marble waste aggregate

2.6.2.1 Chemical properties of marble waste aggregate

The rock marble is metamorphosed limestone. It is composed largely of the mineral calcite(Calcium carbonate). It will thus behave like limestone - giving off CO2 when in contact with hydrochloric acid. It will also give off CO2 when ground down to a powder and heated to high temperatures(Kinde, 2017).

Table 2.3 Typical Chemical properties of marble waste aggregate(Kinde, 2017)

Chemical Composition	% Content
Lime(CaO)	28-32
Silica(SiO2)	3-30
Alumina($A1_2O_3$)	1-4
MgO	15-25
FeO +Fe2O3	1-3
Loss on Ignition(LOI)	20-45

2.6.2.2 Physical properties of marble waste aggregate

Table 2.4 Typical Physical properties of marble waste aggregate(Kinde, 2017)

Physical Properties	Marble waste aggregate
Density (Kg/m^3)	2.55 - 2.7
Hardness	3 - 4 Moh's Scale
Compressive strength (N/mm^2)	70 - 140
Modulus of rupture (N/mm^2)	12 - 18
Water absorption (%)	<0.5
Porosity	Very low
Weather impact	Resistant

2.7 Blending Aggregates

The blending of two or more aggregates is to obtain different aggregate properties. It is the ability to mix aggregates to meet a specified target. Asphalt concrete requires the combining of two or more aggregates, having different gradations, to produce an aggregate blend that meets gradation specifications for a particular asphalt mix.

Blending involves the mixing of materials that have different properties (typically particle size

distribution) to form a material with characteristics that improve upon the limitations of the source materials. In most instances, blending will involve adding coarse aggregates to the finer in situ material. Less common the addition of fine material to in situ sandy or coarse aggregates to fill voids and obtain a denser gradation (Reta, 2018).

2.8 Standards

Under this sub-topic, different standards like ERA, ASTM, AASHTO, BS, and IS are discussed in detail along with their specification for different aggregate tests like gradation, specific gravity, water absorption, California bearing ratio value(CBR), ten percent fines value(TFV), aggregate impact value(AIV), aggregate crushing value (ACV), aggregate shape value & loss angels abrasion value of the aggregate.

Particle size distribution /Gradation/: ERA 2013, *Section 6.1.1 of Chapter 6*, Table 6.2, recommends alternate particle size distribution limits for Base materials as shown in Table 2.5. Gradation limits of nominal maximum particle size of 37.5mm was used in this study due to nominal maximum particle size of CA was 37.5mm.

Table 2.5 Grading requirement for base course material (GB)(ERA 2013 Table 6.2)

Sieve designation		Percentage by mass of total aggregate passing test sieve		
		Nominal maximum particle size		
Standard (mm)	Alternative US standard	37.5mm	28mm	20mm
50	2"	100	-	-
37.5	$1^1/_2$"	95-100	100	-
28	1"	-	-	100
19.5	$^3/_4$"	60-80	70-85	90-100
9.5	$^3/_8$"	40-60	50-65	60-75
4.75	No. 4	25-40	35-55	40-60
2.36	No. 8	15-30	25-40	30-45
0.425	No. 40	7-19	12-24	13-27
0.075	No. 200	5-12	5-12	5-12
Pan				

Specific gravity and Water absorption: The specific gravity of aggregates normally used in road construction ranges from about 2.5 to3.0 with an average value of about 2.68. Though high specific gravity of an aggregate is considered as an indication of high strength, it is not possible to judge the suitability of a sample of road aggregate without finding the mechanical properties such as aggregate crushing, impact and abrasion value.

Water absorption of an aggregate is accepted as measure of its porosity. Coarse aggregate having Water absorption of 2.0 percent or less are considered durable. A value greater than this necessitates a soundness test to be carried out for specification compliance. No value of water absorption is given for fine aggregate.

Plasticity: The fraction passing the 0.425mm (No.40) sieve shall have liquid limit not greater than 25 and plasticity Index not greater than 6 as determined by AASHTO T89 & T90, respectively. ERA 2013, *section 6.1.1 of Chapter 6* recommends the fine fraction of crushed base course material should be non-plastic.

California Bearing Ratio (CBR): The material passing the 19mm sieve shall have a CBR value of not less than 80% as determined by AASHTO T193. ERA 2013, *section 6.1.1 of Chapter 6* recommends crushed stone base course constructed with proper care which means materials contain sufficient fines or binder quantity (amount of material passing the 0.425 mm sieve) to produce dense material when compacted so that dense graded should have CBR values well in excess of 100%.

Aggregate Crushing Value (ACV): The ACV should, preferably, be less than 25% and always less than 29%

Ten percent fine value (TFV): Samples are crushed under a range of loads so that the load which produces 10 percent of fines finer than 2.36mm can be determined. An advantage of the test is that it can be used with all aggregates irrespective of their strength, thus enabling direct comparisons to be made between strong and weak materials. Minimum 10% fines value recommended by ERA standard is 110kN.

Flakiness index: The Flakiness index of aggregate is the percentage by weight of particles whose least dimension [thickness] is less than three- fifths [0.6] times of their mean dimension. The test is not applicable to aggregate size smaller than 6.3 mm. According to BS 812-part-105 flakiness index in excess of 35% is considered undesirable.

Loss angels Abrasion value: The coarse portion retained on 1.7 mm sieve shall have mass percent of wear not exceeding 45 by the Los Angeles Abrasion test determined by AASHTO.

2.9 Summary of standards

Table 2.6 Test on road aggregate for base course and standards for specifying quality

Types of tests	Standard code	ERA, IS & BS Governing specification on Base course layer
Gradation test	AASHTO T27.11	See grading requirement Table 2.5
Specific gravity & water absorption	AASHTOT84,T85	2.5-3.0 &<2%
plasticity test	AASHTOT89, IS-2720-part 5	PI<6%
Shape tests: Flakiness index, Elongation index& Angularity number	BS-812-part -105.1 BS-812-part-1.05.2 BS-812-part-105	<35%, <45% &0 − 11 respectively
Aggregate crushing test & 10% fines test	BS-812-part-110 BS-812-pat-111	<29% &<110KN respectively
Aggregate impact test	IS-2386-part-4	<30%
Los Angeles abrasion test	AASHTO T96 Or ASTM C131	<45%
CBR test	AASHTO T193	>80%

2.10 Summary of Literature Reviews

The finding from the literature reviews shows that in different part of the world, using of recycled concrete and marble wastes are well developed. However, using of demolished concrete and marble waste as a recycled material is not yet known in Ethiopia. This may be due to availability of natural aggregate nowadays, or it may be due to unavailability of enough research done on recycling. The rate of consumption of natural aggregate is increasing as the demand for different construction industries is increasing and landfills fill up, it is wise recycling solid wastes such as demolished concrete and marble waste as conventional aggregate. Using wastes are important to reduce natural aggregate consumption rate and to minimize pollution. Hence, this study was to evaluate the suitability of recycled concrete and marble wastes as conventional aggregates for base coarse material. Finally, the engineering properties of these materials as base layer of pavements were discussed and compared with ERA standard specification.

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 Study Area

Samples of recycled concrete and marble waste were collected from Addis Ababa city, demolished Samsung building and Ethiopian Marble Processing Enterprise, respectively. Addis Ababa city is the capital city of Ethiopia. It has latitude of $8^{0}52' - 9^{0}3'$N and longitude of $38^{0}45'–38^{0}55'$E. The laboratory works were conducted at Jimma University Institute of Technology.

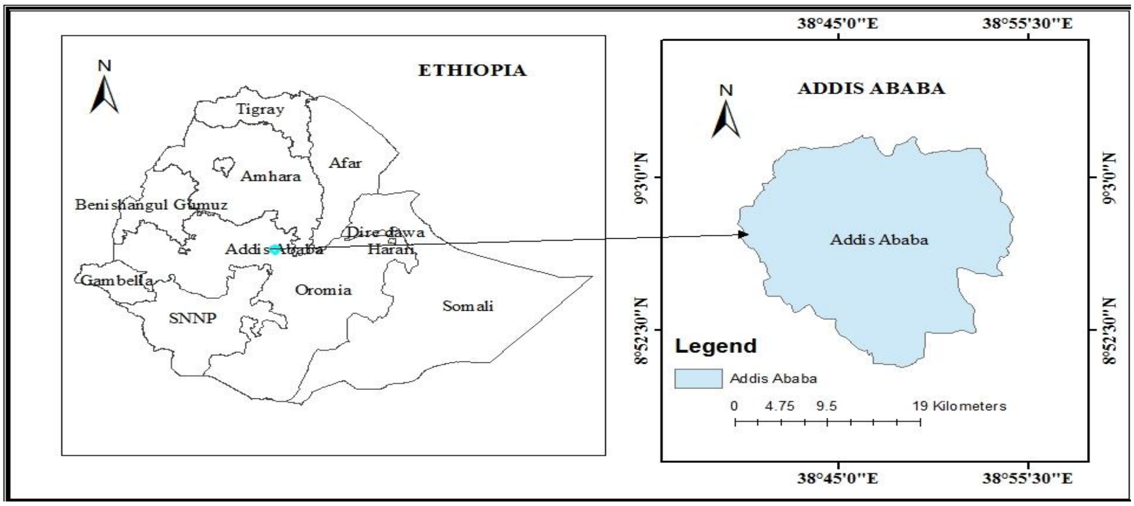


Figure 3.1 Study area map(Source: EMA)

3.2 Study Period and Design

The study period to conduct the thesis was planned to be completed within six months starting fromSeptember2020 up toFebruary2021.

To acquiring new knowledge on solid wastes materials as conventional aggregates different method implemented as Figure 3.2 shows. Demolished concrete and marble wastes crushed using manual crusher. Then, Laboratory tests were conducted to determine engineering properties such as gradation, specific gravity and water absorption, California bearing ratio (CBR), aggregate crushing value (ACV), aggregate impact value (AIV), loss Angeles abrasion value (LAV), plasticity, angularity, flakiness and elongation index of recycled concrete and marble wastes. To achieve these blend (0:100, 20:80, 50:50, 80:20 and 100:0)RCA and CA as well blend (0:100, 20:80, 50:50, 80:20, and 100:20) MWA and CA were conducted. Finally, the data obtained from lab were analyzed and compared with ERA standard specification.

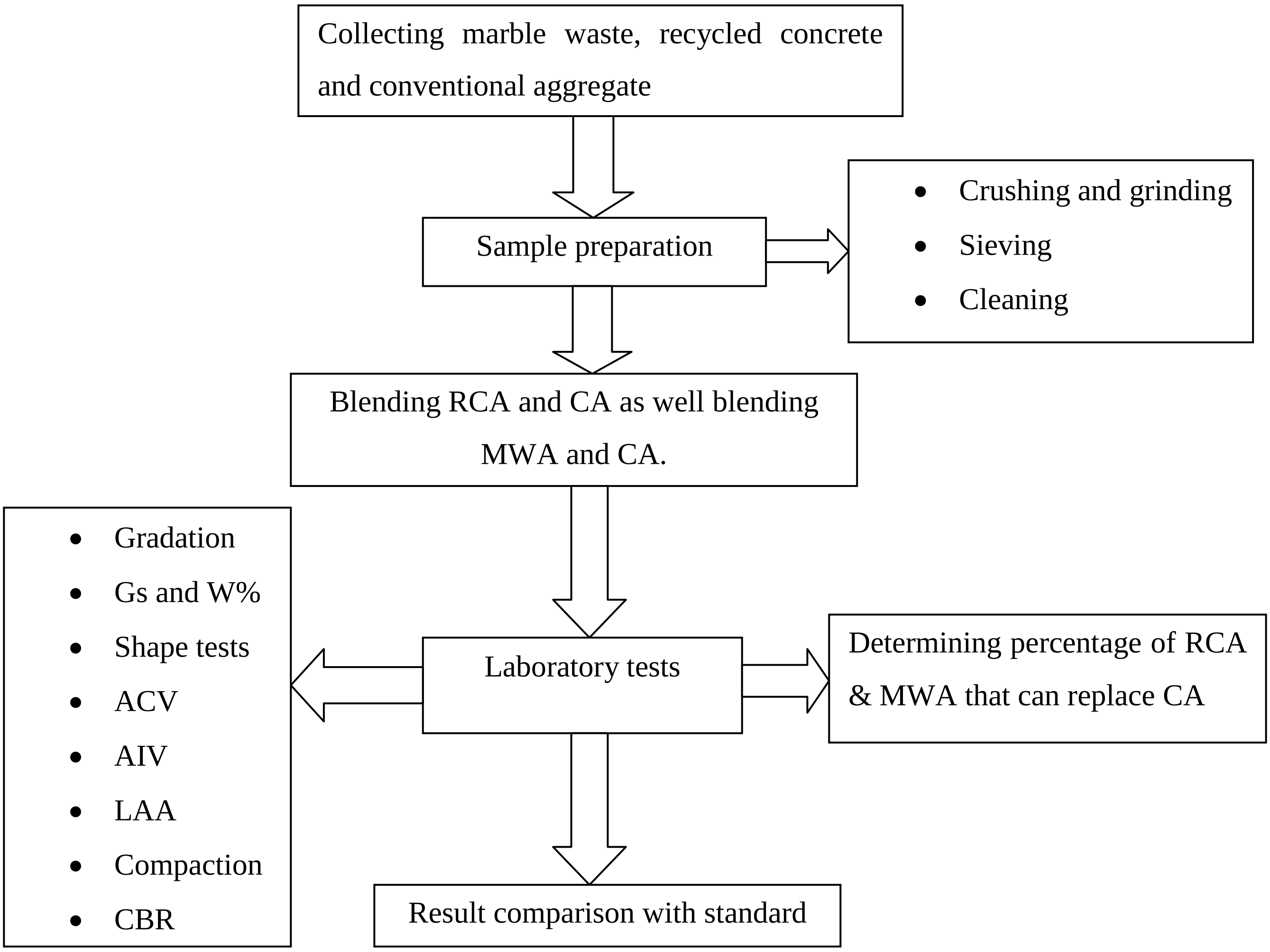


Figure 3.2 Flow chart the study method

3.3 Population

The sampling population were recycled concrete & marble waste which is derived from construction demolition and marble processing industries respectively. And also conventional aggregate.

3.4 Sample Selection and Preparation Technique

Samples of recycled concrete and marble waste were collected from Addis Ababa city, demolished Samsung building and Ethiopian Marble Processing Enterprise, respectively. Purposive sampling technique used. Sample preparation technique to be conducted includes sieving, weighed, discard and cleaning process. As Figure 3.3 shows recycled concrete and marble waste was crushed using manual crusher with NMPS of 37.5 mm sieve up to 0.075 mm sieve in similar situation as conventional aggregate, then laboratory test was conducted to investigate various engineering properties of recycled concrete and marble waste as conventional aggregate.

Figure 3.3 Sample of RCA and MWA crushed with NMPS of 37.5 - 0.075mm sieves

3.5 Methods of Data Collection

3.5.1 Primary Data

The primary data was obtained through undertaken laboratory test on solid wastes materials. Thus, solid wastes that have been considered as conventional aggregates for base course include recycled concrete and marble wastes.

3.5.2 Secondary Data

The secondary data was links primary data to previous research studies and guidelines for example national ERA and international AASHTO, BS and others.

3.6 Study Variables

3.6.1 Dependent Variable

The dependent variable in this study was suitability of recycled concrete and marble waste aggregate as conventional aggregate.

3.6.2 Independent Variables

The independent variables of the study were engineering properties such as, gradation, specific gravity and water absorption, compaction (proctor), California bearing ratio (CBR), aggregate crushing value (ACV), 10% fines value, aggregate impact value (AIV), loss Angeles abrasion value (LAV), plasticity, angularity, flakiness and elongation index.

3.6.3 Investigation of Engineering Properties of MW and RC Materials

Engineering properties such as, gradation, specific gravity and water absorption, compaction (proctor), California bearing ratio (CBR), aggregate crushing value (ACV), 10% fines value, aggregate impact value (AIV), loss Angeles abrasion value (LAV), plasticity, angularity flakiness and elongation index were investigated.

3.6.3.1 Gradation

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

The strength of pavements are highly depends on the particle size of the constituent material and their gradation. Aggregates having good particle size distribution are better to support the traffic load and other loads because they have high density and good interlocking between the particles. In addition the particle size distribution determines the drainage characteristics of the aggregates. Therefore, it is important to conduct the gradation test to analyze the particle size distribution curve, drainage characteristics of the aggregate and the strength of aggregates. As per ERA 2013 flexible pavement design manual, the gradation or particle size distribution for graded stone base layer (GB) is described in Table 2.5.

Strength, or stiffness, in road base and other aggregate layers that carry load is increased greatly if the compaction is dense graded. The larger particles are in contact with each other, developing frictional resistance to shearing failure, and tightly bound together due to the interlocking effect of the smaller particles. When aggregate particles are to be bound together by cement, avariation in the grading of an aggregate will result in a change in the amount of binder required to produce a material of given stability and quality. Proper aggregate grading contributes to the uniformity and workability of the material as it is mixed and compacted.

Grading of an aggregate is determined by sieve analysis, where the mass of an aggregate sample retained on each of a number of standard sieves is recorded. Two key parameters are the maximum aggregate size and the shape of the gradation curve, to achieve this, the known weight of sample aggregate was sieved through set of sieves and material retained on different sieves were determined and percentage finer was obtained. The detail was given in Appendix A-1 and B-1. Then, semi logarithmic of grain size versus % finer was plotted and effective size such as D10,D30 and D60 values were obtained from curves as illustrated in Figure 3.4. Finally, coefficient of curvature (C_c) and coefficient of uniformity (C_u) of the sample aggregates were computed as Eqs.(3.1) and (3.2) (AASHTO). These coefficients would be given well or poor graded sample of aggregates. The shape and slope of gradation curve indicate the type of gradation. A steep or too curve slope indicates poor gradation for most engineering purposes which means there is a deficiency or excess of certain sizes. A gentle or even slope indicates good gradation which means all particles are represented fairly well. The detailsare discussed in *Section 4.2.1.1 and 4.2.2.1 of Chapter 4*.

$C_U = \frac{D60}{D10}$(3.1)

$C_C = \frac{(D30)^2}{D10 \times D60}$(3.2)

Where, D10 = 10% passing point on the curve; D30 = 30% passing point on the curve; and D60 = 60% passing point on the curve

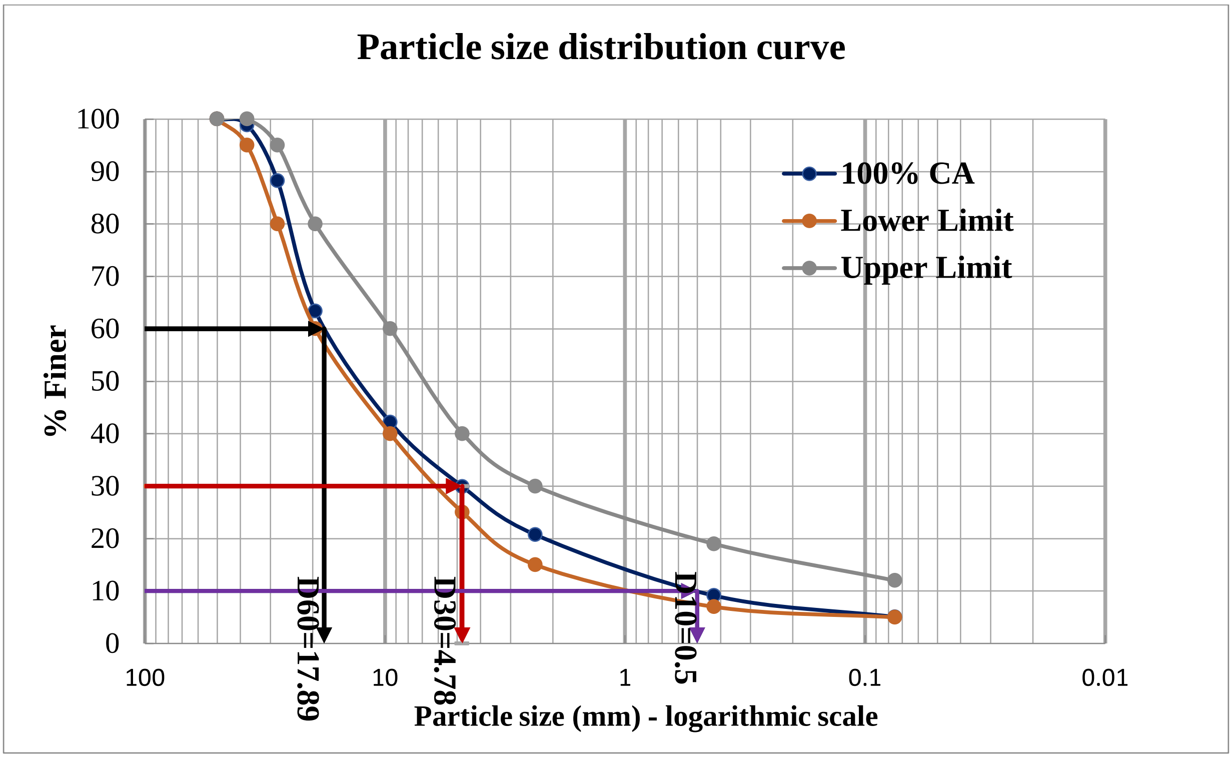


Figure 3.4 Particle size distribution curve of conventional aggregate

Figure 3.5 Sieves used for gradation test

3.6.3.2 Specific Gravity and Water Absorption

Specific gravity is used to establish weight-volume relationships, also for mechanical properties. Based on specific gravity, aggregate are classified as normal weight, heavy weight and light weight. Normal weight aggregates are generally used for pavements because they are most available. Specific gravity can be defined as the ratio of the weight of aggregate in air to the weight of equal volume of water displaced by saturated surface dry aggregate. Water absorption of aggregates is the percentage of water absorbed by an air-dried aggregate when immersed in water for period of 24 hours. Absorption and surface moisture are of significance for calculating water that aggregate will add to or substract from paste, and are used in compaction mix.

To conduct specific gravity and water absorption, about 2.5 kg of aggregate retained on 10 mm sieve was washed thoroughly and placed in the wire basket and immersed in water for about 24 hours as illustrated in Figure 3.6. The basket was lifted slightly up and down under water with gentle agitation to remove entrapped air. The basket with the sample in water was weighed (Weight B). The basket and sample from the water was removed and cooled to drain for a few minutes. The basket was emptied and again weighed (Weight C). The aggregate was spread on dry cloth and allowed to dry in air until no films of water were apparent on its surface. It was then weighed in this saturated and surface dry condition (Weight A). Then aggregate was dried in an oven at 105 ^{0}C for 24 hours, cooled and weighed (Weight D).Specific gravity & water absorption for coarse aggregateusing basket method are calculated as Eqs.(3.3), (3.4), (3.5) and (3.6) (IS: 2386).The detailsare given in Appendix A-2 and B-2.

Apparent specific gravity = $\frac{D}{(D-(B-C))}$(3.3)

Bulk specific gravity = $\frac{D}{(A-(B-C))}$(3.4)

Bulk specific gravity = $\frac{A}{(A-(B-C))}$ (3.5)

Water absorption (w%) = $\frac{(A-D)}{D} \times 100$ (3.6)

Where, A= Weight of saturated surface dry sample in air; B= Weight of basket + sample in water; C= Weight of empty basket in water; and D= Weight of oven dry sample in air

Figure 3.6 Basket method

3.6.3.3 Plasticity

Plasticity index is defined as a range of moisture content, expressed as a percentage of the mass of an oven dried aggregate sample passing a 425µm sieve, within which the material is in a plastic state (BSI, 1992). It is the numerical difference between the liquid and plastic limit of the material as shown in Eqs.(3.7) (AASHTO).Plastic index gives an indication of clay content in the material. The fine faction of both crushed materials about 15 g of sample passing through sieve 0.425 mm (No.40), mixed thoroughly with distilled water were incapable of being molded into ball and materials assume their original shape after the force causing deformation is removed, hence plasticity index reported as non-plastic.

Other standard like ASTM implies that for granular base materials plasticity index should be in non-plastic range. There are certain circumstances under which the plasticity index cannot be determined. These are: When either the liquid limit or plastic limit cannot be determine, report the plasticity index as non-plastic; when the soil is extremely sandy, the plastic limit test shall be done before the liquid limit test. If the plastic limit cannot be determined, then report the plasticity index as non-plastic and when the plastic limit is equal to or greater than the liquid limit, report the plasticity index as non-plastic.

PI=LL-PL (3.7)

Where, PI = plastic index; LL = liquid limit; and PL = plastic limit

3.6.3.4 Shape Factors

The particle shape of the aggregate mass is used to determine the level of workability and stability. The usual shapes of particles of aggregate mass are rounded (river gravel), flaky (laminated rock), elongated and angular (crushed rock). Rounded aggregates are preferred in concrete road (rigid pavement) as the workability of concrete increases due to the less friction between the surfaces. Angular shape of the particles of aggregate mass is desirable in granular base coarse and sub-base course of flexible pavement due to better interlocking and increased stability which contributes to reduction of voids and permeability whereas flaky and elongated particles are considered as a source of weakness with possibility of breaking down during compaction and under loads.

As per ERA 2013 flexible pavement design manual, three mechanical measures of particle shape which may be included in the specifications for aggregates for road construction are the flakiness index, elongation index and angularity number. 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 mean dimension, as used in each instance, is the average of two adjacent sieve aperture sizes between which the particle being measured is retained by sieving. The elongation index of an aggregate is the percentage by weight of particles whose greatest length is greater than 1.8 times their mean dimension. The details are given in Appendix A-3 and B-3. The angularity number of an aggregate is the amount, to the nearest whole number, by which the percentage of voids exceeds 33 when an aggregate is compacted in a specified manner in a standardized metal cylinder. The details are given in Appendix A-4 and B-4.

According to British standard (BS 812), flakiness index exceeding 30% irrespective of the aggregate size and Elongation index value in excess of 45% are considered undesirable for base course. In addition, British standard 812 also states that the angularity number of aggregates generally ranges from zero for highly rounded gravel to about 11 for freshly crushed angular aggregates. The higher the angularity, more angular and less workable in the aggregate mix. Round aggregates are more workable, but angular particles may develop higher flexural strength, which is important for pavements. A high value of angularity (i.e. more cubical) of aggregate should produce high levels of internal friction and good resistance deformation. Texture is aggregate property that affect pavements performance. Texture may be glassy, smooth, granular, rough, crystalline or honey combed. Rough aggregate more strength than smooth aggregate because aggregate particles "lock" together.

Thickness gauge and length gauge are used to determine flakiness index and elongation index respectively for shape test as illustrated in Figure 3.7 and 3.8.

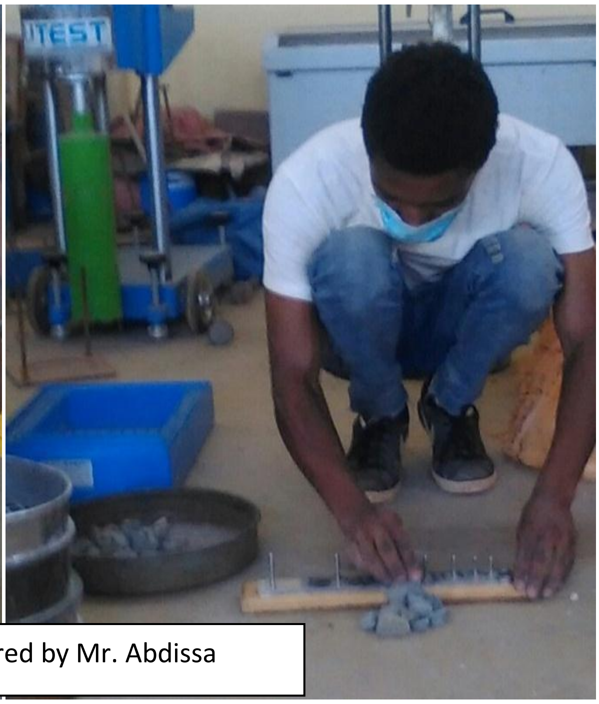


Figure 3.7 Thickness gauge Figure 3.8 Length gauge

3.6.3.5 Aggregate Crushing Value (ACV)

Aggregate used in road construction, should be strong enough to resist crushing under traffic wheel loads. If the aggregate are weak, the stability of the pavement stretches is likely to be adversely affected. The strength of coarse aggregate is assessed by aggregate crushing value. Aggregate crushing test evaluates the resistance of aggregates against the gradually applied load. The test is used to evaluate the crushing strength of available supplies of rock, and in construction, to make sure that minimum specified values are maintained. The test is undertaken using a metal plunger to apply gradually a standard load of 400KN to a sample of the aggregate fraction (14 – 10 mm) contained in a standard test mould. The amount of material passing 2.36 mm sieve in percentage of the total weight of the sample is referred to as the Aggregate Crushing value (ACV). The detailsare given in Appendix A-5 and B-5. To achieve a high quality of pavement, aggregate possessing low aggregate value should be preferred.

Strong aggregates give low aggregate crushing value. ERA 2013, *section 6.1.1 of Chapter 6* recommended the ACV should, preferably, be less than 25 and always less than 29. Compression testing machine of 500KN was used to determine the resistance of an aggregate to crushing under gradually applied load as illustrated in Figure 3.9.

Figure 3.9 Compression testing machine used for aggregate crushing value test

3.6.3.6 Ten Percent Finesse Value (TPFV)

Ten percent fines value is a measure of the resistance of aggregate crushing subjected to loading and it is applicable to both weak and strong aggregates. Fine aggregates are defined as those passing 2.36 mm sieve. The test is conducted to determine the forces required to produce 10% of fine values. This test is very similar to aggregate crushing test in which a standard force 400KN is applied and fines material expressed as percentage of the original mass is the aggregate crushing value.

Granular base is subjected to repeated loading from truck types. The stress level at the contact points of aggregate particles is quite high. The Base course is the basic structural layer of a flexible pavement whose function is to support the wheel load applied on it which is coming from traffic and distribute the load. As such, it is of paramount importance that the base material should itself not be disintegrated under sever traffic loads. Ten percent fines value can be used to reveal the aggregate properties when subjected to mechanical degradation.

In this test, samples are crushed under a range of loads so that the load which produces 10 per cent of fines finer than 2.36mm can be determined. An advantage of the test is that it can be used with all aggregates irrespective of their strength, thus enabling direct comparisons to be made between strong and weak materials. An approximate relationship between ACV and 10%FACT is given in Eqs.(3.8) (ERA). This relationship is valid in the strength range of 14 to 30 ACV and 100 to 300 KN 10%FACT.

ACV = 38 - (0.08 x 10%FACT) (3.8)

A 10%FACT value of 160N is approximately an ACV of 25 using this relationship.

Minimum 10% fines value recommended by ERA standard is 110kN.ERA 2013, *section6.1.1 of Chapter 6* recommends to ensure that base course materials are sufficiently durable, they should satisfy minimum ten percent fines value of 110KN. Figure 3.10 illustrates the durability of MWA and RCA as conventional aggregate for base course material seeing that they satisfy minimum TPFV of 110kN.

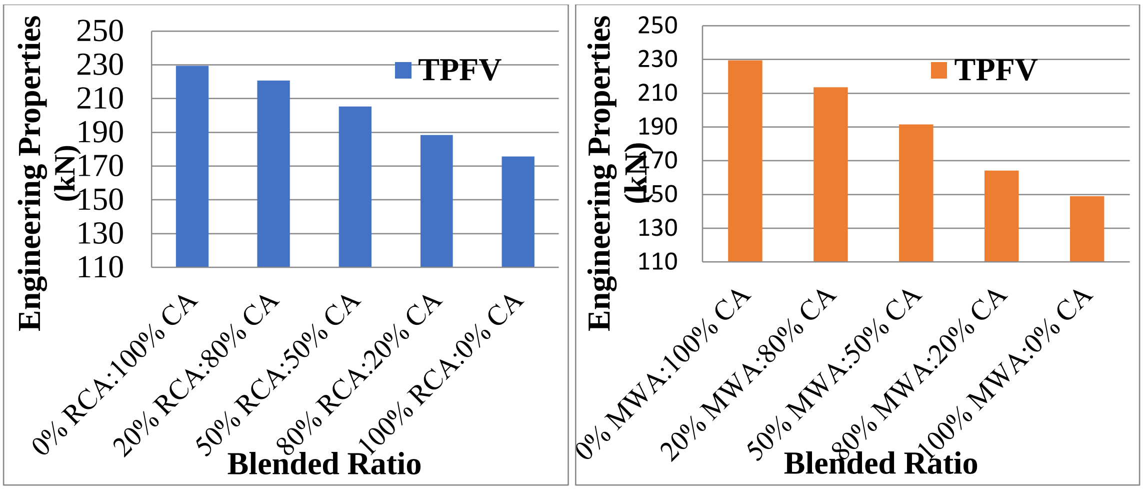


Figure 3.10 TPFV of RCA and MWA as conventional aggregate

3.6.3.7 Aggregate Impact value (AIV)

Toughness is the property of a material to resist impact. Due to traffic loads the road stones are subjected to the impact and there is possibility of stones breaking into smaller pieces. The road stones should therefore be tough enough to resist fracture under impact. A test designed to evaluate the toughness of stones i.e. the resistance of the stones to fracture under repeated impacts may be an impact test for road aggregate. The amount of material passing 2.36 mm sieve in percentage of the total weight of the sample is referred to as the Aggregate Impact value (AIV).The detailsare given in Appendix A-6 and B-6.

The aggregate impact value indicates a relative measure of the resistance of an aggregate to a sudden shock or an impact, which in some aggregate differs from its resistance to a slow compressive load.

Figure 3.11 Aggregate impact testing machine

3.6.3.8 Los Angeles Abrasion value (LAA)

The aggregate used in the course on highway pavements are subjected to wearing due to movement of traffic. When vehicles move on the road, the aggregate particles present between the wheels and road surface cause abrasion of road aggregate. Therefore, the road aggregate should be hard enough to resist the abrasion.

Abrasion test is the test used to know how the aggregate is sufficiently hard to resist the abrasive effect of traffic over its service life. The most widely used abrasion test is the Los Angeles Abrasion Test which involves the use of a steel drum, revolving on horizontal axis, into which the test sample of chippings is loaded together with 12 steel balls of each 46.8 mm diameter

The Los Angeles Abrasion Value (LAV) is the percentage of fines passing the 1.7 mm sieve after a specified number of revolutions of the drum at specified speed, usually 500 revolutions at speed of 30-33 RPM. The drum is fitted with internal baffles causing the aggregate and the steel balls to be lifted and then fall as the drum revolves. The test therefore gives an indication of the impact strength in combination with the abrasion resistance of the aggregate.

In this study, after the test is conducted, the sample aggregate is extracted and separated into material passing the 1.70 mm (No. 12) sieve and material retained on the 1.70 mm (No. 12) sieve. The retained material (larger particle) is then weighed and compared to the original sample weight. The difference in weight is reported as a percent of the original weight and called the "percent loss".The detailsare given in Appendix A-7 and B-7.

Figure 3.12Drum machine and Abrasive charge balls used for Los Angeles Abrasion

3.6.3.9 Compaction (proctor)

Compaction is the process by which air is excluded from aggregate mass to bring the particles closer together and thus increase its density (dry density). The state of compaction of an aggregate material is appropriately expressed in terms of the dry density which is a measure of the state of packing of its particles.

The relationship between moisture content and dry density was first studied by Procter, and the test is sometimes known as Procter test. The dry density that can be obtained by compaction varies with the moisture content, type of material being compacted, and the compaction effort. At low moisture content, the aggregate is dry and stiff and friction between adjacent particles prevents (limits)relative movement between particles to assume denser configuration.

As water is added, larger film of water forms around the particles, causing lubrication effects and facilitating relative movements between particles to assume denser configuration (high density of aggregate mass). Thus, the density increase and the air content decreases as the moisture increases. At some moisture content, the aggregate attains the maximum practical degree of saturation (S<100%). The degree of saturation, S, cannot be increase further due to entrapped air in the void spaces and around the particles.

Thus, any further addition of water will result in the voids being overfilled with water causing separation of particles and reduction of density (the additional water taking the space of the solid particles). The moisture content at which maximum dry density is obtained is known as optimum moisture content (OMC).The details are discussed *section 4.2.1.7 and 4.2.2.7 of Chapter 4.*

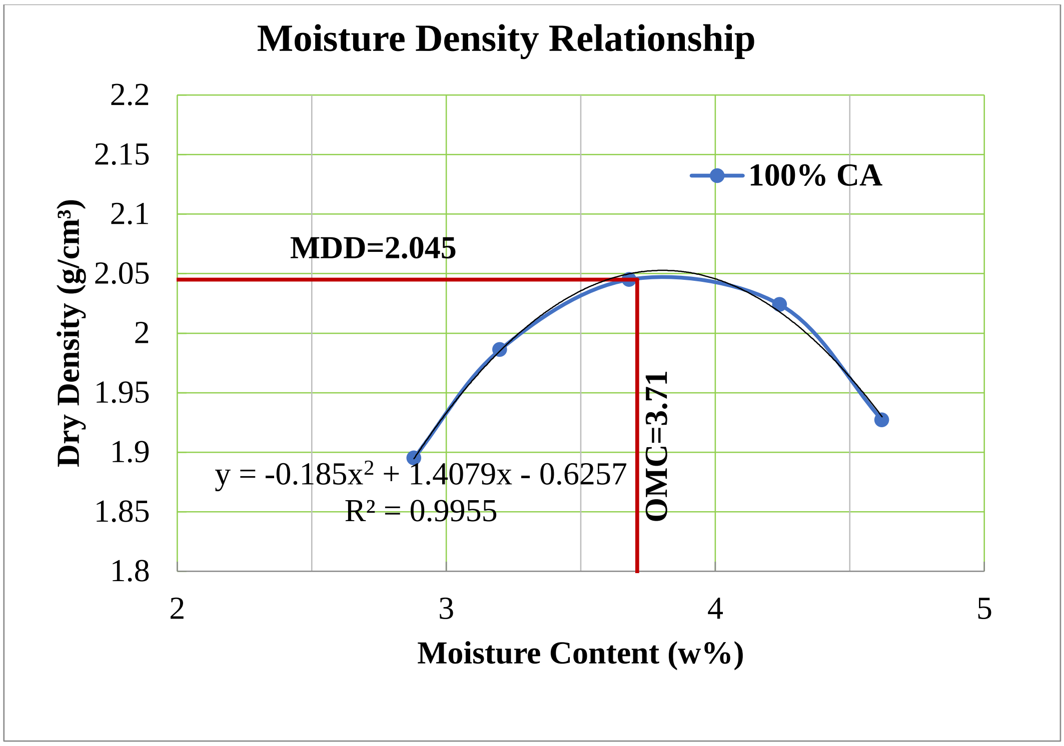


Figure 3.13Compaction curve of conventional aggregate

Modified or heavy compaction test was used for this study which is the test done with the advent of heavier compaction equipment greater densities were now achievable in the field. A modified version of the test was developed to allow the application of greater compactive effort (and achieve greater density) that is compacting the aggregate of the same height in five approximately equal layers using a 4.5kg hammer falling through 457mm height. AASHTO manual was used.

Figure 3.14 Typical compaction test procedures from (a) to (g)

(a) Apparatus (b) Mixing sample thoroughly with the required water (c) Un compacted sample (d) placing sample in the mould (e) Compacting sample with manual rammer (f) Trimming off the excess sample using straight edge (g) Weighing compacted sample

3.6.3.10 California Bearing Ratio (CBR)

CBR evaluate the strength(stiffness)of base materials for the pavements design and the stiffness of the materials are dependent on binder quantity, their properties and full compaction being carried out. As the stiffness and the volume change of the materials depends up on the moisture changes, OMC should be considered for worst conditions so that optimum moisture content (OMC) obtained from modified compaction test at maximum dry density (MDD) and their NMC was used. One point blow that is 56 blows CBR test was conducted for this study.

In this test, a plunger is made to penetrate the aggregate material, which is compacted to the prevalent dry density and moisture content anticipated in the field (or to MDD and OMC as specified) in a standard mould (CBR mould) at a specified rate of penetration. The resulting load-penetration curve is compared with that obtained for a standard crushed rock material, which is considered an excellent base course material. The load is applied by cylindrical metal plunger of 50 mm diameter, the standard penetration rate used is 1.27mm/min and readings of the applied load are taken at appropriate intervals of penetration (0 - 1.27mm (0.5")) up to a total penetration of usually not more than 7.5 - 12.7mm.

The load corresponding to 2.54mm and 5.08mm penetration values are taken as shown in Figure 3.17. The CBR value is determined corresponding to both 2.54mm and 5.08mm penetration using Eqs.(3.9) and (3.10) (AASHTO) respectively and the greater value is used for the design of pavement. If the CBR for 5.08mm penetration is greater than that of 2.54mm penetration, the test is repeated. If the results are unchanged, the value for 5.08mm penetration is used for defining CBR value as AASHTO manual. The standard load values for crushed stone of penetration 2.54mm and 5.08mm are 13.2kN and 20.0kN respectively. The details are discussed in *section 4.2.1.8 and 4.2.2.8 of Chapter 4.*

$$\text{CBR @ 2.54mm} = \frac{\text{Penterationloadat 2.54 mm}}{\text{standardloadat 2.54 mm}} \times 100 \qquad (3.9)$$

$$\text{CBR @ 5.08mm} = \frac{\text{Penteration load at 5.08 mm}}{\text{standard load at 5.08 mm}} \times 100 (3.10)$$

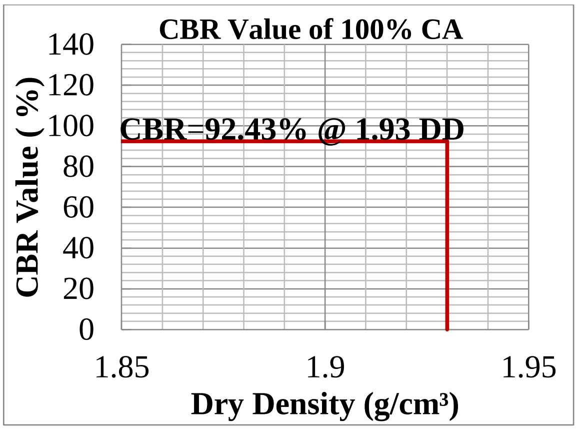


Figure 3.15 CBR machineFigure 3.16 CBR value -Dry density of CA

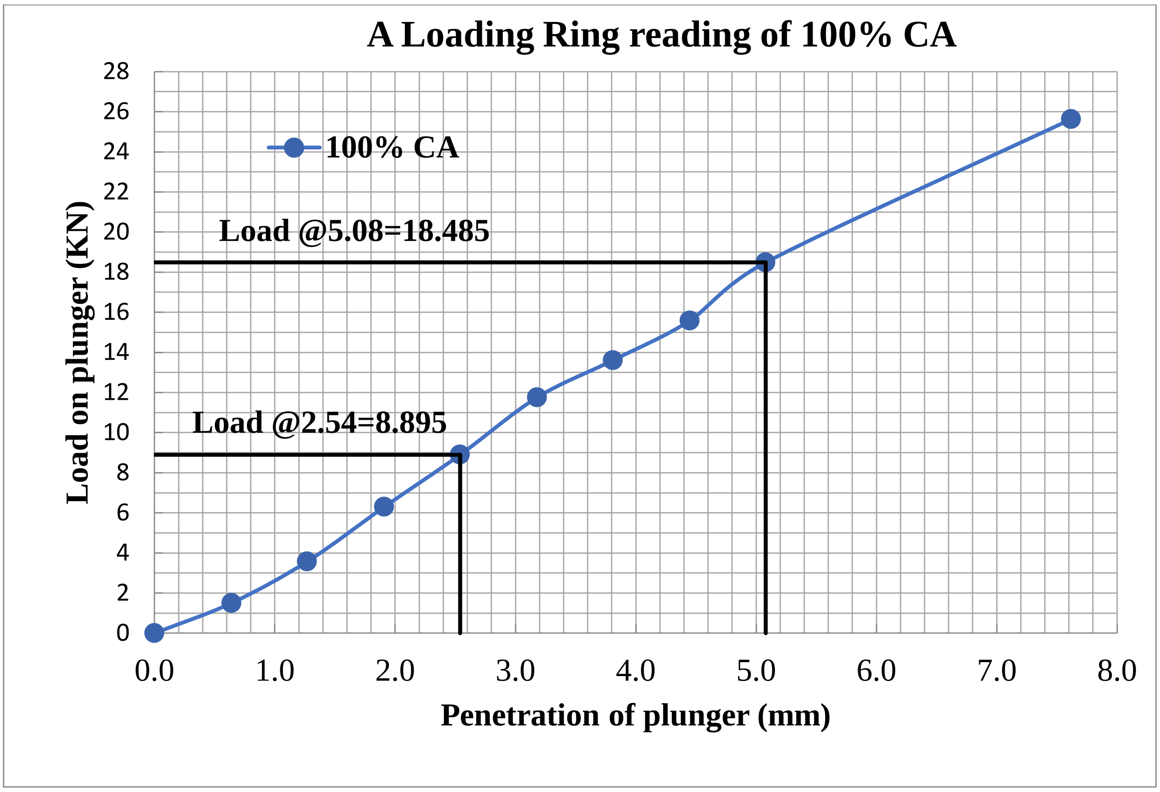


Figure 3.17 Load - Penetration Curveof Conventional aggregate

3.7 Data Quality Management

Laboratory equipment that requires calibration was calibrated and material used was checked for its grade for the analysis. Duplicate measurements of each of the engineering properties were conducted and average $\pm$ SD (standard deviation) was reported.

3.8 Data Processing and Analysis

The data obtained from lab was organized and interpreted according to the objectives. Engineering properties of recycled concrete aggregate and marble waste aggregate were analyzed and compared with ERA standard specification. Processing and analysis of data were presented using graphs, charts and mathematical formula, for example$p_{bulk}(g/cm^3) = \frac{M1}{Moldvolume}$ and $p_{dry}(g/cm^3)= \frac{p_{bulk}}{1+w\%}$.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 General

This chapter deals with the result and discussion of engineering properties such as gradation, specific gravity and water absorption, plasticity, shape factors, aggregate crushing value, ten percent fineness value, aggregate impact value, los Angeles abrasion, compaction and CBR of recycled concrete aggregate and marble waste aggregate. The main results are presented in the form of graphs and tables. The results were organized and discussed in the order of the objectives.

4.2 Engineering Properties

4.2.1 Recycled Concrete

4.2.1.1 Gradation

The large particles of gradation are load bearing and fine particles bind coarse ones to prevent movement between them. The gradation of base materials is very important to achieve maximum contact between particles and maximum water tightness. Table 4.1 Shows the particle size distribution of recycled concrete aggregate and conventional aggregate blended. The results show that as per ERA 2013 flexible pavement design manual, the recycled concrete aggregate at all blended ratio conform the grading requirements and they are mostly inside the grain size distribution limit (range).

Table 4.1Results of sieve analysis for RCA and CA blended

Sieve size (mm)	Passing sieve size (%)					
	Grading for 37.5mm NMA	RCA:CA	RCA:CA	RCA:CA	RCA:CA	RCA:CA
		0 : 100	20 : 80	50 : 50	80 : 20	100 : 0
50	100	100	100	100	100	100
37.5	95-100	98.88	98.91	96.70	97.02	97.36
28	-	88.22	88.09	85.52	87.27	85.47
19.5	60-80	63.41	65.07	64.59	66.30	64.12
9.5	40-60	42.17	43.73	43.93	46.74	44.07
4.75	25-40	29.90	30.44	28.81	31.40	29.77
2.36	15-30	20.74	18.38	19.66	22.13	21.06
0.425	7-19	9.13	6.02	8.89	9.02	8.28
0.075	5-12	5.06	2.33	4.09	2.57	2.11
Pan		0.00	0.00	0.00	0.00	0.00

According to AASHTO manual aggregate particles finer than 0.075mm size cannot be sieved, that is why pan is used, but if the aggregate contains large portion of grains below

0.075mm the grain distributions of this fine fraction is determined by means of hydrometer analysis or wet analysis. As shown in Table 4.1 the fine grained aggregate passing 0.075mm is small and the aggregate contain large portion of coarse and sand, hence it need not had to analysis hydrometer.

The particle size distribution curve results are illustrated in Figure 4.1 and all gradation curves are gentle slope. The effective size such as $D_{10,}$ D_{30} and D_{60} values from the curves and uniformity coefficient (C_u) and coefficient of curvature (C_C) computed are shown in Table 4.2.

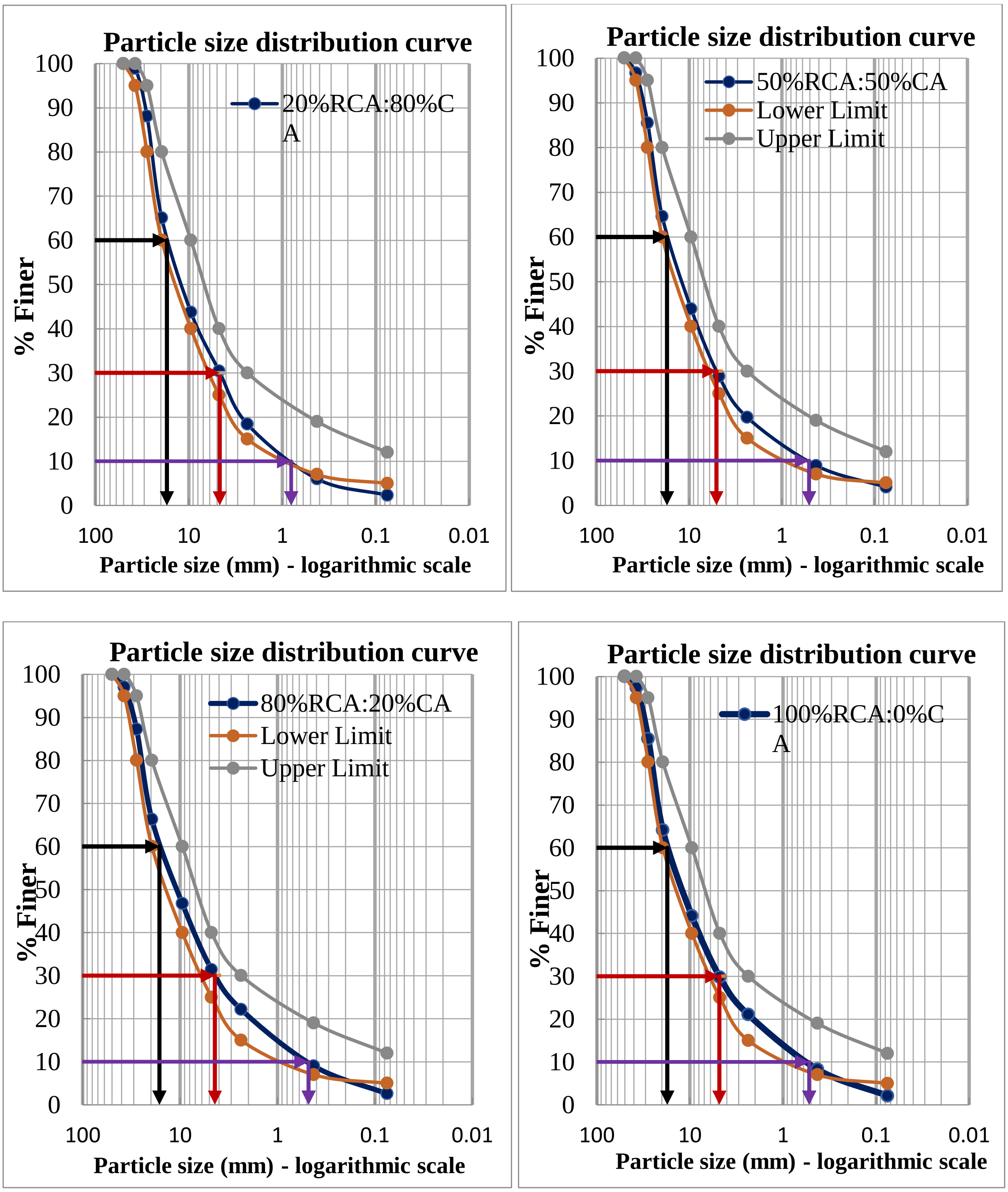


Figure 4.1 Particle size distribution curves for the RCA and CA blended

As shown in Table 4.2according to AASHTO T-27, the recycled concrete aggregate is well graded at all blended ratio. This means sample contains the particles of different sizes in good proportions. However, amount of fine aggregate is insufficient.

Table 4.2 Results of effective size and Coefficients for RCA and CA blended

Blended Ratio(%) RCA:CA	Effective Size			Coefficients		Graded	Extract (%)		
	D10	D30	D60	C_U	C_C		Coarse	Sand	Fine
0:100	0.5	4.78	17.89	35.78	2.55	Well	79.3	15.7	5.1
20:80	0.8	4.66	17.12	21.4	1.59	Well	81.6	16.1	2.3
50:50	0.51	5.06	17.28	33.88	2.91	Well	80.3	15.6	4.1
80:20	0.48	4.39	16.28	33.91	2.46	Well	79.9	19.6	2.6
100:0	0.52	4.81	17.44	33.54	2.55	Well	78.9	18.9	2.2

If $C_U \geq 4$ for gravel and crushed rock, $C_U \geq 6$ for sands and $C_C$is between 1 and 3, it is called well graded soil. If $C_U < 4$ for gravel and crushed rock, $C_U < 6$ for sands and $C_C$is outside between 1 and 3, it is called uniform soil or poorly graded soil. Gap graded soils are outside the limits of C_U and C_C for well graded and poorly graded soils.

In general, since RCA had good particle size distribution it is better to support load because it had high density (compacted to very dense condition) and good interlocking between the particles.

4.2.1.2 Specific Gravity and Water Absorption

As shown in Table 4.3 according to AASHTO the water absorption limit is (2%), the RCA and CA blend water absorption ranging from 1.52 to 11.16% which are relatively higher than that of CA. The water absorption of the blend increased with increase in percentage of RCA. The bulk density of RCA is lower than that of CA. The lower value of RCA bulk density may be attributed to its higher porosity than that of CA. RCA particles generally more absorptive than CA and had lower Gsb values than CA which is less dense than CA due to its porosity as a result of cement paste. Apparent specific gravity greater than bulk specific gravity, it implied materials had valid relationship.

Table 4.3 Results of specific gravity and water absorption for RCA and CA blended

Blended Ratio(%) RCA:CA	Coarse aggregate		
	Gsa	Gsb	W (%)
0:100	2.66	2.55	1.52
20:80	2.69	2.47	3.38
50:50	2.72	2.33	6.21
80:20	2.78	2.21	9.33
100:0	2.80	2.13	11.16
Specification	2.5-3.0	2.5-3.0	<2

4.2.1.3 Plasticity

As shown in Table 4.4 according to ASTM, fine fraction of RCA is non-plastic. That means there is no or little clay contents in its particles and it is suitable materials as base course material and attain higher dry density (compacted to very dense condition).

Table 4.4 Results of plasticity for RCA and CA blended

Blended Ratio: RCA:CA	Plasticity
0:100	Non-Plastic
20:80	Non-Plastic
50:50	Non-Plastic
80:20	Non-Plastic
100:0	Non-Plastic
Specification (%)	<6

4.2.1.4 Shape Factors

As shown in Table 4.5 according to ERA 2013 (BS-812-Part105), RCA had suitable shape for the base course material. The RCA and CA blend flakiness index ranged from 30 to 17% with an average value of about 26% as well elongation index ranged from 24 to 14% with an average value of about 20%. That means they are less flaky and elongated and highly angular shape due to cement paste. Its angularity helps to increase structural strength in the base. However, they are less workable in mix.

Table 4.5 Results of shape factors for RCA and CA blended

Blended Ratio: RCA:CA	FI (%)	EI (%)	AN
0:100	29.99	23.97	12
20:80	27.92	20.23	11
50:50	28.04	20.79	7
80:20	26.34	21.67	4
100:0	17.22	13.51	2
Specification	<35	<45	0 - 11

4.2.1.5 Aggregate Crushing and 10% Fines Value

As shown in Table 4.6 according to ERA (BS-812-Part 111, Part 110), RCA and CA blend conform specification. The RCA and CA blend ACV ranged from 19 to 24% with an average value of about 22% as well TPFV from correlation ranged from 230kN to 176 kN with an average value of about 204 kN. It inferred that they had strong resistance to crushing and sufficiently strong to withstand stress due to traffic wheel load.

Table 4.6 Results of aggregate crushing and 10% fines values for RCA and CA blended

Blended Ratio: RCA:CA	ACV (%)	TPFV (kN)
0:100	19.64	229.54
20:80	20.35	220.66
50:50	21.57	205.34
80:20	22.92	188.49
100:0	23.94	175.69
Specification	<29	>110

4.2.1.6 Aggregate Impact Value and Los Angeles Abrasion

As shown in Table 4.7 according to IS-2386, RCA and CA blend AIV conform specification. The RCA and CA blend had similar range with an average value of about 16%. It inferred that they had toughness to sudden shock or impact due to moving wheel loads. According to AASHTO, RCA and CA blend LAA conform specification. The RCA and CA blend LAA ranged from 11 to 17% with an average value of about 14%. It inferred that they hard enough to resist wear due to abrasive action.

Table 4.7 Results of aggregate impact value and los Angeles abrasion the blend

Blended Ratio: RCA:CA	AIV	LAA
0:100	16.42	11.25
20:80	16.03	11.96
50:50	16.10	13.84
80:20	15.94	15.52
100:0	15.61	16.67
Specification (%)	<30	<45

4.2.1.7 Compaction

Compaction curve results are presented in Figure 4.2. The moisture content which gives the highest dry density is called the optimum moisture content for that type of compaction. As shown in Figure 4.2The RCA and CA blend OMC range from 3.68 to 12.24% as well MDD range from 2.05 g/cm^3 to 1.71 g/cm^3. It implied that as the RCA proportion increase OMC increase and MDD decrease. It inferred that RCA have less density (compacted to low dense condition) at optimum moisture content than CA.

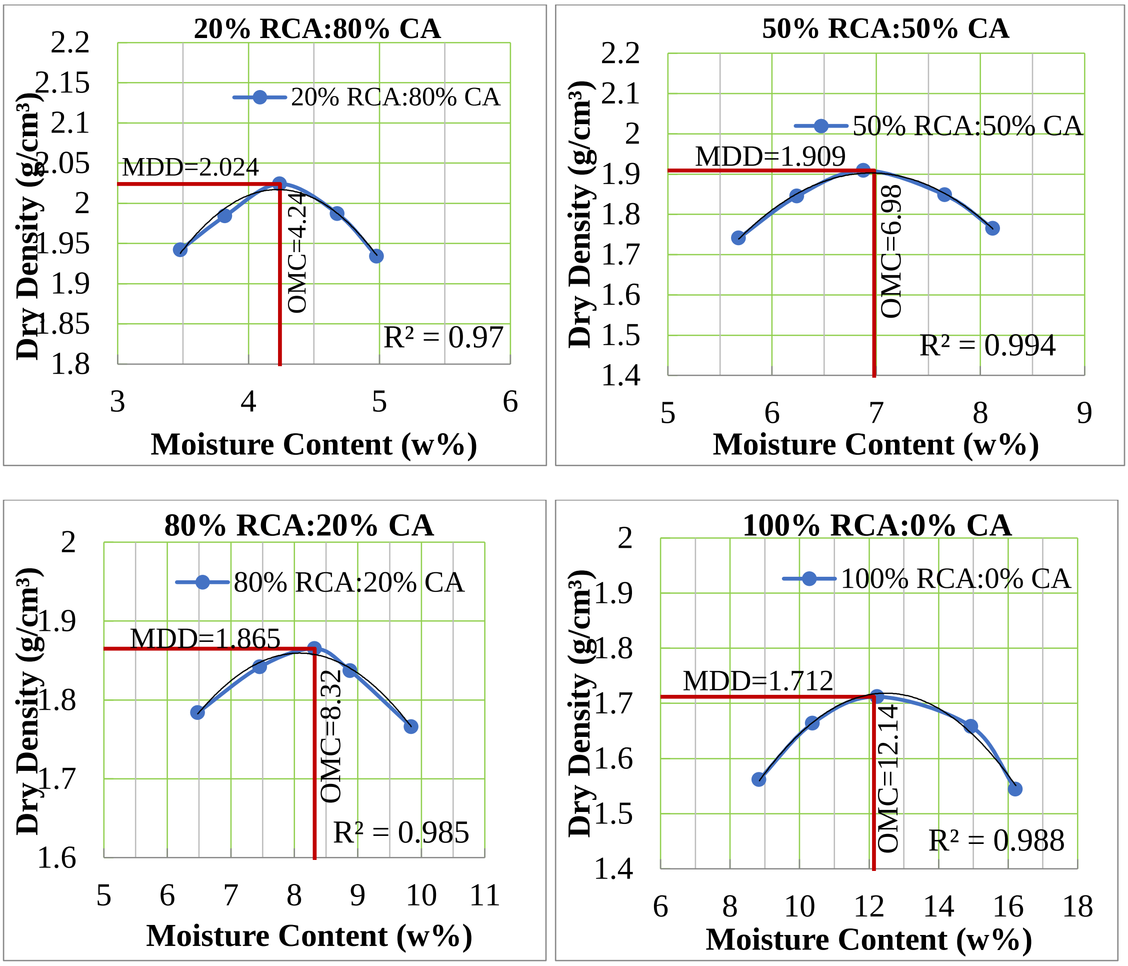


Figure 4.2 Compaction curves for RCA and CA blended

4.2.1.8 California Bearing Ratio (CBR)

Table 4.8 shows moisture content and dry density of CBR specimens for RCA & CA blended. The results show that dry density decreased and moisture content increased as the level of replacement of conventional aggregate with RCA increased due to its porosity as a result of cement past. The load corresponding to 2.54 mm and 5.08 mm penetration values of RCA and CA blended are illustrated in Figure 4.3.The CBR at 5.08 mm penetration used as shown in Table 4.9. Dry density versus CBR values are illustrated in Figure 4.4. As shown in Table 4.9 according to AASHTO, up to 80% of RCA could be blended with CA and CBR value is good as base course materials. It inferred that RCA is stable and strong up to 80% blend.

Full replacement of CA by RCA CBR is 68% which is poor as base course materials. It implied that 100% RCA replacement alone is unstable (easily displaced under load) and weak (less supporting power). However, replacing proportions of CA by RCA from 20 to 80% achieve dense grade with CBR values well in excess of 100% standard crushed rock. It may inferred that the packing of RCA particles are more effective. When the replacement ratio increased to 80% , the CBR strength reduction range from 9 to 22% with a smaller reduction in bearing capacity.

Table 4.8 Moisture content and dry density of CBR specimens for RCA & CA blended

Blended Ratio: RCA:CA	CBR specimens	Moisture content (w%)	Bulk density (g/cm^3)	Dry density (g/cm^3)
0:100	56 blows	3.34	1.99	1.93
20:80	56 blows	4.72	1.955	1.87
50:50	56 blows	7.35	1.909	1.78
80:20	56 blows	6.92	1.862	1.74
100:0	56 blows	12.4	1.755	1.56

Table 4.9 CBR (%) value of RCA and CA blended

Blended Ratio (%) RCA:CA	CBR specimen	Penetration (mm)	Penetration load (kN)	Standards load (kN)	CBR (%)	CBR (%) (max)
0:100	56 blows	2.54	8.90	13.2	68.42	92.43
		5.08	18.49	20.0	92.43	
20:80	56 blows	2.54	12.76	13.2	98.14	128.0
		5.08	25.60	20.0	128.0	
50:50	56 blows	2.54	11.48	13.2	88.34	119.37
		5.08	23.87	20.0	119.37	
80:20	56 blows	2.54	11.42	13.2	87.87	106.05
		5.08	21.21	20.0	106.05	
100:0	56 blows	2.54	7.02	13.2	54.03	68.19
		5.08	13.64	20.0	68.19	
					Specification (%)	>80

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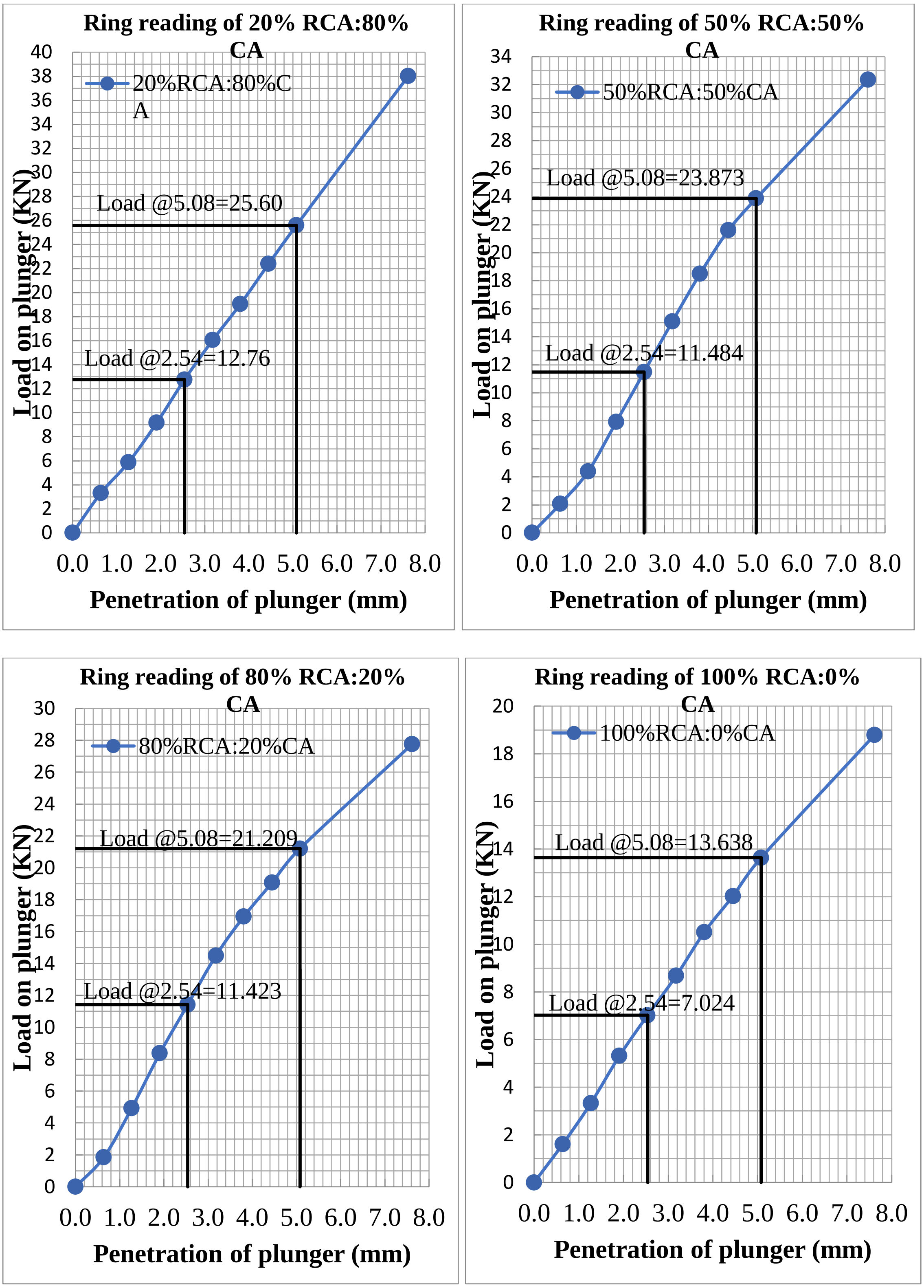

Figure 4.3 Load versus penetration curves of RCA and CA blended

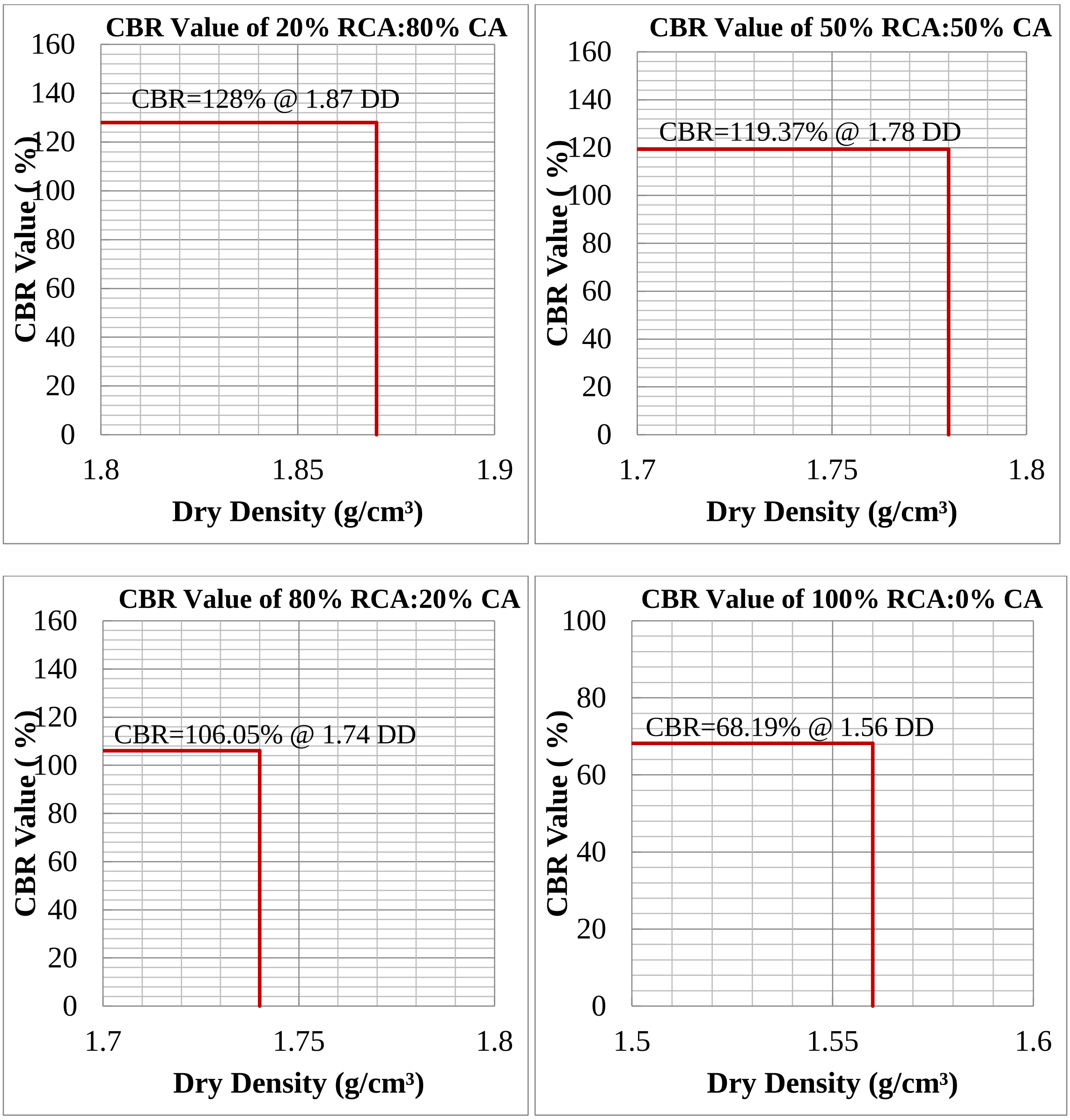

Figure 4.4 Dry density versus CBR value for RCA and CA blended

In general, as CBR usually gives an overall picture of the quality of materials and is directly related with other properties, recycled concrete can be as conventional aggregates up to 80% blend for base course material. The RCA from demolish concrete consists of crushed stone aggregate with cement paste and sand in the material. This cause variation in the grading of an aggregate and change in the amount of binder required to produce dense material. It is inadvisable to utilize sufficient fines for suitability of recycled concrete as conventional aggregates because the aggregate paste bond working as fines.

4.2.2 Marble Wastes

4.2.2.1 Gradation

Table 4.10Shows the particle size distribution of marble waste aggregate and conventional aggregate blended. The results show that as per ERA 2013 flexible pavement design manual, the marble waste aggregate at all blended ratio conform the grading requirements and they are mostly inside the grain size distribution limit (range).

Table 4.10Results of sieve analysis for MWA and CA blended

Sieve size (mm)	Passing sieve size (%)					
	Grading for 37.5mm NMA	MWA:CA 0:100	MWA:CA 20:80	MWA:CA 50:50	MWA:CA 80:20	MWA:CA 100:0
50	100	100	100	100	100	100
37.5	95-100	98.88	100	97.08	97.12	97.10
28	-	88.22	91.38	91.34	92.42	89.56
19.5	60-80	63.41	64.42	70.30	68.67	67.71
9.5	40-60	42.17	41.40	48.66	46.57	46.45
4.75	25-40	29.90	28.32	30.06	31.54	32.40
2.36	15-30	20.74	17.46	17.97	20.39	19.37
0.425	7-19	9.13	8.74	7.70	9.87	6.76
0.075	5-12	5.06	5.60	2.92	3.95	2.30
Pan		0.00	0.00	0.00	0.00	0.00

Although some blending are coarser on some sieve, according to AASHTO manual filler shall be uniformly blended with the base course material on road in the event of coarser for meeting the grading requirements or for satisfactory bonding and filler shall not contain more than 15% material retained on the 4.75mm (No.4) sieve.

ERA 2013, *section 6.1.1 of Chapter 6*recommends all base course materials must have a particle size distribution and particle shape which provide high mechanical stability and should contain sufficient fines (amount of material passing the 0.425 mm sieve) to produce a dense material when compacted. If the amount of fine aggregate produced during the crushing operation is insufficient, non-plastic angular sand may be used to make up the deficiency.

The particle size distribution curve results are illustrated in Figure 4.5. All the shape and slope of gradation curves are gentle slope and they are indicates good gradation which means all particles are represented fairly well. The effective size such as D_{10}, D_{30} and D_{60} values from the curves and uniformity coefficient (C_u) and coefficient of curvature (C_C) computed are shown in Table 4.11.

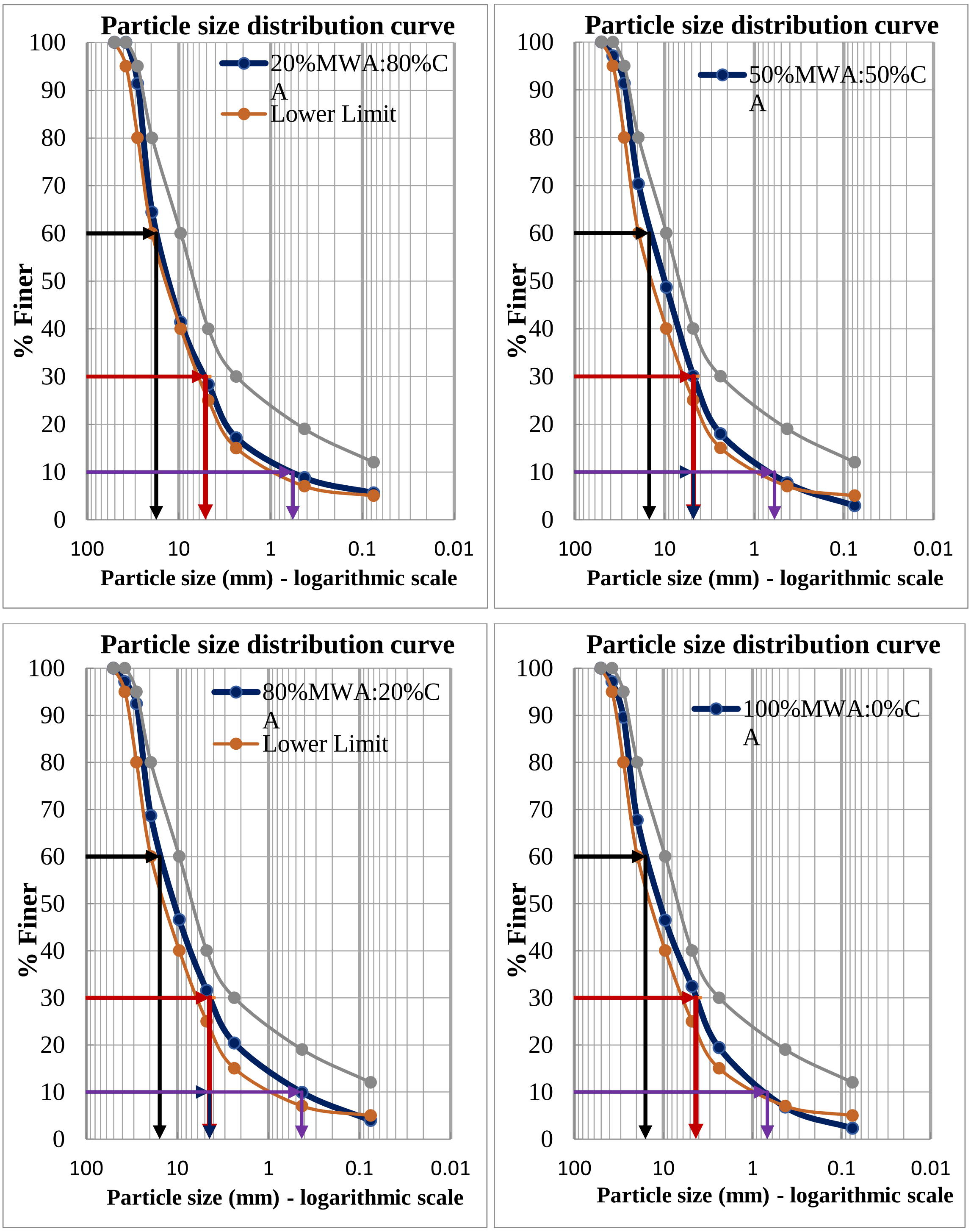

Figure 4.6 Particle size distribution curves of the MWA and CA blended

As shown in Table 4.11 according to AASHTO T-27, the marble waste aggregate is well graded at all blended ratio. This means sample contains the particles of different sizes in good proportions. However, amount of fine aggregate is insufficient. It appears to be difficult to obtain consistent grading for 37.5 mm NMA.

Table 4.11 Results of effective size and Coefficients for MWA and CA blended

Blended Ratio (%) MWA:CA	Effective Size			Coefficients		Graded	Extract (%)		
	D10	D30	D60	C_U	C_C		Coarse	Sand	Fine
0:100	0.5	4.75	17.89	35.78	2.55	Well	79.3	15.7	5.1
20:80	0.57	5.12	17.58	30.84	2.62	Well	82.5	11.9	5.6
50:50	0.59	4.74	14.74	24.98	2.58	Well	82.0	15.1	2.9
80:20	0.43	4.42	15.58	36.23	2.91	Well	79.6	16.4	4.0
100:0	0.68	4.31	15.87	23.34	1.72	Well	80.6	17.1	2.3

If $C_U \geq 4$ for gravel and crushed stone, $C_U \geq 6$ for sands and C_C is between 1 and 3, it is called well graded soil. If $C_U<4$ for gravel and crushed stone, $C_U<6$ for sands and C_C is outside between 1 and 3, it is called uniform soil or poorly graded soil. Gap graded soils are outside the limits of C_U and C_C for well graded and poorly graded soils.

In general, since MWA had good particle size distribution it is better to support the traffic load and other loads because it had high density (compacted to very dense condition) and good interlocking between the particles. However, it required typical binder penetration unlike RCA.

4.2.2.2 Specific Gravity and Water Absorption

As shown in Table 4.12 according to AASHTO the water absorption limit is (2%), MWA and CA blend water absorption ranged from 0.34 to 1.52% which are relatively lower than that of CA. The water absorption of the blend decrease with increase in percentage of MWA. It implied that the MWA had too lower porosity. MWA particles generally less absorptive than CA and had high Gsb values than CA which is more dense than CA due to its low porous. Apparent specific gravity greater than bulk specific gravity, it implied materials had valid relationship.

Table 4.12 Results of specific gravity and water absorption for MWA and CA blended

Blended Ratio (%) MWA:CA	Coarse aggregate		
	Gsa	Gsb	W (%)
0:100	2.66	2.55	1.52
20:80	2.68	2.59	1.27
50:50	2.70	2.63	0.93
80:20	2.73	2.68	0.57
100:0	2.74	2.72	0.34
Specification	2.5-3.0	2.5-3.0	<2

4.2.2.3 Plasticity

As shown in Table 4.13 according to ASTM, fine fraction of MWA is non-plastic. That means there is no or little clay contents in its particles and it is suitable materials as base course material and attain higher dry density (compacted to very dense condition).

Table 4.13 Results of plasticity for MWA and CA blended

Blended Ratio: MWA:CA	Plasticity
0:100	Non-Plastic
20:80	Non-Plastic
50:50	Non-Plastic
80:20	Non-Plastic
100:0	Non-Plastic
Specification (%)	<6

4.2.2.4 Shape Factors

As shown in Table 4.14 according to ERA 2013 (BS-812-Part105), MWA had suitable shape for the base course material. The MWA and CA blend flakiness index ranged from 30 to 18% with an average value of about 22% as well elongation index ranged from 24 to 16% with an average value of about 18%. That means they are less flaky and elongated. MWA more workable in mix.

Table 4.14 Results of shape factors for MWA and CA blended

Blended Ratio: MWA:CA	FI (%)	EI (%)	AN
0:100	29.99	23.97	12
20:80	20.18	17.45	13
50:50	21.58	17.17	13
80:20	22.4	17.43	14
100:0	18.45	15.99	15
Specification	<35	<45	0 - 11

4.2.2.5 Aggregate Crushing and 10% Fines Value

As shown in Table 4.15 according to ERA (BS-812-Part 111, Part 110), MWA and CA blend conform specification. The MWA and CA blend ACV ranged from 19 to 26% with an average value of about 23% as well TPFV from correlation ranged from 230kN to 149kN with an average value of about 190kN. It inferred that they had strong resistance to crushing and sufficiently strong to withstand stress due to traffic wheel load.

Table 4.15 Results of aggregate crushing and 10% fines values for the blend

Blended Ratio: MWA:CA	ACV (%)	TPFV (kN)
0:100	19.64	229.54
20:80	20.91	213.61
50:50	22.69	191.43
80:20	24.87	164.18
100:0	26.09	148.92
Specification	<30	>110

4.2.2.6 Aggregate Impact Value and Los Angeles Abrasion

As shown in Table 4.16 according to IS-2386, MWA and CA blend AIV conform specification. The MWA and CA blend had similar range with an average value of about 16%. It inferred that they had toughness to sudden shock or impact due to moving wheel loads. According to AASHTO, MWA and CA blend LAA conform specification. The MWA and CA blend LAA ranged from 11 to 22% with an average value of about 17%. It inferred that they hard enough to resist wear due to abrasive action.

Table 4.16 Aggregate impact value and los Angeles abrasion for MWA and CA blended

Blended Ratio: MWA:CA	AIV (%)	LAA (%)
0:100	16.42	11.25
20:80	16.7	13.02
50:50	16.36	17.22
80:20	16.23	19.76
100:0	16.24	21.68
Specification	<30	<45

4.2.2.7 Compaction

Compaction curve results are presented in Figure 4.6. The moisture content which gives the highest dry density is called the optimum moisture content for that type of compaction. As shown in Figure 4.6The MWA and CA blend OMC range from 3.68 to 2.22%. It implied that as the MWA proportion increase OMC decrease. However, it appears to be difficult to obtain consistent MDD.

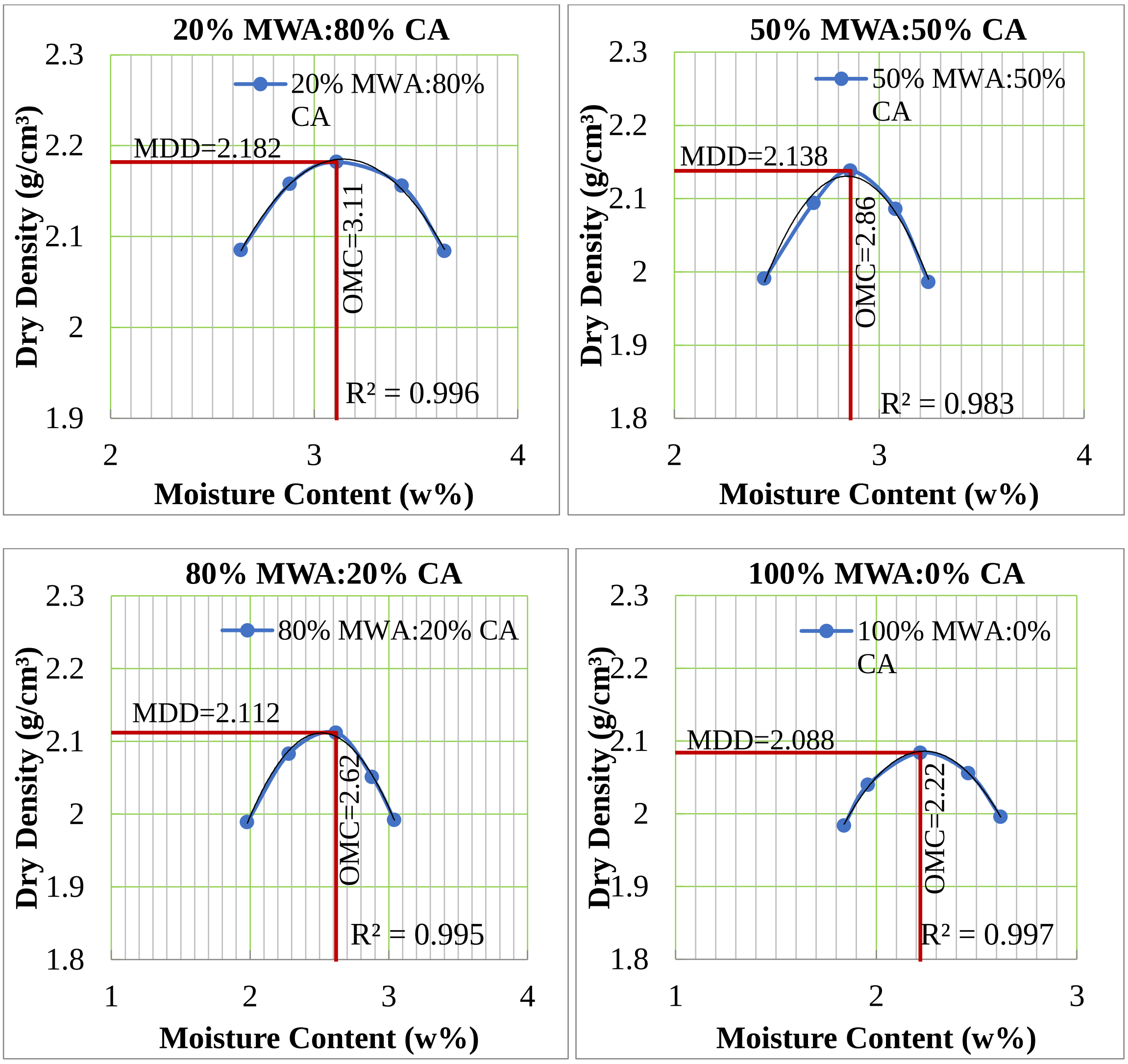

Figure 4.6 Compaction curves for MWA and CA blended

4.2.2.8 California Bearing Ratio (CBR)

Table 4.17 shows moisture content and dry density of CBR specimens for MWA & CA blended. The results show that moisture content decrease as the level of replacement of conventional aggregate with MWA increased. However, it appears to be difficult to obtain consistent MDD. The load corresponding to 2.54 mm and 5.08 mm penetration values of MWA and CA blended are illustrated in Figure 4.7. The CBR at 5.08 mm penetration used as shown in Table 4.18. Dry density versus CBR values are illustrated in Figure 4.8. As shown in Table 4.10 according to AASHTO, up to 80% of MWA could be blended with CA and CBR value is good as base course materials. It inferred that MWA is stable and strong up to 80% blend.

Full replacement of CA by MWA CBR is 62% which is poor as base course materials. It implies that 100% MWA replacement alone is unstable (easily displaced under load) and weak (less supporting power). However, replacing proportions of CA by MWA from 20 to 80% achieve dense graded with CBR values well in excess and more closely of 100% standard crushed rock. It may inferred that the packing of MWA particles with typical binder penetration are more effective. When the replacement ratio increased to 80% , the CBR strength reduction range from 6 to 26% with a smaller reduction in bearing capacity.

Table 4.17 Moisture content and dry density of CBR specimens for MWA & CA blended

Blended Ratio: %MWA:%CA	CBR specimens	Moisture content (w%)	Bulk density (g/cm^3)	Dry density (g/cm^3)
0:100	56 blows	3.34	1.99	1.93
20:80	56 blows	3.63	2.247	2.17
50:50	56 blows	2.85	2.168	2.11
80:20	56 blows	2.54	2.09	2.04
100:0	56 blows	2.32	2.037	1.99

Table 4.18 CBR (%) value of MWA and CA blended

Blended Ratio: % MWA:% CA	CBR specimen	Penetration (mm)	Penetration load (kN)	Standards load (kN)	CBR (%)	CBR (%) (max)
0:100	56 blows	2.54	8.90	13.2	68.42	92.43
		5.08	18.49	20.0	92.43	
20:80	56 blows	2.54	12.57	13.2	96.72	125.59
		5.08	25.12	20.0	125.59	
50:50	56 blows	2.54	11.46	13.2	88.15	119.25
		5.08	23.85	20.0	119.25	
80:20	56 blows	2.54	9.16	13.2	70.46	99.05
		5.08	19.81	20.0	99.05	
100:0	56 blows	2.54	5.68	13.2	43.69	62.52
		5.08	12.50	20.0	62.52	
					Specification (%)	>80

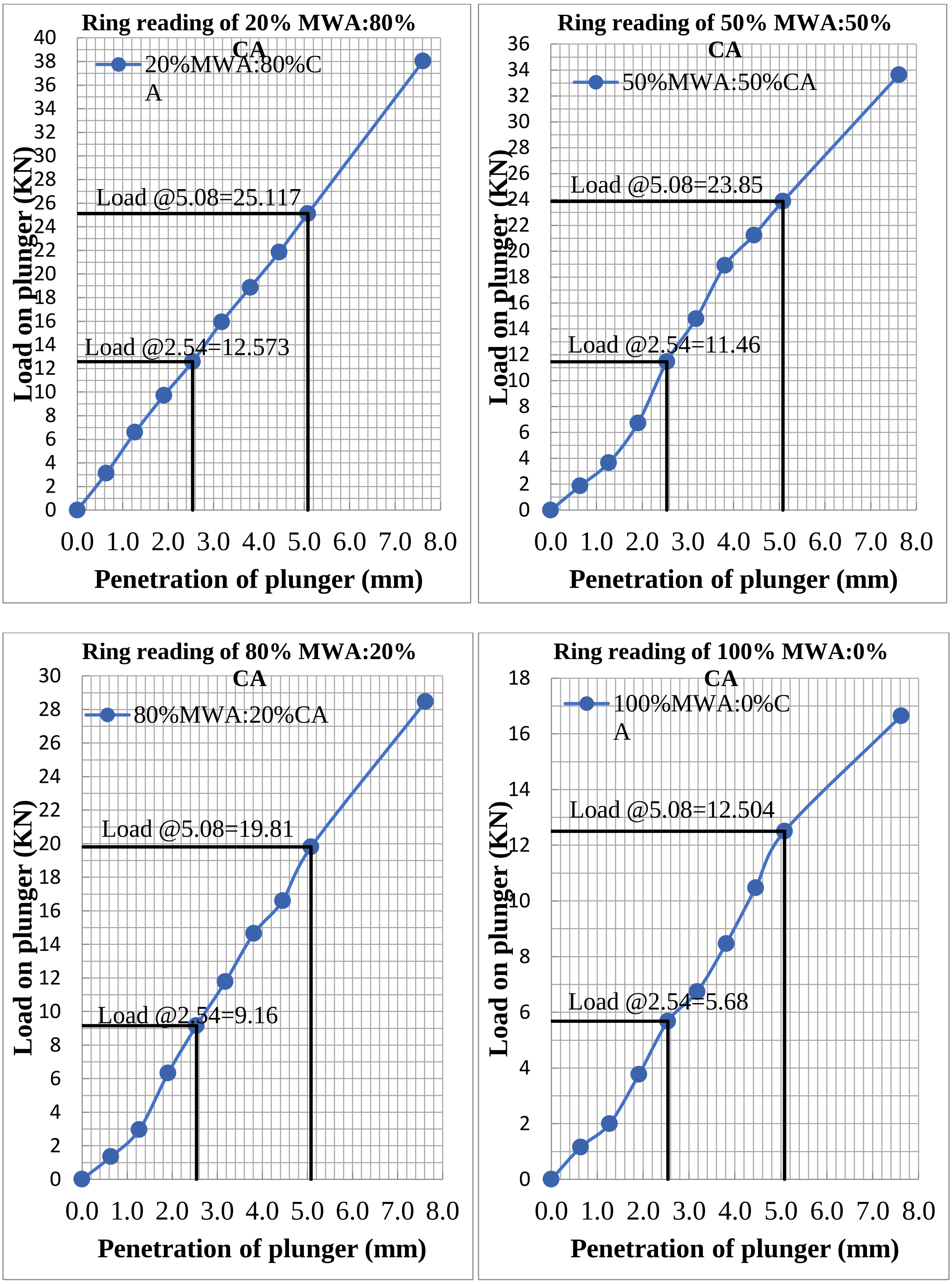

Figure 4.7 Load versus penetration curves of MWA and CA blended

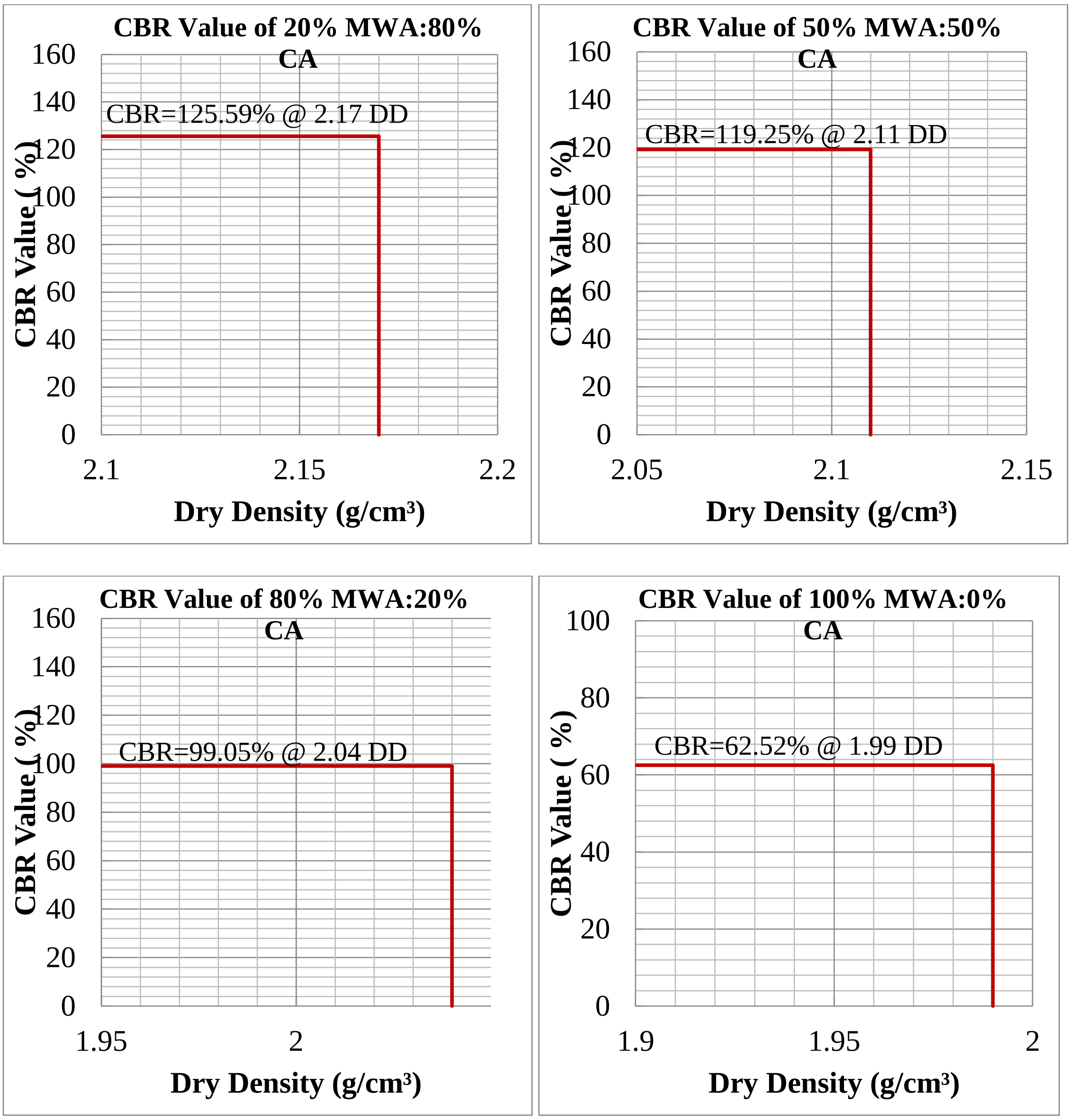

Figure 4.8 Dry density versus CBR value for MWA and CA blended

In general, as CBR usually gives an overall picture of the quality of materials and is directly related with other properties, marble wastes can be as conventional aggregates up to 80% blend for base course material. However, it is advisable to utilize sufficient fines for suitability of marble waste as conventional aggregates as the particles incapable of "lock" together.

4.2.3 Comparison of Engineering Properties of RCA and MWA with ERA

Table 4.19Shows the comparison of engineering properties of both materials up to 80 percent replacement of conventional aggregate.

Table 4.19 Typical RCA and MWA Properties

Properties		RCA	MWA	ERA	Description
Gradation	C_c	1.59 - 2.91	2.62 - 2.91	-	As C_c is the slope of the grade/gradient, both had gentle slope. RCA had more sand than MWA due to cement paste and sand in the material. It appears to be difficult to obtain consistent grading for 37.5 mm NMA of both materials.
	Sand (%)	15.6 - 19.6	11.9 - 16.4	-	
Specific gravity		2.13 - 2.47	2.59 - 2.62	2.5- 3	The specific gravity of RCA is lower as compared to MWA due to its angularity as RCA from demolished concrete consists of crushed stone aggregate with cement paste.
Water absorption (%)		3.38 - 9.33	0.34 - 1.27	<2	The high value for RCA was attributed to porosity of the cement paste and sand in the material.
Plasticity		NP	NP	<6	The sample of both materials of particles pass through 0.425 mm sieve had no or too small clay particles present.
Shape factors	FI (%)	17 - 28	18 -22	<35	Both materials have suitable shape. That means they had less flaky and elongated. However, RCA had high angularity than MWA due to cement paste in concrete as a result less workable to maintain saturated surface dry condition of aggregate.
	EI (%)	14 - 20	16 - 17	<45	
	AN	2 - 11	13 - 15	0 - 11	
Texture		Irregular granular	Slightly granular	-	The smooth texture of marble block after crushed decreased and exhibit slightly granular. RCA due to consists of crushed stone aggregate with cement paste exhibit irregular granular/rough
Aggregate crushing value (%)		20 - 24	20 - 26	<29	The low ACV of RCA could also be attributed to the angular particles because the mechanical bond in aggregate dependent on the surface shape and texture of the aggregate. However, their ACV was found to be similar
CBR (%)		106 - 128	99 - 125	<80	The packing of RCA particles was more effective than MWA. MWA require typical binder penetration unlike RCA.

In general, as CBR usually gives an overall picture of the quality of materials and is directly related with other properties, both materials can be as conventional aggregates up to 80% blend for base course material.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the results from the study, the following conclusions were drawn.

Blend 80:20 RCA and CA engineering properties obtained are Gs, W, FI, EI, ACV, AIV,LAA and CBR with corresponding values of 2.21, 9.3%, 26.3, 21.8, 22.9, 15.9, and 15.5, 106% respectively with well graded gradation. Blend 80:20 MWA and CA engineering properties obtained are Gs, W, FI, EI, ACV, AIV,LAA and CBR with corresponding values of 2.68, 0.57%, 22.4, 17.4, 24.9, 16.2, and 19.7, 99%, respectively with well graded gradation.

Full replacement of CA by RCA CBR is 68% which is poor as base course materials. It implies that 100% RCA replacement alone is unstable (easily displaced under load) and weak (less supporting power). However, replacing proportions of CA by RCA from 20 to 80% achieve dense grade with CBR values well in excess of 100% standard crushed rock. It may inferred that the packing of RCA particles are more effective. When the replacement ratio increased to 80% , the CBR strength reduction range from 9 to 22% with a smaller reduction in bearing capacity as well Full replacement of CA by MWA CBR is 62% which is poor as base course materials. It implies that 100% MWA replacement alone is unstable (easily displaced under load) and weak (less supporting power). However, replacing proportions of CA by MWA from 20 to 80% achieve dense graded with CBR values well in excess and more closely of 100% standard crushed rock. It may inferred that the packing of MWA particles with typical binder penetration are more effective. When the replacement ratio increased to 80% , the CBR strength reduction range from 6 to 26% with a smaller reduction in bearing capacity.

RCA and CA blend water absorption have ranged from 1.5 to 11% with an average value of about 6% which are relatively higher than that of CA The water absorption of the blend increased with increase in percentage of RCA. The high value for RCA have attributed to porosity of cement paste and sand in the material. The bulk density of RCA is lower than that of CA. The lower value of bulk density of RCA may be attributed to its higher porosity than that of CA. The MWA and CA blend water absorption have ranged from 1.5 to 0.3% with an average value of about 0.9% which are relatively lower than that of CA. The water absorption of the blend decreased with increased in percentage of MWA.

It implies that the MWA have had too lower porosity. The bulk density of MWA is higher than that of CA due to its lower porosity.

The smooth surface block of marble exhibit slightly granular surface after crushed. This property enhance the performance of MWA due to better interlocking. The RCA due to cement paste on the surface of crushed rock aggregate, it exhibit irregular granular surface.

The effect of aggregate surface demonstrate in the strength of pavement structure and workability of the compaction. Slightly granular aggregate such as MWA produce pavements that exhibit reduced strength compared to one constructed from aggregate having irregular surfaces.

The RCA from demolish concrete consists of crushed stone aggregate with cement paste and sand in the material. This cause variation in the grading of an aggregate and change in the amount of binder required to produce dense material. It is inadvisable to utilize sufficient fines for suitability of recycled concrete as conventional aggregates because the aggregate paste bond working as fines. However, it is advisable to utilize sufficient fines for suitability of marble waste as conventional aggregates as the particles incapable of "lock" together.

The fine faction of both crushed materials are non-plastic It implies that the fine particles have had no or little clay content. This property enhances the bonding between aggregate particles.

In general, seeing that CBR usually gives an overall picture of the quality of materials and is directly related with other properties, both materials can be as conventional aggregates up to 80% blend for base course material.

5.2 Recommendation

Based on conclusion, the following recommendations have been drawn.

Both materials can be as conventional aggregates for base course material.

Aggregate with irregular granular surface have more strength than regular granular surface.

Gradation, shape factors and other engineering properties, viz. ACV, TPFV, AIV and LAA of both materials as conventional aggregates are conform ERA specification.

When aggregate particles are to be bound together by cement water absorption of about 6% have used. However, soundness test has needed.

Field verification degree of compaction of both materials as conventional aggregates for base course, a minimum of 100% of modified compaction density, has needed to avoid future consolidation.

Further research is needed particularly on the long term field performance of both materials as conventional aggregates for base course, viz. Layer thickness, compaction equipment and grade tolerance as they are necessary for preventing pumping and spreading load.

Field verification plate bearing test is needed to evaluate the supporting capacity of bases materials.

Further research is needed particularly on the long term field performance of recycled concrete aggregate and marble waste aggregate before they can be used with confidence due to vary of recycled concrete quality at different ages and due to vary of marble quality as per marble processing plants.

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APPENDIX A: RESULTS OF RCA AND CA BLENDED

A-1:Grain Size Analysis

weight of sample = 5kg for one test

% retained on $i^{th} seive$ = $\frac{sample retained on i^{th} seive}{Total mass of sample retained} \times 100$Equation A-1(AASHTO)

% passing on $i^{th} seive$ = 100-∑% retained on $i^{th} seive$ Equation A-2(AASHTO)

Table A-1 Sieve analysis of 0% RCA and 100% CA blended

Sieve designation		Sample retained (g)	% retained	∑% retained	% passing
Standard (mm)	Alternative US standard				
50	2"	0	0	0	100
37.5	$1^1/_2$"	55.50	1.12	1.12	98.88
28	1"	530.20	10.66	11.78	88.22
19.5	$^3/_4$"	1233.50	24.81	36.59	63.41
9.5	$^3/_8$"	1056.50	21.25	57.83	42.17
4.75	No. 4	610.10	12.27	70.10	29.90
2.36	No. 8	455.50	9.16	79.26	20.74
0.425	No. 40	577.20	11.61	90.87	9.13
0.075	No. 200	202.50	4.07	94.94	5.06
Pan		241.50	5.06	100	0.00

Table A-2 Sieve analysis of 20% RCA and 80% CA blended

Sieve designation		Sample retained (g)	% retained	∑% retained	% passing
Standard (mm)	Alternative US standard				
50	2"	0	0	0	100
37.5	$1^1/_2$"	54.50	1.09	1.09	98.91
28	1"	538.50	10.81	11.91	88.09
19.5	$^3/_4$"	146.50	23.02	34.93	65.07
9.5	$^3/_8$"	1062.0	21.34	56.27	43.73
4.75	No. 4	662.0	13.29	69.56	30.44
2.36	No. 8	600.0	12.06	81.62	18.38
0.425	No. 40	615.50	12.36	93.98	6.02
0.075	No. 200	184.0	3.69	97.67	2.33
Pan		116.0	2.33	100	0.00

Table A-3 Sieve analysis of 50% RCA and 50% CA blended

Sieve designation		Sample retained (g)	% retained	∑% retained	% passing
Standard (mm)	Alternative US standard				
50	2"	0	0	0	100
37.5	1 1/2"	164.5	3.3	3.3	96.7
28	1"	556.5	11.17	14.48	85.52
19.5	3/4"	1042.5	20.93	35.41	64.59
9.5	3/8"	1029.0	20.66	56.07	43.93
4.75	No. 4	753.0	15.12	71.19	28.81
2.36	No. 8	456.0	9.16	80.34	19.66
0.425	No. 40	536.0	10.76	91.11	8.89
0.075	No. 200	239.0	4.81	95.91	4.09
Pan		203.5	4.09	100	0.00

Table A-4 Sieve analysis of 80% RCA and 20% CA blended

Sieve designation		Sample retained (g)	% retained	∑% retained	% passing
Standard (mm)	Alternative US standard				
50	2"	0	0	0	100
37.5	1 1/2"	148.5	2.98	2.98	97.02
28	1"	485.5	9.75	12.73	87.27
19.5	3/4"	1044.5	20.97	33.70	66.30
9.5	3/8"	974.0	19.56	53.26	46.74
4.75	No. 4	764.0	15.34	68.60	31.40
2.36	No. 8	462.0	9.28	77.87	22.13
0.425	No. 40	653.0	13.11	90.98	9.02
0.075	No. 200	321.0	6.45	97.43	2.57
Pan		128.0	2.57	100	0.00

Table A-5 Sieve analysis of 100% RCA and 0% CA blended

Sieve designation		Sample retained (g)	% retained	∑% retained	% passing
Standard (mm)	Alternative US standard				
50	2"	0	0	0	100
37.5	1 1/2"	131.6	2.64	2.64	97.36
28	1"	593.5	11.89	14.3	85.47
19.5	3/4"	1065.5	21.35	35.88	64.12
9.5	3/8"	1000.7	20.05	55.93	44.07
4.75	No. 4	714.0	14.31	70.23	29.77
2.36	No. 8	434.6	8.71	78.94	21.06
0.425	No. 40	637.6	12.77	91.72	8.28
0.075	No. 200	308.0	6.17	97.89	2.11
Pan		105.5	2.11	100	0.00

A-2:Specific Gravity and Water Absorption

I) For coarse aggregate. i.e. material retained on 10mm sieved

weight of sample = 2.5kg for one test

Table A-6 Specific gravity & water absorption for coarse aggregate of RCA and CA blended

Blended Ratio	0%RCA: 100%CA		20%RCA: 80%CA		50%RCA: 50%CA		80%RCA: 20%CA		100%RCA: 0%CA	
Trial No.	I	II	I	II	I	II	I	II	I	II
A	2519.4	2520.4	2541.4	2540.8	2573.4	2572.4	2605.8	2615.6	2627.4	2627.8
B	2228	2228	2221.3	2220.7	2211.3	2210.1	2201.4	2211.2	2194.7	2194.9
C	681	680	677	680	678	680	680	678	676	677
D	2482.1	2482.4	2458.4	247.58	2422.9	2421.9	2387.4	2388.4	2363.7	2364
Gsa	2.65	2.66	2.69	2.68	2.72	2.72	2.76	2.79	2.80	2.79
Gsbd	2.55	2.55	2.47	2.46	2.33	2.32	2.20	2.21	2.13	2.13
Gsbs	2.60	2.61	3.58	2.7	2.53	2.52	2.48	2.50	2.46	2.46
W %	1.51	1.53	3.38	3.38	6.21	6.21	9.15	9.51	11.16	11.16
Mean Gsbs	2.60		2.57		2.52		2.49		2.46	
Mean Gsbd	2.55		2.47		2.33		2.21		2.13	
Mean Gsa	2.66		2.69		2.72		2.78		2.80	
Mean W %	1.52		3.38		6.21		9.33		11.16	

Where:

A= Weight of saturated surface dry sample in air Apparent specific gravity (Gsa) = $\frac{D}{(D-(B-C))}$

B= Weight of basket + sample in water Bulk specific gravity OD (Gsbd) = $\frac{D}{(A-(B-C))}$

C= Weight of empty basket in water Bulk specific gravity SSD (Gsbs)=$\frac{A}{(A-(B-C))}$

D= Weight of oven dry sample in air Water absorption (w%) = $\frac{(A-D)}{D} \times 100$

Note: Apparent specific gravity >Bulk specific gravity SSD>Bulk specific gravity OD

A-3:Flakiness and Elongation Index

Weight of sample (w_1) = 2kg for one test. i.e. material pass 50mm & retained on 6.3mm sieved

Table A-7 Determination of flakiness index of RCA and CA blended

Size of aggregate		Corresponding thickness gauge size	Weight of aggregate passing through thickness gauge									
Passing through IS sieve	Retained on IS sieve		0%RCA: 100%CA		20%RCA: 80%CA		50%RCA: 50%CA		80%RCA: 20%CA		100%RCA: 0%CA	
			I	II	I	II	I	II	I	II	I	II
50	37.5	26.2	103	104.2	113	96	124.2	118	141.6	109	95.5	105
37.5	28	19.65	232.8	240	212.4	184	230.4	162.3	242.3	137	121	172
28	20	14.4	154	152	161	152	142.3	152	120	142.2	80	99
20	14	10.2	104.2	100	103.4	86	96.1	86	83.1	64.5	2.3	6.4
14	10	7.2	2.9	3.6	2.6	3.6	3.1	3.4	3.6	4.7	2.1	2.2
10	6.3	4.89	1.2	1.6	1.1	1.6	1.6	2.2	2.2	3.3	1.8	1.6
		Total (w_2) =	598.1	601.4	593.5	523.2	597.7	523.9	592.8	460.7	302.7	386.2
		Fl = $\frac{w2}{w1} \times 100$	29.91	30.1	29.68	26.16	29.89	26.20	29.64	23.04	15.14	19.31
		Avg. FI in %	29.99		27.92		28.04		26.34		17.22	

Table A-8 Determination of elongation index of RCA and CA blended

Size of aggregate		Corresponding length gauge size	Weight of aggregate retained on length gauge									
Passing through IS sieve	Retained on IS sieve		0%RCA: 100%CA		20%RCA: 80%CA		50%RCA: 50%CA		80%RCA: 20%CA		100%RCA: 0%CA	
			I	II	I	II	I	II	I	II	I	II
50	37.5	78.75	48.6	0	129	108	134	116	129.4	105.6	0	52
37.5	28	58.95	179.7	0	91.2	201	84.9	213.2	112.3	213.2	138	140
28	20	43.2	259.5	248.5	71.6	86.4	79	82	96.7	99.4	62.5	75
20	14	30.6	96.2	60.1	37.4	71.1	41	69	51	46.7	31.2	34.1
14	10	21.6	18.1	42.4	41	3.9	3.8	4.1	4.9	3.4	3.2	3.3
10	6.3	14.67	5.7	0	3.2	2.1	2.2	2.3	3.1	1.2	0	1.2
		Total (w_2) =	607.8	351	336.5	472.5	344.9	486.6	397.4	469.5	234.9	305.6
		El = $\frac{w2}{w1} \times 100$	30.39	17.55	16.83	23.63	17.25	24.33	19.87	23.48	11.7	15.28
		Avg. EI in %	23.97		20.23		20.79		21.67		13.51	

A-4:Angularity Number

Note: Angularity number = 67-$\left(\frac{100W}{C\times GS}\right)$Where: W= Mean weight of aggregate in the cylinder

C= Weight of water filling the cylinder=2860 g GS= Specific gravity of the aggregate

Aggregate is sieved through 20mm to 4.75mm sieves.

Table A-9 Determination of angularity number of RCA and CA blended

Blended Ratio	0%RCA: 100%CA		20%RCA: 80%CA		50%RCA: 50%CA		80%RCA: 20%CA		100%RCA: 0%CA	
Trial No.	I	II	I	II	I	II	I	II	I	II
W	3963.5	4028.5	3967.4	4013.6	3973.3	3991.3	3979.1	3968.9	3983	3954
Mean W	3996		3990.5		3982.3		3974		3968.5	
Angular No.	12		11		7		4		2	

A-5:Aggregate Crushing Value (ACV)and Ten Percent Fineness Value(TPFV)

weight of sample = 3kg for one test i.e. material pass 14mm & retained on 10mm sieved

Table A-10Aggregate crushing value determination of RCA and CA blended

Blended Ratio	0%RCA: 100%CA		20%RCA: 80%CA		50%RCA: 50%CA		80%RCA: 20%CA		100%RCA: 0%CA	
Trial	I	II	I	II	I	II	I	II	I	II
M_1	11920.6	11920.6	11920.6	11920.6	11920.6	11920.6	11920.6	11920.6	11920.6	11920.6
M_2	14438.6	14439	14354.1	14354.6	14227.4	14228	14100.6	14101.2	14015.4	14016.8
M_3	2518	2518.4	2433.5	2434	2306.8	2307.4	2180	2180.6	2094.8	2096.2
M_4	495.1	494	496.4	494	496.4	499	500.5	499	519.4	484.1
ACV	19.66	19.62	20.40	20.30	21.52	21.63	22.96	22.88	24.79	23.09
Mean ACV	19.64		20.35		21.57		22.92		23.94	
TPFV	229.54		220.66		205.34		188.49		175.69	

Where:M_1= Mass of mouldM_2= Mass of mould +mass of sample

M_3= Mass of sample filling in the mould = M_2-M_1

M_4= Mass of sample passing 2.36mm sieve

ACV = $\frac{Wt.of\ fraction\ passing\ 2.36mm\ sieve}{Wt.of\ samle\ filling\ in\ the\ mould} \times 100 = \frac{M4}{M3} \times 100$ Equation A-3 (BS)

ACV = 38 - (0.08 x 10%FACT)i.e. TPFV= $\frac{8-ACV}{0.08}$

A-6:Aggregate Impact Value (AIV)

Weight of sample = 3kg for one test i.e. material pass 14mm & retained on 10mm sieved

Table A-11 Aggregate impact value determination of RCA and CA blended

Blended Ratio	0%RCA: 100%CA		20%RCA: 80%CA		50%RCA: 50%CA		80%RCA: 20%CA		100%RCA: 0%CA	
Trial	I	II	I	II	I	II	I	II	I	II
M_1	2819.5	2819.5	2819.5	2819.5	2819.5	2819.5	2819.5	2819.5	2819.5	2819.5
M_2	3446.	3446.8	3439	3440	3427.8	3428.8	3416.5	3417	3409.5	3408.5
M_3	627	627.3	619.5	620.5	608.3	609.3	597	597.5	590	589
M_4	103.5	102.4	100.8	98	97.8	98.2	94.38	96	97.5	86.6
AIV	16.51	16.32	16.27	15.79	16.08	16.12	15.81	16.07	16.53	14.70
Mean AIV	16.42		16.03		16.10		15.94		15.61	

Where: M_1= Mass of mouldM_2= Mass of mould +mass of sample

M_3= Mass of sample filling in the mould = M_2-M_1

M_4= Mass of sample passing 2.36mm sieve

AIV = $\frac{Wt.of\ fraction\ passing\ 2.36mm\ sieve}{Wt.of\ samle\ filling\ in\ the\ mould} \times 100 = \frac{M4}{M3} \times 100$ Equation A-4 (BS)

Note: Compression test machine used for ACV while Impact testing machine used for AIV.

A-7:Los Angeles Abrasion (LAA)

Weight of sample (M_1) = 5kg for one test

Table A-12 Los angles abrasion determination of RCA and CA blended

Blended Ratio	0%RCA: 100%CA		20%RCA: 80%CA		50%RCA: 50%CA		80%RCA: 20%CA		100%RCA: 0%CA	
Trial No.	I	II	I	II	I	II	I	II	I	II
M_1	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
M_2	4463.6	4411.2	4404.2	4400.1	4315.1	4301.3	4224.9	4223.4	4212	4121.2
M_3	536.4	588.8	595.8	599.9	6684.9	698.7	775.1	776.6	788	878.8
LAA	10.73	11.78	11.92	12.0	13.70	13.97	15.50	15.53	15.76	17.58
Mean LAA	11.25		11.96		13.84		15.52		16.67	

Where:M_1= Mass of sample before test M_2= Mass retained on sieve size 1.7mm

M_3= Mass passing sieve size 1.7mm = (M_1-M_2) Number of spheres = 12

LAA = $\frac{Wt.of\ fines\ passing\ 1.7mm}{Wt.of\ sample} \times 100 = \left(\frac{M1-M2}{M1}\right) \times 100$ Equation A-5 (ASTM)

A-8:Compaction (proctor)

I) Moisture content determination by oven dry method

M_1=Mass of container M_2=Mass of moist sample +containerM_3=Mass of dry sample +container M_4=Mass of moisture(water) = M_2-$M_3$$M_5$=Mass of dry sample =$M_3$-$M_1$Moisture content (w%) = $\left(\frac{M4}{M5}\right) \times 100$

Table A-13 Moisture content determination of RCA and CA blended

Blended Ratio	Specimen	Container No./code	M_1 (g)	M_2 (g)	M_3 (g)	M_4(g)	M_5 (g)	W (%)
0%RCA: 100% CA	1	P_{15}	33.5	236.8	231.1	5.7	197.6	2.88
	2	ZE	33	281.6	273.9	7.7	240.9	3.20
	3	A-13	37.7	187.2	181.9	5.37	144.2	3.68
	4	A	35.6	212.8	205.6	7.2	170	4.24
	5	A_2	36.5	197.3	189.9	7.4	153.4	4.82
	NMC	P_5	17.11	126.5	126.18	0.32	108.74	0.29
20%RCA: 80% CA	1	P_{10}	18.4	152.3	147.8	4.5	129.4	3.48
	2	A-11	18.1	140.5	136	4.5	117.9	3.82
	3	B-13	17.6	118.4	114.3	4.1	96.7	4.24
	4	A-7	18.3	132.4	127.3	5.1	109	4.68
	5	B_{14}	17	126.6	121.4	5.2	104.4	4.98
50%RCA: 50% CA	1	A_3	18.4	139.4	132.9	6.5	114.5	5.68
	2	K-4	18	120.2	114.2	6	96.2	6.24
	3	P_{11}	17.7	114	107.8	6.2	90.1	6.88
	4	N	18.2	106.7	100.4	6.3	82.2	7.66
	5	G	17.5	112	104.9	7.1	87.4	8.12
80%RCA: 20% CA	1	G_{10}	24.9	120.2	114.4	5.8	89.5	6.48
	2	P_{12}	32	121.2	115	6.2	83	7.46
	3	A_2	36.5	122.7	116.1	6.6	79.3	8.32
	4	K-4	18	166.4	154.3	12.1	136.3	8.88
	5	P_{11}	17.7	107	99	8	81.3	9.84
100%RCA: 0% CA	1	N_3	17.4	197.1	182.5	14.6	165.1	8.84
	2	B_3	17.5	152.5	139.8	12.7	122.3	10.38
	3	1A	17.3	147.5	133.3	14.2	116	12.24
	4	LC	17.9	142.5	126.3	16.2	108.4	14.94
	5	B-13	17.6	168.1	147.1	21	129.5	16.22
	NMC	K-8	17.8	112.8	107.59	5.21	89.79	5.80

II) Dry density determination

Weight of sample = 4.5kg for one test required. i.e. material pass 19mm sieved

M_1=Mass of mold +Spacer disc M_2= Mass of compacted sample & mold+ Spacer disc

M_3=Mass of compacted sample =M_2-M_1Mold volume = 944/2124 cm^4

Bulk density, $p_{bulk}(g/cm^3) = \frac{M2-M1}{Mold\ volume}$

Dry density, $p_{dry}(g/cm^3) = \frac{p_{bulk}}{1+\text{Actual avg.w\%}}$ 1 gram of water = 1 ml of water

Water Added (in ml)= $\frac{(Sample\ mass\ in\ gram)\times Assumed\ water}{100}$ Equation A-6 (AASHTO)

Table A-14 Dry density determination of RCA and CA blended

Blended Ratio	Sample No.	Assumed W (%)	Water Added	Actual W (%)	M_1 (g)	M_2 (g)	M_3 (g)	p_{bulk}	p_{dry}
0%RCA: 100% CA	1	2	90	2.88	14058.5	15899.3	1840.8	1.95	1.895
	2	4	180	3.20	14058.5	15992.7	1934.2	2.05	1.986
	3	6	270	3.68	14058.5	16059.5	2001.0	2.12	2.045
	4	8	360	4.24	14058.5	16050.3	1991.8	2.11	2.024
	5	10	450	4.82	14058.5	15965.4	1906.9	2.02	1.927
20%RCA: 80% CA	1	2	90	3.48	15217.4	19486.6	4269.2	2.01	1.942
	2	4	180	3.82	15217.4	19586.4	4369	2.06	1.984
	3	6	270	4.24	15217.4	19699	4481.6	2.11	2.024
	4	8	360	4.68	15217.4	19635.4	4418	2.08	1.987
	5	10	450	4.98	15217.4	19538.5	4321.1	2.03	1.934
50%RCA: 50% CA	1	4	180	5.68	15217.4	19124.6	3907.2	1.84	1.741
	2	6	270	6.24	15217.4	19380.6	4163.2	1.96	1.845
	3	8	360	6.88	15217.4	19549.4	4332	2.04	1.909
	4	10	450	7.66	15217.4	19444.2	4226.7	1.99	1.848
	5	12	540	8.12	15217.4	19283.4	4066	1.91	1.766
80%RCA: 20% CA	1	4	180	6.48	15217.4	19257.6	4040.2	1.90	1.784
	2	6	270	7.46	15217.4	19422.9	4205.5	1.98	1.842
	3	8	360	8.32	15217.4	19507.9	4290.5	2.02	1.865
	4	10	450	8.88	15217.4	19465.4	4248	2.0	1.837
	5	12	540	9.84	15217.4	19338.1	4120.7	1.84	1.766
100%RCA: 0% CA	1	4	180	8.84	14058.5	15663.3	1604.8	1.70	1.562
	2	6	270	10.38	14058.5	15795.5	1737	1.84	1.664
	3	8	360	12.24	14058.5	15861.1	1802.6	1.91	1.712
	4	10	450	14.94	14058.5	15841	1782.5	1.89	1.654
	5	12	540	16.22	14058.5	15757.7	1699.2	1.80	1.549

A-9:CBR

I) Dry density determination

weight of sample = 4.5kg for one test required i.e. material pass 19mm sieved

M_1=Mass of mold M_2=Mass of compacted sample & mold

M_3=Mass of compacted sample =M_2-M_1 Mold volume = 2124 cm^4

Bulk density, $p_{bulk}(g/cm^3) = \frac{M2-M1}{Mold\ volume}$ OMC =

Dry density, $p_{dry}(g/cm^3) = \frac{p_{bulk}}{1+w\%}$ NMC=

Water Added (in ml)= $\frac{(Sample\ mass\ in\ gram)\times(OMC-NMC)}{100+NMC}$ Equation A-7 (AASHTO)

Table A-15 Dry density determinationof RCA and CA blended

Blended Ratio	CBR specimen	Mold No.	M_1 (g)	M_2 (g)	M_3 (g)	W (%)	p_{bulk}	p_{dry}
0%RCA: 100% CA	56 blows	M-4	6672.4	10891.9	4219.5	3.34	1.99	1.93
20%RCA: 80% CA	56 blows	T-12	6831.0	10983.6	4152.6	4.72	1.955	1.87
50%RCA: 50% CA	56 blows	T-5	6948.1	11002.2	4054.1	7.35	1.909	1.78
80%RCA: 20% CA	56 blows	M-7	6670.0	10625.6	3955.6	6.92	1.862	1.74
100%RCA: 0% CA	56 blows	G-8	6995.1	10722.8	3727.7	12.4	1.755	1.56

II) Moisture content determination by oven dry method

M_1=Mass of containerM_2=Mass of moist sample +container M_3=Mass of dry sample +container M_4=Mass of moisture(water) =M_2-M_3 M_5=Mass of dry sample =M_3-M_1Moisture content (w%) = $\left(\frac{M2-M3}{M3-M1}\right) \times 100$

Table A-16 Moisture content determination of CBR specimen by oven dry of the blend

Blended Ratio	CBR specimen	Container No.	M_1 (g)	M_2 (g)	M_3 (g)	M_4 (g)	M_5 (g)	W (%)
0%RCA: 100% CA	56 blows	B-13	17.6	120.1	116.8	3.3	99.15	3.34
20%RCA: 80% CA	56 blows	Z	17.7	116.43	111.98	4.45	94.28	4.72
50%RCA: 50% CA	56 blows	N_3	17.4	105.9	100.1	5.8	82.65	7.35
80%RCA: 20% CA	56 blows	B_3	17.7	111.0	104.95	6.05	87.45	6.92
100%RCA: 0% CA	56 blows	K-4	18	101.75	92.55	9.2	74.55	12.4

III) Penetration Test

Table A-17 Reading of a loading ring observed during the penetration test of the blend

Penetration (mm)	Standards load (kN)	0%RCA: 100%CA	20%RCA: 80%CA	50%RCA: 50%CA	80%RCA: 20%CA	100%RCA: 0%CA
		56 blows	56 blows	56 blows	56 blows	56 blows
		Penetration load (kN)	Penetration load (kN)	Penetration load (kN)	Penetration load (kN)	Penetration load (kN)
0		0	0	0	0	0
0.64		1.503	3.13	2.068	1.85	1.61
1.27		3.576	4.73	4.382	4.923	3.331
1.91		6.299	6.17	7.931	8.376	5.32
2.54	13.2	8.895	12.76	11.484	11.423	7.024
3.18		11.754	16.05	15.091	14.506	8.683
3.81		13.605	19.05	18.503	16.949	10.517
4.45		15.132	22.39	21.604	19.078	12.029
5.08	20.0	18.485	25.60	23.873	21.209	13.638
7.62		25.633	38.02	32.346	27.765	18.797

Table A-18CBR (%) value of RCA and CA blended

Blended Ratio: % RCA:% CA	CBR specimen	Penetration (mm)	Penetration load (kN)	Standards load (kN)	CBR (%)	CBR (%) (max)
0:100	56 blows	2.54	8.895	13.2	68.42	92.43
		5.08	18.485	20.0	92.43	
20:80	56 blows	2.54	12.76	13.2	98.14	128.0
		5.08	25.60	20.0	128	
50:50	56 blows	2.54	11.484	13.2	88.34	119.37
		5.08	23.873	20.0	119.37	
80:20	56 blows	2.54	11.423	13.2	87.87	106.05
		5.08	21.209	20.0	106.05	
100:0	56 blows	2.54	7.024	13.2	54.03	68.19
		5.08	13.638	20.0	68.19	

APPENDIX B: RESULTS OF MWA AND CA BLENDED

B-1:Grain Size Analysis

weight of sample = 5kg for one test

% retained on i^{th} $seive$ = $\frac{sample\ retained\ on\ i^{th}\ seive}{Total\ mass\ of\ sample\ retained} \times 100$ Equation B-1(AASHTO)

% passing on i^{th} $seive$ = 100-∑% retained on i^{th} $seive$ Equation B-2(AASHTO)

Table B-1 Sieve analysis of 0% MWA and 100% CA blended

Sieve designation		Sample retained (g)	% retained	∑% retained	% passing
Standard (mm)	Alternative US standard				
50	2"	0	0	0	100
37.5	$1^1/_2$"	55.5	1.12	1.12	98.88
28	1"	530.2	10.66	11.78	88.22
19.5	$^3/_4$"	1233.5	24.81	36.59	63.41
9.5	$^3/_8$"	1056.5	21.25	57.83	42.17
4.75	No. 4	610.1	12.27	70.1	29.90
2.36	No. 8	455.5	9.16	79.26	20.74
0.425	No. 40	577.2	11.61	90.87	9.13
0.075	No. 200	202.5	4.07	94.94	5.06
Pan		251.5	5.06	100	0.00

Table B-2 Sieve analysis of 20% MWA and 80% CA blended

Sieve designation		Sample retained (g)	% retained	∑% retained	% passing
Standard (mm)	Alternative US standard				
50	2"	0	0	0	100
37.5	$1^1/_2$"	0	0	0	100
28	1"	429.0	8.62	8.62	91.38
19.5	$^3/_4$"	1342.5	26.96	35.58	64.42
9.5	$^3/_8$"	1146.5	23.02	58.60	41.40
4.75	No. 4	651.5	13.08	71.68	28.32
2.36	No. 8	540.5	10.85	82.54	17.46
0.425	No. 40	434.5	8.73	91.26	8.74
0.075	No. 200	156.0	3.13	94.40	5.60
Pan		279.0	5.6	100	0.00

Table B-3 Sieve analysis of 50% MWA and 50% CA blended

Sieve designation		Sample retained (g)	% retained	∑% retained	% passing
Standard (mm)	Alternative US standard				
50	2"	0	0	0	100
37.5	$1^1/_2$"	146.0	2.92	2.92	97.08
28	1"	286.5	5.74	8.66	91.34
19.5	$^3/_4$"	1050.5	21.04	29.7	70.30
9.5	$^3/_8$"	1080.0	21.63	51.34	48.66
4.75	No. 4	929.0	18.61	69.94	30.06
2.36	No. 8	603.5	12.09	82.03	17.97
0.425	No. 40	512.5	10.27	92.30	7.7
0.075	No. 200	238.5	4.78	97.08	2.92
Pan		146.0	2.92	100	0.00

Table B-4 Sieve analysis of 80% MWA and 20% CA blended

Sieve designation		Sample retained (g)	% retained	∑% retained	% passing
Standard (mm)	Alternative US standard				
50	2"	0	0	0	100
37.5	$1^1/_2$"	143.5	2.88	2.88	97.12
28	1"	234.5	4.70	7.58	92.42
19.5	$^3/_4$"	1185.5	23.76	31.33	68.67
9.5	$^3/_8$"	1102.5	22.09	53.43	46.57
4.75	No. 4	750.0	15.03	68.46	31.54
2.36	No. 8	556.5	11.15	79.61	20.39
0.425	No. 40	525.0	10.52	90.13	9.87
0.075	No. 200	295.5	5.92	96.05	3.95
Pan		197.0	3.95	100	0.00

Table B-5 Sieve analysis of 100% MWA and 0% CA blended

Sieve designation		Sample retained (g)	% retained (g)	∑% retained (g)	% passing
Standard (mm)	Alternative US standard				
50	2"	0	0	0	100
37.5	$1^1/_2$"	144.7	2.9	2.9	97.10
28	1"	376.5	7.54	10.44	89.56
19.5	$^3/_4$"	1090.7	21.85	32.29	67.71
9.5	$^3/_8$"	1061.4	21.26	53.55	46.45
4.75	No. 4	701.0	14.04	67.60	32.40
2.36	No. 8	650.5	13.03	80.63	19.37
0.425	No. 40	629.6	12.61	93.24	6.76
0.075	No. 200	222.7	4.46	97.7	2.30
Pan		114.6	2.30	100	0.00

B-2:Specific Gravity and Water Absorption

I) For coarse aggregate. i.e. material retained on 10mm sieved

weight of sample = 2.46-2.5kg for one test

Table B-6 Specific gravity & water absorption for coarse aggregate of MWA and CA blended

Blended Ratio	0%MWA: 100%CA		20%MWA: 80%CA		50%MWA: 50%CA		80%MWA: 20%CA		100%MWA: 0%CA	
Trial No.	I	II	I	II	I	II	I	II	I	II
A	2519.4	2520.4	2511.3	2511.5	2499.2	2499.8	2487.2	2488	2479.1	2479.6
B	2228	2228.1	2231.1	2231.3	2235.7	2235.9	2240.3	2241	2243.4	2243.9
C	681	680	680	678	680	676	678	674	673.6	674
D	2482.1	2482.4	2479.9	2480.1	2476.6	2476.2	2473.2	2473.8	2471	2471
Gsa	2.65	2.66	2.67	2.68	2.69	2.70	2.72	2.73	2.74	2.74
Gsbd	2.55	2.55	2.58	2.59	2.62	2.63	2.67	2.69	2.72	2.72
Gsbs	2.60	2.61	2.63	2.63	2.66	2.67	2.69	2.71	2.73	2.73
W %	1.51	1.53	1.27	1.27	0.91	0.95	0.56	0.57	0.33	0.35
Mean Gsbs	2.60		2.63		2.66		2.70		2.73	
Mean Gsbd	2.55		2.59		2.63		2.68		2.72	
Mean Gsa	2.66		2.68		2.70		2.73		2.74	
Mean W %	1.52		1.27		0.93		0.57		0.34	

Where:

A= Weight of saturated surface dry sample in air Apparent specific gravity (Gsa) = $\frac{D}{(D-(B-C))}$

B= Weight of basket + sample in water Bulk specific gravity OD (Gsbd) = $\frac{D}{(A-(B-C))}$

C= Weight of empty basket in water Bulk specific gravity SSD (Gsbs)=$\frac{A}{(A-(B-C))}$

D= Weight of oven dry sample in air Water absorption (w%) = $\frac{(A-D)}{D} \times 100$

Note: Apparent specific gravity >Bulk specific gravity SSD>Bulk specific gravity OD

B-3:Flakiness and Elongation Index

weight of sample (w_1) = 2kg for one test material pass 50mm & retained on 6.3mm sieved

Table B-7 Determination of flakiness index of MWA and CA blended

Size of aggregate		Corresponding thickness gauge size	Weight of aggregate passing through thickness gauge									
Passing through IS sieve	Retained on IS sieve		0%MWA: 100%CA		20%MWA: 80%CA		50%MWA: 50%CA		80%MWA: 20%CA		100%MWA: 0%CA	
			I	II	I	II	I	II	I	II	I	II
50	37.5	26.25	103	104.2	139	140.3	144	135	181.3	121	120	112
37.5	28	19.65	232.8	240	66	89.4	120	74.6	130	84.6	49.6	96
28	20	14.4	154	152	134	142	162	142.9	151	132.9	135.8	142
20	14	10.2	104.2	100	37.6	44	31	40.7	42	41.7	32	42
14	10	7.2	2.9	3.6	4.9	4.2	3.6	4.2	4.2	3.5	2.6	2.2
10	6.3	4.89	1.2	1.6	3.1	2.8	2.2	2.8	1.3	2.4	2.1	1.6
		Total (w_2) =	598.1	601.4	384.6	422.7	462.8	400.2	509.8	386.1	342.1	395.8
		Fl = $\frac{w2}{w1} \times 100$	29.91	30.1	19.23	21.14	23.14	20.01	25.49	19.31	17.11	19.79
		Avg. FI in %	29.99		20.18		21.58		22.4		18.45	

Table B-8 Determination of elongation index of MWA and CA blended

Size of aggregate		Corresponding length gauge size	Weight of aggregate retained on length gauge									
Passing through IS sieve	Retained on IS sieve		0%MWA: 100%CA		20%MWA: 80%CA		50%MWA: 50%CA		80%MWA: 20%CA		100%MWA: 0%CA	
			I	II	I	II	I	II	I	II	I	II
50	37.5	78.75	48.6	0	62	124	61	110	124.2	116.3	54	0
37.5	28	58.95	179.7	0	151	96	141	100.1	96.3	96.9	142	153
28	20	43.2	259.5	248.5	72	84	77	80.2	67.1	86.4	68	77
20	14	30.6	96.2	60.1	38	49	42.6	56	32.5	61.2	33	82.7
14	10	21.6	18.1	42.4	4.7	11.1	5.1	8.1	4.8	5.2	3.2	22.3
10	6.3	14.67	5.7	0	2.9	3.4	3.3	2.3	3.7	2.4	2.2	2.3
		Total (w_2) =	607.8	351	330.6	367.5	330	356.7	328.6	368.4	302.4	337.3
		El = $\frac{w2}{w1} \times 100$	30.39	17.55	16.53	18.38	16.5	17.84	16.43	18.42	15.12	16.87
		Avg. EI in %	15.99		17.45		17.17		17.43		15.99	

B-4:Angularity Number

Note: Angularity number = 67-$\left(\frac{100W}{C\times GS}\right)$ Where: W= Mean weight of aggregate in the cylinder

C= Weight of water filling the cylinder=2860 g GS= Specific gravity of the aggregate

Aggregate is sieved through 20mm to 4.75mm sieves.

Table B-9 Determination of angularity number of MWA and CA blended

Blended Ratio	0%MWA: 100%CA		20%MWA: 80%CA		50%MWA: 50%CA		80%MWA: 20%CA		100%MWA: 0%CA	
Trial No.	I	II	I	II	I	II	I	II	I	II
W	3963.5	4028.5	3988.3	4028	4025.5	4029	4062.7	4029.3	4087.5	4029.5
Mean W	3996		4008.2		4027.3		4046		4058.5	
Angular No.	12		13		13		14		15	

B-5:Aggregate Crushing Value (ACV) and Ten Percent Fineness Value (TPFV)

Weight of sample = 3kg for one test material pass 14mm & retained on 10mm sieved

Table B-10 Aggregate crushing value determination of MWA and CA blended

Blended Ratio	0%MWA: 100%CA		20%MWA: 80%CA		50%MWA: 50%CA		80%MWA: 20%CA		100%MWA: 0%CA	
Trial	I	II	I	II	I	II	I	II	I	II
M_1	11920.6	11920.6	11920.6	11920.6	11920.6	11920.6	11920.6	11920.6	11920.6	11920.6
M_2	14438.6	14439	14424.5	14423.1	14403.4	14408	14382.3	14383	14368.2	14367
M_3	2518	2518.4	2503.9	2502.5	2482.8	2487.4	2461.7	2462.4	2447.6	2446.4
M_4	495.1	494	524.1	522.8	567.5	560	611	613.4	690.7	586
ACV	19.66	19.62	20.93	20.89	22.86	22.51	24.82	24.91	28.22	23.95
Mean ACV	19.64		20.91		22.69		24.87		26.09	
TPFV	229.54		213.61		191.43		164.18		148.92	

Where: M_1= Mass of mould M_2= Mass of mould +mass of sample

M_3= Mass of sample filling in the mould = M_2-M_1

M_4= Mass of sample passing 2.36 mm sieve

ACV = $\frac{Wt.of\ fraction\ passing\ 2.36mm\ sieve}{Wt.of\ samle\ filling\ in\ the\ mould} \times 100 = \frac{M4}{M3} \times 100$ Equation B-3 (BS)

ACV = 38 - (0.08 x 10%FACT)i.e. TPFV= $\frac{8-ACV}{0.08}$

B-6:Aggregate Impact Value (AIV)

weight of sample = 3kg for one test material pass 14mm & retained on 10mm sieved

Table B-11 Aggregate impact value determination of MWA and CA blended

Blended Ratio	0%MWA: 100%CA		20%MWA: 80%CA		50%MWA: 50%CA		80%MWA: 20%CA		100%MWA: 0%CA	
Trial	I	II	I	II	I	II	I	II	I	II
M_1	2819.5	2819.5	2819.5	2819.5	2819.5	2819.5	2819.5	2819.5	2819.5	2819.5
M_2	3446.5	3446.8	3462.9	3463.2	3487.6	348.9	3512.2	3513.6	3528.6	3528.1
M_3	627	327.3	643.4	643.7	668.1	669.5	692.7	6.94.1	709.1	708.6
M_4	103.5	102.4	105.6	110	108.8	110	111.9	113.2	114	116.2
AIV	16.51	16.32	16.41	17.09	16.29	16.43	16.15	16.31	16.08	16.40
Mean AIV	16.42		16.75		16.36		16.23		16.24	

Where: M_1= Mass of mould M_2= Mass of mould +mass of sample

M_3= Mass of sample filling in the mould = M_2-M_1

M_4= Mass of sample passing 2.36mm sieve

$$AIV = \frac{Wt.of\ fraction\ passing\ 2.36mm\ sieve}{Wt.of\ samle\ filling\ in\ the\ mould} \times 100 = \frac{M4}{M3} \times 100 \text{ Equation B-4 (BS)}$$

Note: compression test machine used for ACV while Impact testing machine used for AIV.

B-7:Los Angeles Abrasion (LAA)

weight of sample (M_1) = 5kg for one test

Table B-12 Los angles abrasion determination of MWA and CA blended

Blended Ratio	0%MWA: 100%CA		20%MWA: 80%CA		50%MWA: 50%CA		80%MWA: 20%CA		100%MWA: 0%CA	
Trial No.	I	II	I	II	I	II	I	II	I	II
M_1	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
M_2	4463.6	4411.2	4354.1	4344.1	4189.8	4088	4025.5	3998.4	4012	3820
M_3	536.4	588.8	645.9	655.9	810.2	912	974.5	1001.6	988	1180
LAA	10.73	11.78	12.92	13.12	16.20	18.24	19.49	20.03	19.76	23.60
Mean LAA	11.25		13.02		17.22		19.76		21.68	

Where:M_1= Mass of sample before test M_2= Mass retained on sieve size 1.7mm

M_3= Mass passing sieve size 1.7mm = (M_1-M_2) Number of spheres = 12

$$LAA = \frac{Wt.of\ fines\ passing\ 1.7mm}{Wt.of\ sample} \times 100 = \left(\frac{M1-M2}{M1}\right) \times 100 \text{ Equation B-5 (ASTM)}$$

B-8:Compaction (proctor)

I) Moisture content determination by oven dry method

M_1=Mass of container M_2=Mass of moist sample +containerM_3=Mass of dry sample +container M_4=Mass of moisture(water) = M_2-$M_3$$M_5$=Mass of dry sample =$M_3$-$M_1$Moisture content (w%) = $\left(\frac{M4}{M5}\right) \times 100$

Table B-13 Moisture content determination of MWA and CA blended

Blended Ratio	Specimen	Container No.	M_1(g)	M_2 (g)	M_3 (g)	M_4 (g)	M_5 (g)	W (%)
0%MWA: 100% CA	1	P_{15}	33.5	236.8	231.1	5.7	197.6	2.88
	2	ZE	33	281.6	273.9	7.7	240.9	3.20
	3	A-13	37.7	187.2	181.9	5.37	144.2	3.68
	4	A	35.6	212.8	205.6	7.2	170	4.24
	5	A_2	36.5	197.3	189.9	7.4	153.4	4.82
	NMC	P_5	17.11	126.5	126.18	0.32	108.74	0.29
20%MWA: 80% CA	1	GT	17	148.3	144.9	3.4	127.9	2.64
	2	B_{14}	17	131.3	128.1	3.2	111.1	2.88
	3	P_{11}	17.7	120.4	117.3	3.1	99.6	3.11
	4	B-13	17.6	141.1	137	4.1	119.4	3.43
	5	M	18.6	118.3	114.8	3.5	96.2	3.64
50%MWA: 50% CA	1	GT	17	117.5	115.1	2.4	98.1	2.44
	2	B_{14}	17	116.2	113.6	2.6	96.6	2.68
	3	P_{11}	17.7	104.1	101.7	2.4	84	2.86
	4	B-13	17.6	131.3	127.9	3.4	110.3	3.08
	5	N_3	17.4	122.4	119.1	3.3	101.7	3.24
80%MWA: 20% CA	1	B_{14}	17	119.3	117.3	2	100.4	1.98
	2	B-13	17.6	125.1	122.7	2.4	105.1	2.28
	3	GT	17	130.4	127.5	2.9	110.5	2.62
	4	L	18.9	122.4	119.5	2.9	100.6	2.88
	5	PQ	18.8	109.1	106.4	2.7	87.6	3.08
100%MWA: 0% CA	1	P_{11}	17.7	139.5	137.3	2.2	119.6	1.84
	2	Z	17.7	174.5	171.5	3	153.8	1.96
	3	M	18.6	166.2	163	3.2	144.4	2.22
	4	Q	34	217.4	213.2	4.4	179.2	2.46
	5	R	33.2	225.3	220.4	4.9	187.2	2.62
	NMC	A-6	18.16	120.14	120.0	0.14	101.84	0.14

II) Dry density determination

Weight of sample = 4.5kg for one test required. i.e. material pass 19mm sieved

M_1=Mass of mold + Spacer disc M_2= Mass of compacted sample & mold + Spacer disc

M_3=Mass of compacted sample =M_2-M_1Mold volume = 944/2124 cm^4

Bulk density, $p_{bulk}(g/cm^3) = \frac{M2-M1}{Mold\ volume}$

Dry density, $p_{dry}(g/cm^3) = \frac{p_{bulk}}{1+\text{Actual avg.w\%}}$ 1 gram of water = 1 ml of water

Water Added (in ml)= $\frac{(Sample\ mass\ in\ gram)\times Assumed\ water}{100}$ Equation B-6 (AASHTO)

Table B-14 Dry density determination of MWA and CA blended

Blended Ratio	Sample No	Assumed W (%)	Water Added	Actual W (%)	M_1 (g)	M_2 (g)	M_3 (g)	p_{bulk}	p_{dry}
0%MWA: 100% CA	1	2	90	2.88	14058.5	15899.3	1840.8	1.95	1.895
	2	4	180	3.20	14058.5	15992.7	1934.2	2.05	1.986
	3	6	270	3.68	14058.5	16059.5	2001.0	2.12	2.045
	4	8	360	4.24	14058.5	16050.3	1991.8	2.11	2.024
	5	10	450	4.82	14058.5	15965.4	1906.9	2.02	1.927
20%MWA: 80% CA	1	1.5	68	2.64	15217.4	19772.6	4555.2	2.14	2.085
	2	3.5	158	2.88	15217.4	1993.2	4715.3	2.22	2.158
	3	5.5	248	3.11	15217.4	19988.1	4770.7	2.25	2.182
	4	7.5	338	3.43	15217.4	19944.2	4726.8	2.23	2.156
	5	9.5	428	3.64	15217.4	19800.4	4583	2.16	2.084
50%MWA: 50% CA	1	1	45	2.44	15217.4	19556.1	4338.7	2.04	1.991
	2	3	135	2.68	15217.4	19784	4566.6	2.15	2.094
	3	5	225	2.86	15217.4	19890.2	4672.8	2.20	2.138
	4	7	315	3.08	15217.4	19788	4570.6	2.15	2.086
	5	9	405	3.24	15217.4	19571.6	4354.2	2.05	1.986
80%MWA: 20% CA	1	1	45	1.98	15217.4	19529.1	4311.7	2.03	1.989
	2	3	135	2.28	15217.4	1974.19	4524.5	2.13	2.083
	3	5	225	2.62	15217.4	19826.5	4609.1	2.17	2.112
	4	7	315	2.88	15217.4	19708.1	4490.7	2.11	2.051
	5	9	405	3.04	15217.4	19603.1	4385.7	2.06	1.992
	1	1	45	1.84	14058.	15965.	1906.	2.02	1.98

100%MWA : 0% CA					5	4	9		4
	2	3	135	1.96	14058.5	16025.3	1966.8	2.08	2.040
	3	5	225	2.22	14058.5	16066.8	2008.3	2.13	2.084
	4	7	315	2.46	14058.5	16054.2	1995.7	2.11	2.056
	5	9	405	2.62	14058.5	15993.7	1935.2	2.05	1.996

B-9:CBR

I) Dry density determination

Weight of sample = 4.5kg for one test required. i.e. material pass 19 mm sieved

M_1=Mass of mold M_2=Mass of compacted sample & mold

M_3=Mass of compacted sample =M_2-M_1Mold volume = 2124 cm^4

Bulk density, $p_{bulk}(g/cm^3) = \frac{M2-M1}{Mold\ volume}$OMC =

Dry density, $p_{dry}(g/cm^3) = \frac{p_{bulk}}{1+w\%}$ NMC=

Water Added (in ml)=$\frac{(Sample\ mass\ in\ gram)\times(OMC-NMC)}{100+NMC}$Equation B-7 (AASHTO)

Table B-15 Dry density determination of MWA and CA blended

Blended Ratio	CBR specimen	Mold No.	M_1 (g)	M_2 (g)	M_3 (g)	W (%)	p_{bulk}	p_{dry}
0%MWA: 100% CA	56 blows	M-4	6672.4	10891.9	4219.5	3.34	1.99	1.93
20%MWA: 80% CA	56 blows	N-14	6678.1	11450.6	4772.5	3.63	2.247	2.17
50%MWA: 50% CA	56 blows	T-20	6672.1	11277.4	4605.3	2.85	2.168	2.11
80%MWA: 20% CA	56 blows	T-15	6676.8	11114.9	4438.1	2.54	2.0895	2.04
100%MWA: 0% CA	56 blows	T-11	6949.8	11276.4	4326.6	2.32	2.037	1.99

II) Moisture content determination by oven dry method

M_1=Mass of container M_2=Mass of moist sample +container

M_3=Mass of dry sample +container M_4=Mass of moisture(water) =M_2-M_3

M_5=Mass of dry sample =M_3-M_1Moisture content (w%) = $\left(\frac{M2-M3}{M3-M1}\right)\times 100$

Table B-16 Moisture content determination of CBR specimen by oven dry of the blend

Blended Ratio	CBR specimen	Container No.	M_1 (g)	M_2 (g)	M_3 (g)	M_4 (g)	M_5 (g)	W (%)
0%MWA: 100% CA	56 blows	B-13	17.6	120.1	116.8	3.3	99.15	3.34
20%MWA: 80% CA	56 blows	P_{11}	17.7	93.25	90.6	2.65	72.9	3.63
50%MWA: 50% CA	56 blows	TZ	17.6	115.05	112.35	2.7	94.75	2.85
80%MWA: 20% CA	56 blows	Z	17.7	112.02	109.68	2.34	91.98	2.54
100%MWA: 0% CA	56 blows	L	17.6	110	107.9	2.1	90.25	2.32

III) Penetration Test

Table B-17 Reading of a loading ring observed during the penetration test of the blend

Penetration (mm)	Standards load (kN)	0%MWA: 100%CA	20%MWA: 80%CA	50%MWA: 50%CA	80%MWA: 20%CA	100%MWA: 0%CA
		56 blows	56 blows	56 blows	56 blows	56 blows
		Penetration load (kN)	Penetration load (kN)	Penetration load (kN)	Penetration load (kN)	Penetration load (kN)
0		0	0	0	0	0
0.64		1.503	3.132	1.86	1.35	1.155
1.27		3.576	6.583	2.66	2.96	1.947
1.91		6.299	9.722	6.73	6.33	3.048
2.54	13.2	8.895	12.573	11.46	9.16	5.68
3.18		11.754	15.935	17.79	11.78	6.747
3.81		13.605	18.865	19.90	14.65	8.471
4.45		15.132	21.854	21.24	16.6	10.073
5.08	20.0	18.485	25.117	23.85	19.81	12.504
7.62		25.633	38.032	33.63	28.47	16.645

Table B-18CBR (%) value of MWA and CA blended

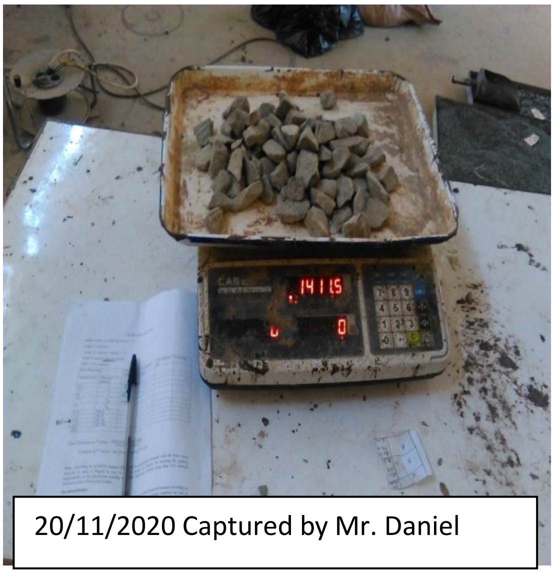
Blended Ratio: % MWA:% CA	CBR specimen	Penetration (mm)	Penetration load (kN)	Standards load (kN)	CBR (%)	CBR (%) (max)
0:100	56 blows	2.54	8.895	13.2	68.42	92.43
		5.08	18.485	20.0	92.43	
20:80	56 blows	2.54	12.573	13.2	96.72	125.59
		5.08	25.117	20.0	125.59	
50:50	56 blows	2.54	11.46	13.2	88.15	119.25
		5.08	23.85	20.0	119.25	
80:20	56 blows	2.54	9.16	13.2	70.46	99.05
		5.08	19.81	20.0	99.05	
100:0	56 blows	2.54	5.68	13.2	43.69	62.52
		5.08	12.504	20.0	62.52	

APPENDIX C: DATA COLLECTION INSTRUMENTS

The apparatus and equipments was used in this studies are a riffle box, sieves, sieve shaker, cylindrical mould, collar, base plate, spacer disc and compaction hammer etc.

Oven dry was used to dry sample. Electronic balance was used to measure the sample. Loading machine, compression testing machine and impact testing machine were used for CBR, aggregate crushing value and impact value.

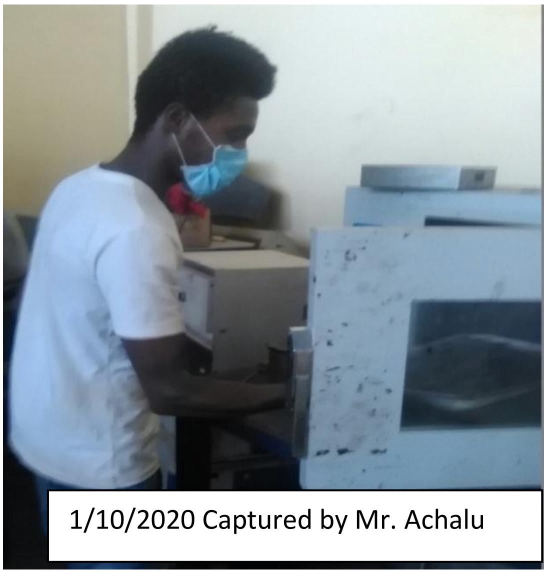
APPENDIX D: PHOTO ILLUSTRATION OF LABORATORY WORK



(a)

(b)

(c)



(d)

(a) Weighing sample (b) Tamping sample (c) Surface drying aggregate using cloth (d) Oven drying sample

APPENDIX E: PHOTO ILLUSTRATION OF SAMPLES

(a) (b) (c)

(d) (e) (f)

(a) Conventional Aggregate (CA) quarry located at Deneba, Jimma (b) Recycled Concrete Aggregate (RCA) crushed with NMZ of 37.5 mm sieve up to 0.075 mm sieve (c) Marble Waste Aggregate (MWA) crushed with NMZ of 37.5 mm sieve up to 0.075 mm sieve (d) Replacement of CA with 50% of RCA (e) Replacement of CA with 50% of MWA (f) Retained sample in sieve analysis