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EXPERIMENTAL STUDY ON THE USE OF RECLAIMED ASPHALT PAVEMENT AS BASE COURSE MATERIALS THROUGH BLENDING WITH CRUSHED STONE AGGREGATES

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ABSTRACT

Overlay and maintenance resolve medium distress, but reconstruction may feasible and economical while Asphalt pavement are badly deteriorated with time and traffic. This requires the removal of existing pavement surfaces. Recycling such construction waste has benefited from economic to sustainability point of view and reduce the exploitation of natural resources. The shortage of virgin aggregate supplies along with the increase in processing and hauling cost have encouraged the use of reclaimed material from the old structure as base course construction materials, and involved in regular practice in various countries around the world. Unfortunately, using Reclaimed asphalt pavement (RAP) is to take off in Ethiopia despite the current ambitions of road building program ongoing. However, RAP material may be not conventional road making materials and need for improvement. This study was aimed to investigation the Engineering properties effect of using RAPs and CSA in their natural state by conducting common laboratory tests in first phase, and Second phase of the study was intended to analysis the strength and interpret the optimum allowable percentage as partial replacement of CSA blended with 10/90, 20/80, 30/70, 40/60, 50/50 proportions by total weights from the two quarries site in Jimma town for RAP as compared results with specification for highly trafficked road (GB1) materials. According to the AASHTO soil classification system the natural and blends of RAP-CSA were classified under A-1-a. The mechanical and physical properties test results for neat natural blended Jimma-Sokoru with Jimma-Agaro roads RAP aggregate gives ACV, AIV, LAA, SG, CBR and Water absorption of 7.9%, 9.5%, 7.8%, 2.31, 42.1% and 0.98% respectively. Also the mechanical blending of 30% RAP aggregate and 70% CSA test results were 15.7%, 12.8%, 16.5%, 107.63%, 2.67 and 1.24% for ACV, AIV, LAA, CBR, SG, Water absorption values respectively with 143KN and 114KN when soaked and unsoaked in water for TFV results. The results obtained from Gradation, Atterberg's limits, SG and water absorption ACV, AIV, LAA, Compaction and CBR results indicate that Mixes containing 30% RAP contents were successful replaced CSA in highly trafficked unbound road base course layer of Asphalt concretes.

KEYWORDS: CBR, CSA, GB1, LAA, Mechanical blending, Strength, RAP.

1. INTRODUCTION

Humanity has traveled the face of the earth throughout untold millenniums and used the natural earth surface for transportation. After the time the road surface was widened and covered with rock and gravel and thus made suitable to tackle, and better increasing number of traffic and challenges from environmental condition has led to establishing pavement design guidelines involving two major pavement types which are based on the assumption that aggregate is essential ingredients of the pavement structure. Asphalt pavements are being increasingly constructed in Ethiopia, as the government is allocating a huge amount of resources to construct and maintaining the existing road network nationwide. The road sector plays crucial role in the economic development of the country. The government has set out a successive Road Sector Development Program to speed up the improvement and expansion of the road network to maintain sustainable development in the country.[1] Even though, the use of virgin aggregate in the asphalt layer is seen as wasteful of limited natural resource, with the need for sustainable development of the country. If asphalt pavements are constructed at one time, it will not last forever. After a time, it needs maintenances and reconstruction. Due to these in a various country, researchers have been conducting the test to recycling of material in high value product, if it is economically feasible. Improving the properties of asphalt layer by altering the virgin aggregate material with recycled material is desirable if it is considered by an engineer.[2] The road shall be reconstructed by milling and replacing the part or entire asphalt pavement. Existing asphalt pavement materials are commonly removed during resurfacing, rehabilitation, or reconstruction operations. Reclaimed asphalt pavement (RAP) is a mixture of aggregate coated with bitumen and is collected from failed asphalt pavement surfaces and is the process in which used asphalt pavement is recycled to reuse.[3] RAP may be generated during cold milling of existing hot mix asphalt (HMA) pavement. Large quantities of Recycled asphalt pavement materials are produced during highway maintenance, demolition, and construction. The RAP material is milled into a well-graded gradation. The millings are loaded onto trucks by the milling machine, removed from the site, and are stockpiled. A part of this can be used in new HMA concrete and rest is available for other uses. If these materials could be recycled for the base - course of the roads, resulting in the minimization of environmental impact, reduce the waste stream and also transportation costs to obtain virgin aggregate that connected with road maintenance and construction activities.[4] One of the today's engineering world cornerstones is sustainability. RAP is the most prominent sustainable materials in asphalt concrete pavements. Developed countries have been used RAP for more than 30 years. In many countries, the use of RAP in surface, base, and sub-base courses is limited, and large quantities of RAP aggregate remain unused. While currently there are many thousands of miles of roads, many of which are near, at or past their design life.[5] The need for roadway maintenance and roadway deconstruction has afforded a material that can be readily used for the repairs and reconstructs. According to the Federal Highway Administration’s (FHWA) recycled materials policy: The same materials used to build the original highway system can be recycled and re-used to repair, reconstruct, and maintain them. Where appropriate, recycling of aggregates and other highway construction materials makes sound economic, environmental, and engineering sense.[6] The major problems facing transportation agencies is the need to maintain and upgrade the level of service that highways provide, while copies with rapidly escalating costs and a nearly fixed level of highway funding. Asphalt pavement recycling can be a part of the solution to this multi-faceted problem. If an existing pavement with a base failure is reconstructed by conventional methods, then the existing pavement material must be excavated and hauled from the site. This produces additional hauling costs, consumes fuel for transportation, provides additional wear on nearby roads, and wastes valuable landfill space. Also, the construction of the replacement, pavement uses virgin aggregate, hauled over the same roads, using additional fuel for transportation and construction.[7] The use of cheaper construction materials without loss of performance is crucial for developing country like Ethiopia. Hence a continuous increase in the cost of conventional construction materials, the researcher explored possible alternative and cheaper in the overall cost of construction without compromising safety. However, using Reclaimed Asphalt Pavement is not common in Ethiopia. While several factors influence the use of RAP in Asphalt pavement, such as costs and scarcity of virgin materials are motivating to use recycled pavement materials in pavement construction by blending with crushed stone aggregates. Currently, the production of demolition and construction waste has been increasing at a gradual rate. The use of RAP material in road construction has been proven to reduce both the rate of depletion of natural resources and the amount of construction debris reaching the urban landfills. The study was intended to investigate the use of Reclaimed asphalt pavement as the base course material through blending with crushed stone aggregate. Different laboratory tests have been conducted on samples that have been collected from two different locations in the Jimma zone to study material properties and find a maximum replacement rate of CSA with RAP needed to produce material that can be used as alternative base course construction material. The tests have been conducted in laboratories found at the Jimma Institute of Technology (JIT) and China Communication Construction Company (CCCC) project. Those tests were, Sieve analysis, ACV, TFV, AIV, LAA, Modified compaction test, CBR, SG and Water absorption tests were used to investigate the materials in the laboratory. The possibility of partially replacing conventional crushed stone aggregate with RAP was assessed to minimize the cost of road construction by incorporating the removed and cheaper construction materials in road projects to the extent they cannot significantly decrease the strength and stability of the whole compacted mass in a base course layer of flexible pavement.

1.1 Statement of the problem

Currently, due to the end up of its design life and traffic loads, asphalt pavements may badly deteriorate. The reconstruction of the pavement may become an economical and feasible solution. Reconstruction of a pavement requires removal of pavement surfaces. Waste asphalt removed from a failed pavement surface is a mixture of aggregate coated with bitumen and is collected from failed asphalt pavement surfaces and has been used as flexible layer construction material for more than 30 years.[8] Successive road improvement and expansion of road network play the crucial role in economic development and to maintain sustainable development of our country. The most common type of pavement structure used for highway construction is flexible pavement which is made up of natural or treated subgrade, unbound subbase and base course materials and bituminous bound surfacing materials. The quality of these pavement structures largely depends on aggregate materials which are the main constituents of pavement structural layers.[9] Since top strata of road pavements (Base course layer) would need high-quality material for construction of asphalt pavement, the locally available material at road project may not provide the projected quality and may not be accessible. Therefore, searching materials beyond 10Km would induce additional cost and can offer the contractors to delay the construction industry. In spite of the steady rise in prices and a shortage of virgin aggregates that is necessary for the production of asphalt concrete base layers. To overcome such problems, appropriate modification and utilization of available marginal materials is the best alternative. All of this has attracted the attention of researcher to modify and utilize the available marginal material that is less expensive and environmentally friendly. Currently, the use of RAP in surface, base, and sub-base courses is not common, and large quantities of RAP aggregate remain unused in our country. While currently there are many roads are past their design life and feasible to reconstruct. RAP will reduce the cost of highway construction and haul, and reduce exploitation of local natural resources. One attractive option is to use the RAP material as a base course with thin overlay. However, the hardness of bitumen in RAP, brittles of age asphalt and fines that may be the problem associated with RAP.

1.2 Research questions

1. Which are the engineering properties of Reclaimed Asphalt Pavement for Base course materials?
2. What is the strength of the modified aggregate base course materials and how much deviation from the ERA Standard Specification?
3. What is the optimum amount of crushed stone which can be replaced by Reclaimed Asphalt Pavement to obtain a stable and strong mix?

1.3. Objectives of the study

1.3.1 General objective

The general objective of this research is to investigate the utilization of Reclaimed Asphalt Pavements in base course construction as a partial replacement to crushed stone aggregate.

1.3.2 Specific objectives

- To determine the engineering properties of Reclaimed asphalt pavement aggregate.

- To analyze the strength of the modified aggregate base course materials and to compare with the ERA standard specification.
- To determine the optimum percentage of Reclaimed Asphalt Pavement replaced in crushed stone aggregate for base course.

1.4 Significance of the study

This study will help further research to be conducted in the area of investigation of reclaimed asphalt pavement on road construction in Jimma Zone particularly and other parts of Ethiopia in general. When the asphalt pavements are badly deteriorated, maintenance and overlay may not be economical, and reconstruction can be a feasible solution by removing these pavement surfaces. By processing these removed surfaces into recycled asphalt pavement material, the amount of using freshly crushed aggregate will have reduced, which implies that the additional cost expensed to fresh stone aggregate are reduced when the optimum amount of RAP mixed with four base course construction. Cost reduced and environmental benefit gained from using waste asphalt fallen from asphalt surfaces as base course material for projects to be built in the study area will help the government to build more road networks by eliminating extra costs of hauling from far distance and time delay, and environmental damage due to exploiting the natural resource. Both clients and contractors were enforced to recycle construction waste material since the shortage of standard material near the project site would face added cost and delay on a construction project. Utilization of RAP materials was not familiar with road construction industries of Ethiopia, due to its characteristic and properties. While mechanically treated with CSA it gives better properties to replace in partial percent for highly trafficked roads. Therefore, client and contractor can utilize a RAP aggregate for unbound base course layer in asphalt pavement construction.

1.5 Scope of the Study

This study reported herein will be confined to the laboratory test to investigating the use of Reclaimed asphalt pavement collected from Jimma-Agaro and Jimma-Sokoru roads in Jimma zone. The relevant laboratory tests that had conducted were Gradation test, ACV, AIV, LAA test, Compaction test, CBR test, Water absorption and SG tests, and then Atterberg’s (Liquid limit, Plastic limit and Plasticity index) test. To achieve the objective of this study, suitability only for base course construction based on ERA specification was checked.

2. Study Area, Materials And Research Methodology

2.1 Study area

Although, the RAP is spreading throughout the country where the asphalt pavement roads are constructed; the study area for this thesis had been located in Jimma zone. This study covers an area where asphalt concrete pavement has been built within Ethiopia regulated by Ethiopian road authority (ERA). The study area is located in Jimma zone, is the southwestern Ethiopia zone and Located in Oromia National, Regional State, the center of the study area, Jimma town, is found at a distance 325 Km from Addis Ababa. It contains around eighteen woredas and 324 kebeles. Jimma zone is known as the smallest part of Ethiopia for that it is a different nation and nationalities from different regions are living this moment. The total area of the study area is around 15,568.58 square kilometers. It has the total population of 2.5 million, approximately The Jimma city is the zone city, and its astronomical location is 7°40′ North Latitude and 36°50′ East Longitude and has altitudes of 1780m-2000m above mean sea level. The groundwater level in the area is variable which ranges from 3- 7m [16]. As data obtained from the Ethiopian Meteorological Agency, Jimma branch, show that, Jimma area has three seasons;

a) Kiremt season (June-September); with the maximum and minimum temperature of 27.13°c and 11.20°c respectively. The rainfall ranges from bega -213mm to kiremt 819mm.
b) Bega season (October-January); with maximum and minimum temperatures of 27.63°c and 8.73°c respectively.
c) Belg season (February-May); with maximum and minimum temperatures of 28.7°c and 11.5°c respectively.

This study was conducted on samples that have been collected from two locations in Jimma area namely: on the Jimma-Sokoru main road to the Capital city of the country, Addis Ababa and Jimma- Agaro Asphalt road. The Figure 2.1 show the map ofthe study areaa, in which the bold marked, was the route under consideration to collect the RAP samples.

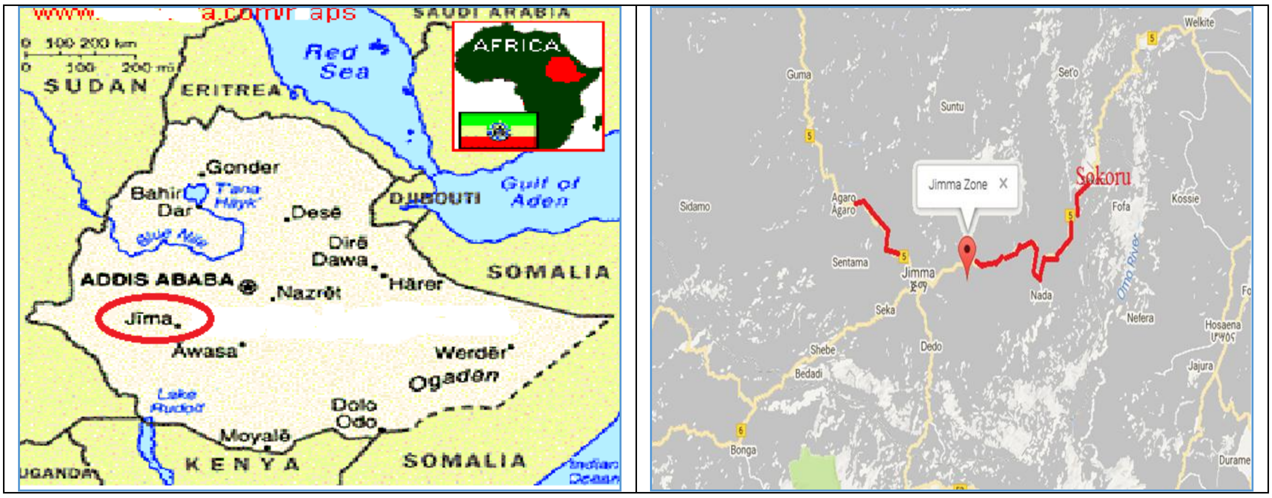

Figure 2.1: Satellite image where samples were taken. (Source: Google map 2017).

Figure 2.2: RAP quarry site on Jimma-Sokoru road.

2.2 Study Design

The study design for this study was an experimental type of study that was started by collecting samples from the study area. Different stages were involved to determine physical and mechanical properties of these materials in a laboratory by experiment. Those were:

Taking samples, Preparation of samples for each laboratory tests, Laboratory tests to check suitability of neat RAP materials and CSA,

The process of blending by 0%, 10%, 20%30%, 40% and 50% of RAPs by weight with conventional crushed stone to find out the maximum replacement amount that satisfies requirements of the standard specification.

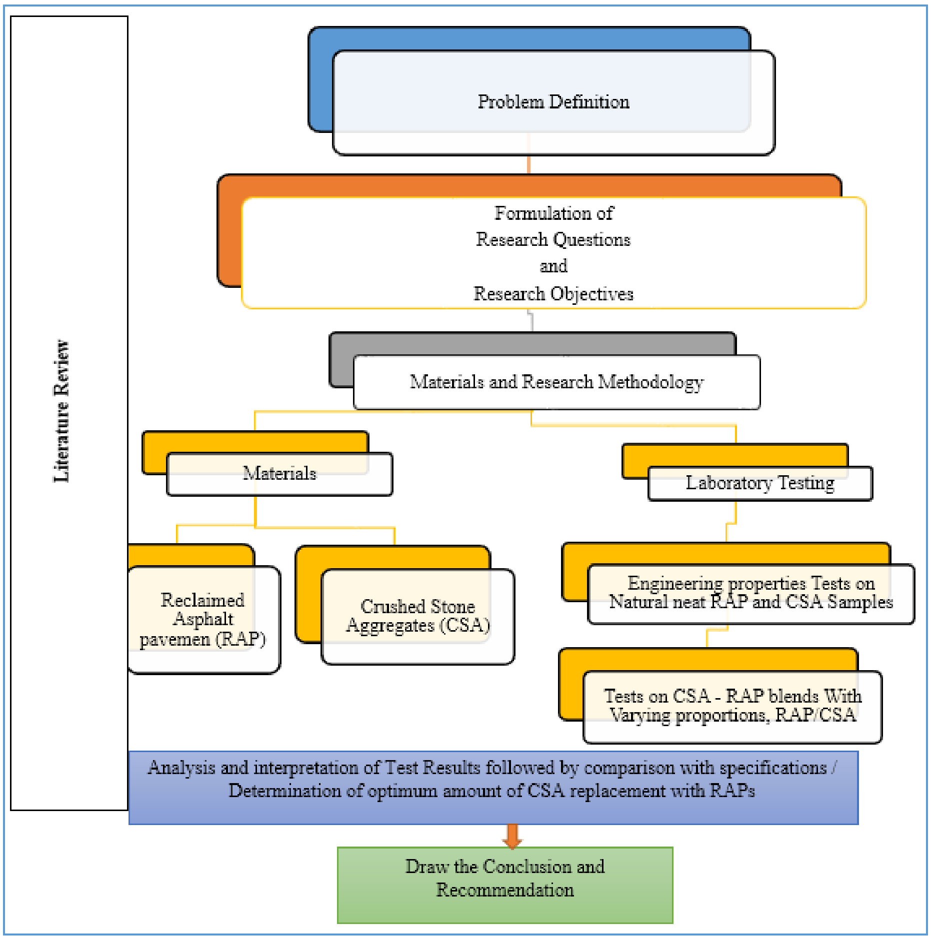

Figure 2.3: Flow chart showing general outline of the study.

2.3 Sampling technique

The Reclaimed asphalt pavements were extracted from two different road areas, namely, Jimma-Sokoru and Jimma-Agaro road which will remain from now on through the paper as their designation in this research for result analysis. The sample source for the RAP were from the ongoing rehabilitation. These locations were selected due to their accessibility and sampling areas were limited to two because of time and money constraints. Representative Samples were collected by the AASHTO T-2 methodology for sampling from stockpiles. Samples of RAP were taken in increments, taking care weathered material not to be included. Chine communication, construction company Jimma Industrial park (CCCC) was supplying CSA for this study.

2.4 Preparation of specimens

After the specimen was collected from the site and transported to the laboratory, the mechanical splitter was used to obtain a uniform and a representative sample for all tests and was used before starting with the testing sample of RAP and CSA. Details of this procedure can be referred in AASHTO T – 248 reducing samples of aggregate to testing size. The test specimens were prepared using a different amount of RAP based on the rate of replacement proportion by weight in the blending. After taking a representative sample by Mechanical splitting, 4 neat and 5 blends sample was prepared with recycled to CSA percent of 0/100% 10/90%, 20/80%, 30/70%, 40 /60 %, 50/50%, and 100/0%.

Figure 2.4: Photo show preparation of specimen for laboratory test.

2.5 Laboratory test

The laboratory test was undertaken to evaluate the mechanical and physical properties of RAP and CSA in detail procedure. The mixture was designed for GB1 unbound granular base course asphalt concrete layer, which is a high traffic road type according to ERA specification. To ensure the accuracy of laboratory result, a careful following of proper test procedure as described by AASHTO, BS and ASTM standard specifications were carefully undertaken. Before commencing the laboratory test, the prepared samples were first air-dried under the sun to allow moisture to evaporate and reduced to test size using a mechanical splitter in accordance with procedures outlined in AASHTO T-248 various laboratory tests were conducted on the samples of RAP and CSA materials. The gathered representative samples for laboratory test were performed in the laboratory of JIT and CCCC Jimma Industrial park.

This study had two phases to meet objective of the research

- The first part of this study focuses on the mechanical characterization and determining of index properties of RAP aggregates as well as conventional CSA.
- The second part is all about determining the optimum RAP –CSA blending ratio.

The following tests were carried out in the first phase includes: Sieve analysis, Atterberg's limits, compaction and CBR tests, ACV, TFV, AIV, LAA, SG and Water absorption had been conducted on RAP samples collected from two different locations (Jimma-Sokoru and Jimma-Agaro roads). On crushed stone aggregate received from the CCCC stockpile for base course construction at the Jimma park site, the tests mentioned above were also conducted. The purpose of this phase was to characterize the properties of the materials and for examining the type and degree of deficiency in the quality of RAP materials as to select the initial mixing ratio of RAP and CSA. The necessary tests were conducted for all the samples, and the summary of the results is presented in a tabulated form to achieve the above-stated objectives. Error! **Unknown switch argument.** shows the trial prweight, of started with minimum %, 10%, by weight of RAP and continued increasing by 10%, to avoid complicated ratios, until the blend fails to satisfy the requirements for base course materials.

Table 2.1: Blending ratios.

No	Sample Designation	% By replacing RAP by weight	% Of Crushed stone aggregate
1	RAP-0	100 (Neat RAP)	0
2	RAP -1	0 (Neat CSA)	100
3	RAP -2	10	90
4	RAP -3	20	80
5	RAP -4	30	70
6	RAP -5	40	60
7	RAP-6	50	50

Note: Percent (0%) RAP samples are to be controlled of purely crushed stone aggregate.

2.5.1 Grain size analysis

Grading of material used as/being used as aggregates was determined by this method. Since Removed Asphalt surface aggregate will often have made up of a grain of many different sizes, the size used in a base course layer should be processed to coarse and fine aggregate size. Grain-size analysis of aggregate containing relatively large particles is accomplished using sieves. It is an apparatus having openings of equal size and shape through which grains smaller than the size of the opening will pass, while larger grains are retained. Sieve analysis involves a nested column of sieves with punch plate, woven wire mesh and or cloth screens nested in decreasing order and the sample is shaken through the sieve until no more will pass and the retained portion on each sieve is weighed and recorded. The calculation is commonly performed to represent the results expressed as percentage passing a particularly selected sieve.[37] This procedure is typically performed on a sample in the dry state; however, wash grading may also be undertaken where the sample is washed over a 0.075mm sieve during the grading process to determine an amount of material passing 0.075mm sieve. Sieve analysis is the name of the operation of dividing a sample of aggregate into fractions, each consisting of particles of the same size. A grain size analysis is used to determine the various amounts of material contained in standard size segments from largest to smallest within a given sample of the aggregate. For base course, the individual grading of each aggregate size used and the combination of these is essential to the production of the material and its ability to withstand and distribute loads during its time in service. Gradation of aggregates affects the compaction characteristics and shearing resistance of the compacted base course layer. Almost all other tests are conducted based on the gradation of the material under study, and it is necessary to accurately conduct this test with good precision.[9] In this test, the method AASHTO T-27 was used. After reducing the sample to test size according to AASHTO T 248, the method for reducing samples of aggregate to testing size the materials were weighed before washing on 0.075mm sieve and placed in an oven. After 24 hours the samples were taken out of the oven and weighed to determine a total amount of material passing 0.075mm sieve, then the dry sample had been shaking through a series of sieves to examine the grain size distribution of aggregate.

2.5.2 Atterberg's limit

Atterberg's Limits are defined as water contents at certain limiting or critical stages in soil behavior. They, along with the natural water content, are the most essential items in the description of fine-grained soils. Determining these Atterberg's limits will help in examining the consistency of the soil and also used for classifying the soil type either using AASHTO or USCS soil classification systems because they correlate with the engineering properties and engineering behavior of soils.[5] The liquid limit, shrinkage limit and plastic limit of soils are collectively referred to as the Atterberg's Limits. The liquid limit is arbitrarily defined as the water content, in percent, at which a part of the soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second. This the moisture content where the soil changes from a piece of plastic to a viscous fluid state. The plastic limit is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2 mm diameter threads without crumbling. This is the moisture content that defines where the soil changes from a semi-solid to a plastic (flexible) state. The plasticity index of soil is the numerical difference between its liquid limit and its plastic limit and is a dimensionless number. The plasticity index is the size of the range of water contents where the soil exhibits plastic properties. Soils with a high pi tend to be clay, those with a lower pi tend to be silt, and those with a pi of zero (non-plastic) tend to have little or no silt or clay.[37] In most cases, it is standard for the road base specification to designate a small amount of plasticity in a product to aid in the compaction of the material and to assist in the surface cohesion of the pavement layer. As there can be traffic movement over a new pavement during construction and as more construction is performed under traffic, a small quantity of plasticity can help to keep the new surface from raveling. That is allowing segregation of the fines away from the coarse particles. The tests were conducted based on procedures outlined in AASHTO T-89 for Liquid limit and AASHTO-90 standard test methods for Plastic Limit.[5]

Classification of soil

A soil classification system is an arrangement of different soils into groups having similar properties. The purpose of soil classification is to make possible the estimation of soil properties by association with soils of the same class whose properties are known and to provide the engineer with the accurate method of soil description. AASTHO and UCS soil classification are among the widely used classification of soil. The soils under investigation have been classified according to AASHTO M-145. Since this method is widely used classification systems in a highway.

Table 2.2: AASHTO soil classification system.

General Classification	**Granular Materials (35% or less of total sample passing No. 200**				**Silt-clay materials (More than 35% of total sample passing No. 200)**	
Group Classification	A-1	A-3	A-2		A-4 A-5	A-6 A-7
	A-1-a A-1-b		A-2-4 A-2-5	A-2-6 A-2-7		A-7-5 A-7-6
Sieve analysis % passing						
No.10	50 max					
No. 40	30 max 50 max	51 min				
No. 200	15 max 25 max	10 max	35 max 35 max	35 max 35 max	36 min 36 min	36 min 36 min
Characteristics of fraction passing No. 40	6 max	NP	40 max 41min 10 max 10 min	40 max 41min 11 max 11 min	40 max 41min 10 max 10 min	40 max 41min 11 max 11 min
Usual type of significant constituent materials	Stone fragments-Gravel and Sand	Fine Sand	Silty or clayey Gravel and Sand		Silty Soils	Clayey Soils

2.5.3 Moisture-Density Relations test

In Geotechnical engineering, soil compaction is the process in which a stress applied to a soil causes densification as air is displaced from the pores between the soil grains. This laboratory test is performed to determine the relationship between the moisture content and the dry density of soil in a specified compaction effort. The compact effort is the amount of mechanical energy that is applied to the soil mass. This laboratory method is used to determine the optimal moisture content at which a given soil type will become denser and achieve its maximum dry density.[38] An essential task of Geotechnical engineers is the performance and analysis of field control tests to assure that compacted fills are meeting the prescribed design specifications. Design specifications usually state the required density (as a percentage of the "maximum" density measured in a standard laboratory test), and the water content. In general, most engineering properties, such as the strength, stiffness, resistance to shrinkage, and imperviousness of the soil, will improve by increasing the soil density. The optimum water content is the water content that results in the greatest density in a specified compaction level. Compacting at water contents higher than (wet of) the optimum water content results in a relatively dispersed soil structure (parallel particle orientations) that is weaker, more ductile, less previous, softer, more susceptible to shrinking, and less susceptible to swelling than soil compacted dry of optimum to the same density. The soil compacted lower than (dry off) the optimum water content typically results in a flocculated soil structure (random particle orientations) that has the opposite characteristics of the soil compacted wet of the optimum water content to the same density. Two methods are outlined namely light and heavy compaction for fine and coarse-grained materials, respectively. Since the materials were tested to be used as base course materials, heavy compaction method is appropriate. The compaction test was performed by the modified proctor testing procedure stated in AASHTO T-180, standard specification for moisture-density relations of soils using a 4.54 kg rammer and a 457 mm drop, method C. The mold dimensions were 101.6 mm in diameter by 116.4 mm in height.[5]

2.5.4. California Bearing Ratio (CBR) test

CBR is a measure of the resistance of a material to penetration of a plunger under controlled density and moisture conditions. The CBR test is one of the most commonly used methods to evaluate the strength of a subgrade soil, sub base, and base course material. The results obtained from these tests are used with the empirical curves to determine the thickness of pavement and its component layers. This is the most widely used methods for the design of flexible pavement. The CBR value for a soil depends upon its density, molding moisture content and moisture content after soaking. The CBR test is a long established, very extensively applied test yielding an empirical measure of the quality of granular road materials. The CBR-test was developed initially for the evaluation of the laboratory and in-situ subgrade strength. Presently, the laboratory CBR-test is used throughout the world as a quick means of characterizing qualitatively the bearing capacity of soils and unbound base and subbase materials.[14] A standard piston is used to penetrate the soil at a standard rate. The pressure up to a penetration of 10mm and its ratio to the bearing value of a standard crushed rock is termed as the CBR. The principle is to determine the relation between force and penetration when a cylindrical plunger with a standard cross-section area is made to penetrate the soil at a given rate. It pushed with a constant 1.27 mm/min displacement rate in a sample contained in a steel cylinder with a diameter of 152.4 mm. Although vast experience is built up with this specific test, it is actually at best a strength test which gives some information on the shear resistance of the material about its degree of compaction and moisture content. The CBR value is determined by the force needed to penetrate the plunger 2.54 mm, and 5.08 mm into the compacted specimens.[5] The method uses material passing 19 mm size and provides the CBR value of material at optimum water content. The specimen shall be soaked before penetration. A surcharge is placed on the surface to represent the mass of pavement material above base course. The sample is soaked to simulate its weakest condition in the field. Expansion of the sample is measured during soaking to check for potential swelling. To determine the strength and swelling potential of the samples, a test has been carried out by 4-days soaking-3-point CBR and loaded Swell testing procedure. The material strength has been used for design purpose by interpolating the CBR values at different compaction levels, with 10, 30 and 65 blows and compacting in 5 layers by heavy compaction. This procedure is necessary to obtain 98% of dry density as determined by laboratory compaction test. Water to be added was calculated from compaction test results which is the OMC obtained at MDD and by considering the natural moisture content of the material on the test. The results of the CBR tests are summarized in the appendix.

2.5.5 Loss Angeles Abrasion resistance test

Abrasion is a measure of resistance to wear or hardness of course aggregates used in pavement design. It is an essential property for road aggregates, mainly when used in wearing coarse. Due to the movements of traffic, the road stones used in the surfacing course are subject to wearing actions at the top. When traffic moves on the road the soil particle which comes between the wheel and road surface causes abrasion on the road stone. The LAA value which is expressed as the percentage of fine material passing the 1.18mm, BS sieves an estimate of the abrasion resistance of the aggregate.[39] The Los Angeles Abrasion test is very widely accepted as a suitable test to assess the hardness of aggregates used in pavement construction. Los Angeles machine and sieves were utilized for the test. Clean oven-dried sample was sieved through a 1.8 mm sieve and weighed. The specimen was placed in the cylinder machine. And then a rotation of 500 revolutions at a speed of 30 to 33 revolutions per minute had been done. After the desired number of revolutions, the material discharged and graded through 1.8 mm size sieve. The material that was coarser than 1.7 mm size had been washed and dried in an oven and weighed. The difference between the original and final weights of the sample was expressed as a percentage of the total weight of the sample and recorded as the percentage wear.

LAA calculation formula

LAA value % $= \frac{M1-M2}{M1} * 100$----------------------Equation 2.1

Where M1=mass of a sample before a test in gm.

M2= the mass of sample retained on sieve 1.7mm in gm. After the test

2.5.6 Crushing value test

The principal mechanical properties required in road stone are:

- Satisfactory resistance to crushing under the rolling during construction and
- Adequate resistance to surface abrasion under traffic

Crushing values test uses the ability of the aggregates used in road construction to withstand the stresses induced by moving vehicles in the form of crushing and also provide sufficient resistance to crushing under the roller during construction. If the aggregates are weak the integrity of the pavement structure is likely to be adversely affected, breaking down on aggregate increase fines and decrease coarse particles of a compacted mass which alters the gradation of the material and cause decrease in the stability and bearing capacity of roads layers constructed by compacting unbound granular materials.[39]

The strength and toughness of coarse aggregates can be measured by ACV test which is a relative measure of the resistance of an aggregate to crushing under gradually applied load. ACV is determined by measuring the material passing a 2.36 mm BS. Sieve after crushing under a load of 400kn applied to test specimens containing fractions of aggregates passing 14mm and retained on 10mm BS sieves. The test samples were pulverized in compression testing machine after 4 hours of drying in an oven and letting them cool. Two trials for each material were conducted and the Average value taken as an ACV for the material. This method is not suitable to indicate the strength and toughness of soft aggregates with an ACV higher than 30 which was the case for all RAP samples collected from two different places. Detailed test procedures can be referred in BS 812: part 110 of ACV and BS 812: part 111 for TFV.

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

$$\text{ACV} = \frac{W2}{W1} \text{---Equation 2.2}$$

Where: WI= Total weight of dry sample taken (in gm).
W2= weight of the portion of crushed material passing 2.36mm IS sieve (in gm).

The most appropriate method of test for aggregates is TFV test. TFV gives a relative measure of the resistance of an aggregate to crushing under a gradually applied load. It is determined by measuring the load required to crush samples prepared in the same way as for ACV test discussed above with the exception that two sets of samples are required, one set for testing in a dry condition while the other for testing in soaked condition to allow an understanding of the change in strength when moist. The trials will be acceptable if 7 -12% of materials passing 2.36mm, BS sieve is produced otherwise the test should be repeated by decreasing or increasing the load.

$$\mathbf{TFV} = \frac{\mathbf{14*f}}{\mathbf{m+4}} \text{--Equation 2.3}$$

TFV calculation formula
Where: f- is the maximum load required to produce (7-12) % of materials passing 2.36mm after compression test

m- is percentage of materials passing 2.36 mm sieve after compression test (should be in the range of 7 -12%).

In ERA pavement design manual there are specific requirements of both ACV & TFV that should be fulfilled by materials to approve their use of a flexible pavement base course material (GB1). The maximum value set under this manual for ACV is 29 while for TFV is a minimum of 111 in dry condition test and 75% and 60% ratio of wet-dry test for areas with typical annual rainfall of >500mm and <500mm respectively.[14] For materials whose stability decreases with a breakdown, an aggregate hardness based on a minimum soaked ten percent fines value of 50 KN may be specified for materials to be used as a GB2 material.

2.5.7 Aggregate Impact Value test

Toughness is the property of material to most comfortable impact. Due to moving loads, the aggregates are subjected to pounding action, and there is a possibility of stones breaking into smaller pieces. Therefore, a test designed to evaluate the toughness of stones, i.e., The resistance of the stones to fracture under repeated impacts may be called Impact test on aggregates.[39] The aggregate Impact value indicates a relative measure of the resistance of the aggregate to a sudden shock or an Impact, which in some aggregates differs from its resistance to a slope compressive load in crushing test. The test can also be carried on cylindrical stone specimen known as a Page Impact test. The test applies to a standard fraction aggregate passing 14mm BS sieve and retained on a 10mm BS sieve. The aggregate impact test is conducted as per BS 812: part112: 1990. The counter fitted to the machine automatically records the number of blows delivered to the sample. Supplied complete with a 75 mm internal diameter measuring detachable metal cylinder cup, and a steel tamping rod, 16 mm diameter, 600 m length and 13.5 to 14 Kg weight. Arrangement for raising the hammer and allow it to fall freely between vertical guides from a height of 38cm on the test sample in the cup. The test sample is subjected to a total of 15 such blows each being delivered at an interval of not less than one second. The crushed aggregate is then removed from the cup and the whole of it is sieved on the 2.36 mm, BS sieve until no significant amount passes and the fraction passing the sieve is weighted accurately to 0.1g. Calculate the aggregate impact value (AIV) expressed as a percentage to the first decimal place for each test specimen from the following expression.

AIV calculation formula

$$AIV = 100 \times M2 / M1 \text{---------------------------------Equation 2.4:}$$

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

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

2.5.8 Flakiness index

Shape test for aggregate materials includes flakiness index, angularity number, and elongation index when used in the construction of pavement, may cause the pavement to fail due to the preferred orientation that the aggregates take under repeated loading and vibration. Elongation Index is the percentage by weight of particles in it, whose largest dimension (i.e., Length) is greater than one and four-fifths times its mean dimension. For base course and wearing course aggregates, the presence of flaky particles is considered undesirable as they may cause inherent weakness with a possibility of breaking down under heavy loads. They are not conducive to good interlocking, and hence the mixes with an excess of such particles are difficult to compact to the required degree. Flakiness index of an aggregate sample is found by separating the flaky particles and expressing their mass as a percentage of the mass of the sample.[39] ERA pavement design manual rates materials for use as a GB1 material inroad by using their flakiness index as determined by tests conducted based on BS 812: section 105.1: 1989. The flakiness index of an aggregate sample is found by separating the flaky particles and expressing their mass as a percentage of the mass of the sample tested. The test is not applicable to materials passing 6.3mm, BS test sieve or retained on a 63.0mm BS test sieve. The test is performed using a measuring gauge that has standard sized slots through which the sample pieces are either passed through or retained. The result is based on a combined Calculation of that which passes through the slots divided by those retained on the gauge. The test is conducted by trying to pass materials prepared by sieving through standard gauges for each fraction of aggregates (50.0mm, 37.5 mm, 28.0 mm, 20.0 mm, 14.0 mm, 10.0 mm, and 6.3 mm) and recording the weights of particles passing and retained. The value of the flakiness index is calculated from the expression blow. This test was conducted on CSA samples.

FI calculation formula

Flakiness Index in %, FI= $\frac{M3}{M2} * 100$--------------------Equation 2.5

Where: M2=total weight of the sample taken, M3= combine and weight all the particle passing each of the gauges

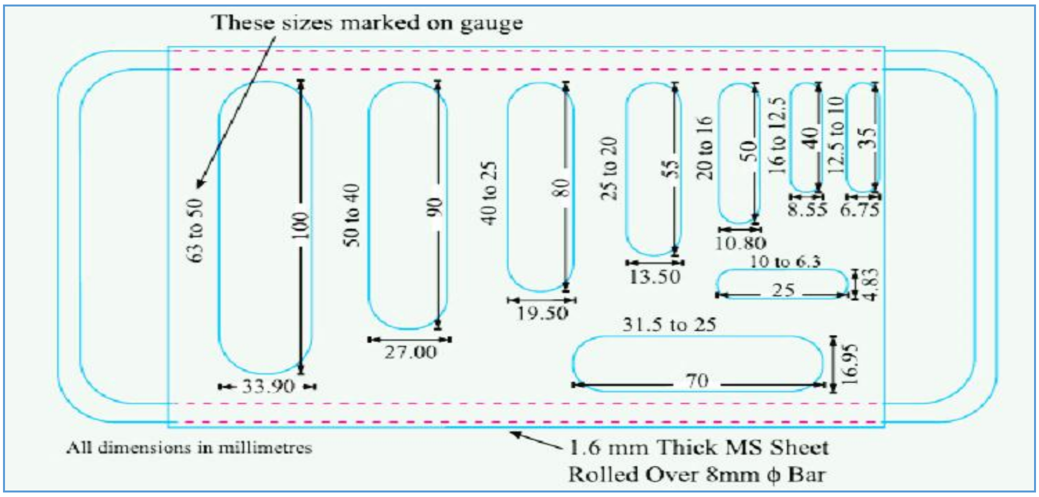

Figure 2.5: Dimensions of thickness and length gauges.

2.5.9 Specific gravity and water absorption test

Specific gravity is the ratio of the mass (or weight, in air) of a unit volume of material to the mass of the same volume of water at the stated temperature to the weight in air of an equal volume of gas-free distilled water at the same temperature. The specific gravity may be expressed as dry bulk specific gravity, saturated bulk specific gravity SSD or apparent specific gravity. The water Absorption is the increase in the mass of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a % of the dry mass. The aggregate is considered dry when it has been maintained at $105C^0$ plus or minus $5C^0$ for sufficient time to remove all. The bulk specific gravity and absorption are based on aggregate after 24 + 4 hours soaking in water. This method is not intended to be used with lightweight coarse aggregate as they may not become saturated after soaking for 15 hours as described in AASHTO T 85 Therefore, AASHTO T-84 method which is used for the determination of absorption and specific gravity of grain size less than 4.75mm was followed instead of AASHTO T-85.[5]

Table 2.3: Summary of test carried out and their uses.

Test conducted	Standard specifications	Purpose of tests
Aggregate Crushing Value (ACV) Test and TFV	BS 812: part 110 for ACV and BS 812: part 111 for TFV	Used to evaluate the crushing resistance of aggregates under gradually applied load.
Los Angeles Abrasion (LAA) Test	ASTM C535-89	Used to evaluate how the aggregate is sufficiently hard to resist the abrasion effect. Or resistance to wearing action.
Flakiness index (FI) test	BS 812: section 105.1: 1989	Used to test course aggregate shape and classify aggregates and stones.
Sieve Analysis	BS1377:Part 2:1990 and ASTM C 136	Used to determine the particle size distribution (gradation) of coarse aggregates.
Moisture-density relation	ASTM C 566-84	Used to determine the dry density and moisture contents of aggregate
California bearing ratio (CBR) test	BS1377: Part 4:1990	Used to determine a strength of base course and other AC layer.
Aggregate impact value (AIV) test	BS 812: part112: 1990	To evaluate the toughness of coarse aggregate under sudden shock or impact.
Atterberg's limit	BS1377: part 2:1990	To evaluate to soil passes from the liquid state to a plastic state for LL and to determine soil in which too dry to be plastic for PL.
Specific gravity and Water Absorption	AASHTO T-84	Used for analysis, aggregate density with relative to water.

3. RESULTS AND DISCUSSION

This chapter presents the result of laboratory investigation and data analysis that conducted to study the effect of using crushed and reclaimed asphalt pavement in partial replacement of crushed stone aggregate for base course material of Asphalt concrete. The experiments evaluate the Mechanical and physical properties of RAP which were sampled from the ongoing rehabilitation of Jimma-Sokoru and Jimma-Agaro roads, and CSA that was sourced from CCCC Jimma industrial park query site. AASHTO, BS and ERA manuals, specifications where the followed procedure during specimens taken, and laboratory test was performed. The samples were collected and laboratory tests conducted on neat RAP, CSA and varying percentage of RAP and CSA in different proportion by weight based. The purpose of this test study was to determine the practicability of RAP for unbound base course layer, comparing engineering properties and recycling the removed asphalt material as the partial replacement with the basalt crushed stone aggregate for highly trafficked roads in Ethiopia country as an improvement for the base course layer.

The following laboratory tests were carried out for base-course asphalt concrete materials.

- Gradation, Flakiness index, Atterberg's limit, Specific gravity and Water Absorption, ACV and TFV, AIV, LAA, Moisture-density relation, CBR test.

3.1 Effect of particle size distribution

The mechanical analysis to determine the proportion of course material distribution by use of sieve analysis were undertaken on RAP sample collected from two quarry sites and crushed stone sampled from one site, and all blended proportional in percent by weight were conducted for gradation tests. The result was expressed by a plot of percent finer (% passing) by weight against the size of soil particles in millimeters on a log scale.

3.1.1 Result for unblended neat RAP and CSA samples

The mix of particles present in the RAP will depend on the asphalt concrete from which it was produced. The gradation of RAP material is comparable to that of a crushed natural aggregate, but, depending on the milling and stockpiling operation, it contains higher courser than the standards of GB1 base course material. This means gradation was not within the standard limit graph. Sieve analysis, conduct on the two RAP sample collected on Jimma-Agaro and Jimma-Sokoru roads showed that the RAP contains Graves and sand particles and also fine particles after washed in a sieve and analyzed. From the

Table 3.1 the maximum particle size ranged from about 0.425mm to 19mm.This crushed RAP contained a high percentage of small diameter materials. Fines (mineral dust) bound to the asphalt during the milling or crushing processes, so they do not appear as fines in the RAP gradation analysis.

Table 3.1: Results of sieve analysis on CSA sample.

Sieve size (mm)	**Weight retained**	**% retained**	**Cumulative % retained**	**% passing**	**ERA specification for GB1**	
					Lower limit	**Upper limit**
50	0	0	0	100	100	100
37.5	0	0	0	100	95	100
25	330.5	11.0	11.0	89	80	100
19	305	10.2	21.2	78.8	60	80
9.5	458.5	15.3	36.5	63.5	40	60
4.75	380.5	12.7	49.2	50.8	25	40
2.36	582.5	19.4	68.5	31.5	15	30
0.6	275.5	9.2	77.7	22.3		
0.425	125	4.2	81.9	18.1	7	19
0.15	145.5	4.9	86.8	13.2		
0.075	75	2.5	89.3	10.7	5	12
Total passing 0.075mm	322	10.7	100.0			

Mass sample before wash(M_1) = 3000 (g)
Mass of sample after wash(M_2**)** **=** 2678 (g)
Total Passng0.075mm sieve (M_1-M_2) = 322 (g)

Table 3.2 and Figure 3.1 results show that gradation of CSA collected from CCCC ltd Jimma park quarry site is parallel to upper and lower limits of the ERA specification recommended value for GB1, which means it would exist between the specification limit as we compared with the ERA specification for GB1 granular unbound base course layer.

Table 3.2: Sieve analysis of blended neat RAP samples

Sieve size (mm)	Weight retained (g) (a)	Percent retained (%) (a/b)*100	Com. % retained (c)	% passing (100-c)
50	0	0.0	0.0	100.0
37.5	35	0.8	0.8	99.2
25	215	4.7	5.5	94.5
19	630	13.9	19.4	80.6
9.5	645	14.2	33.7	66.3
4.75	770	17.0	50.7	49.3
2.36	970	21.4	72.1	27.9
0.425	895	19.8	91.8	8.2
0.075	165	3.6	95.5	4.5
Total passing 0.075mm	205	4.5	100.0	

Mass sample before wash (M1) =4530 (g)

Mass of sample after wash (M2) =4325 (g)

Total Passing 0.075 mm sieve (M1-M2) =205 (g)

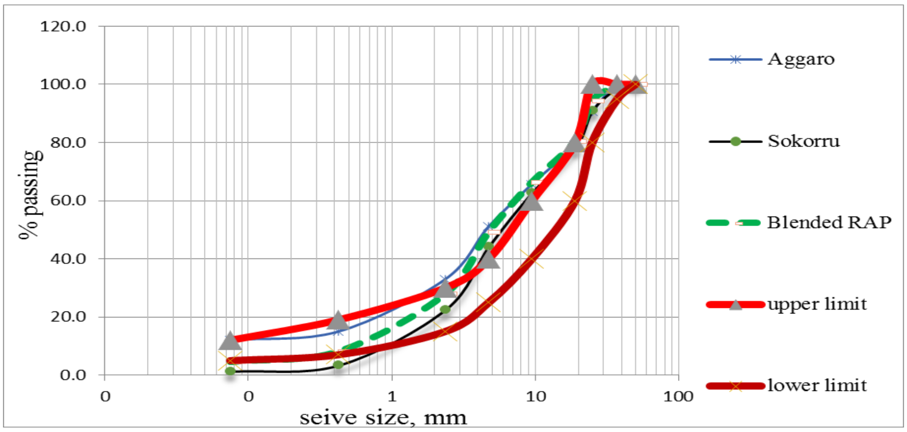

Figure 3.1: Particle size distribution curve for RAP.

The result indicated that the RAP materials collected from the stated site and the blending of both places failed to fit within the gradation limit of the ERA manual specification for GB1 road base course. This means their gradation curve is not parallel with an upper and lower limit of the specification by having fine material less than specified and cause more than the recommended ERA specification values. This was sampled gradation test for RAP aggregate for all blended and unblended samples; the test was conducted according to BS and ERA specification procedure.

3.1.2 Result for RAP-CSA blended sample

RAP from the stated sources was fractioned above or below the ERA specification designated for a base course to evaluate their engineering properties. Therefore, it requires augmentation with fresh aggregate to meet the standard specification. Through trial and error, 40% RAP blended with 60% fresh aggregate were fully fitted with ERA specification for GB1 base course material which is normally used for a heavy trafficked road in Ethiopia. This 40% RAP can be replaced for CSA by having gradation curve within the tolerable limit of GB1 since all blend proportion are parallels to the limited curves requirement, i.e., The upper and lower limit value of the RAP-CSA mixes up to 40% RAP were within the ERA specified. This gives the physical properties of RAP are similar to those of crushed basalt stone at the limited percent.

Table 3.3: Gradation result of blending neat RAPs samples in equal proportion by weight.

Sieve size	**Weight retained (g) (a)**	**% retained b=(a*100/4517)**	**Cumulative % Retained (c)**	**% passing d=(100-c)**
50	0	0	0	100
37.5	32	0.70	0.7	99.3
25	215	4.76	5.46	94.54
19	1130	25.01	30.47	69.53
9.5	1925	42.61	73.08	26.92
4.75	645	14.28	87.36	12.64
2.36	210	4.65	92.01	7.99
0.425	95	2.1	94.11	5.88
0.075	60	1.33	95.45	4.55
Total passing 0.075mm sieve	205	4.55		

Mass sample before wash (M1) =4517 (g)

Mass of sample after wash (M2) =4312 (g)

Total Passing 0.075 mm sieve (M1-M2) =205 (g)

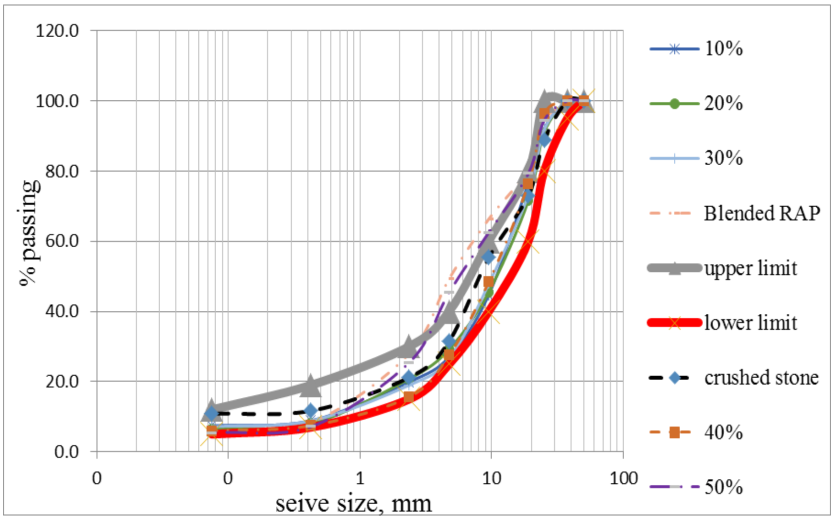

Figure 3.2: Particle size distribution curve for RAP-CSA mixes.

3.2 Effect of Atterberg's limit

To obtain necessary index information about the soil used to estimate the strength and settlement characteristics.

Table 3.2: Result of liquid limit, plastic limit and plastic index of CSA sample.

Item/Description	Liquid limit			Plastic limit	
Trial	1	2	3	1	2
No. Of Blows	28	21	17		
Wt. Of cont. + Wet soil (g)=w1	43.5	45.8	60.3		
Wt. Of cont. + dry soil (g)=w2	42.7	44.7	58.7		
Wt. Of cont. (g) =w3	14.2	14.2	17.2		
Wt. Of water(g)(w1-w2)=x	0.8	1.1	1.6		
Wt. Of dry soil (g) (w2-w3)=y	28.5	30.5	41.5		
Moisture content (%) = (100x/y	2.81	3.61	3.86	0.00	0.00
LL and PL	3.42			0.0	
Plasticity index = LL -PL	3.42				

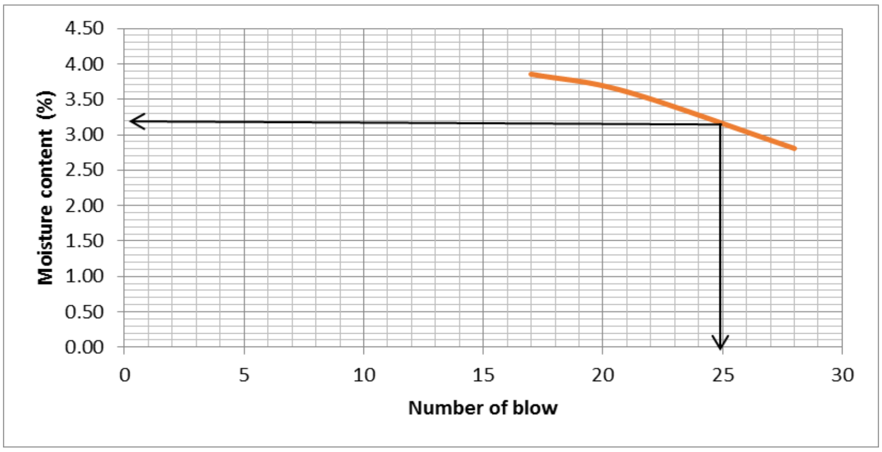

Figure 3.3: Liquid limit curves for CSA sample.

During the liquid limit test for RAP, materials passing 0.425mm was unable to make a paste to be placed in Casagrande's cup of liquid limit testing apparatus to record no. Of blows needed to close the groove opening which is the basic procedure for a liquid limit test. In addition to this, the RAP was also observed to crumble before reaching a thickness of 3.2mm, when rolled in an attempt to determine the plastic limit of the material. This occurs because of the sandy nature of RAP and according to the observations, materials of this type are regarded as non-plastic about according to AASHTO T–90. Hence, both RAP and CSA have a liquid limit (LL<25%) and plastic limit (PL<6) and it is satisfied according to the specification.

Classification of soil

Soils in nature rarely exist separately as gravel, sand, silt, clay or organic matter, but are usually found as mixtures with varying proportions of these components. Grouping of soils by certain definite principles would help the engineer to rate the performance of a given soil either as a base course, sub-base material for roads and other civil works. Among the many soil classification system, the systems that are quite popular amongst engineers are the AASHTO Soil Classification System and the Unified Soil Classification System. This system is used by highway engineers for classification of base course material for the highway pavement. The method used us classifying the soil material are based on grain size distribution and Atterberg's limit (consistence) of a soil.

Table 3.3: AASHTO soil classification for RAPs and CSA before blended.

Sample reference	**% passing sieve**			**Atterberg's limits**			**Classification**
	2mm	**0.425mm**	**0.075**	**LL**	**PL**	**PI**	
Jimma-Agaro	33	15	12	NP			A- 1 - a
Jimma-Sokoru	22.6	3.4	1.3				A- 1 - a
Blended neat RAP	27.9	8.2	4.5				A- 1 - a
Neat CSA	21.2	11.7	10.8	3.42	0	3.42	A- 1 - a

For those materials depend on AASHTO soil classification system the material are granular materials since less than 35% of total samples was passing #200 (0.075mm) sieve size. But, this granular classification also had A-1, A-3 and A-2 sub-classification. Hence again depend on soil passing #10, #40 and #200 sieve size and LL and PL the soil was classified. From the values indicated in the table all materials are classified as A-1-a type of soils having less than 15% of particles passing 0.075mm, less than 30% pass the no. 40 sieve and less than 50%

pass the No. 10 sieve and PI < 6. The material constitutes gravel and sandstone fragment. In the AASHTO classification system, and A-1-a soil is preferred for highway construction soil.

3.3 Specific gravity and Water absorption of aggregate

The aggregate density with relative to water decreases with the increasing RAP amount after blended with CSA. The change of result was observed from.

Table 3.6 when it was blended with a different percent of crushed stone aggregate. The aggregate particles in the RAP were partially covered in asphalt, which decreased the specific gravity.

The result of the discussion was concluded in the form of a table for all the assessed parameters.

Table 3.6 show that the variation of the test results in each trial when it was blended with crushed stone aggregate. ERA specification recommends that specific gravity of 2.65 and above for GB1 base course material. Hence, the result analysis is shown in.

Table 3.6 except blended neat RAP the rest fit the requirements for specific gravity as the value is greater than specifications. RAP sample has a specific gravity range from 2.3 to 2.4 which indicate the lightweight nature of RAP and also implies that lower density of RAP gives lower specific gravity. This is due to minimal fine material in RAP particles. For RAP mix with CSA by percent in weight based, Water absorption range from 1.08% to 1.35%, and show low effective porosity. The neat CSA average absorption is 1.44% by mass with range values of 1.23% to about 1.65% with a minimum and maximum value, respectively. Low water absorption neat RAP, while comparing to neat CSA, shows that neat RAP material were not absorbed more water than that of CSA and this result were due to an asphalt coated that can resist water to absorbed by a recycled material. As a percent of RAP blending were increased the both Specific gravity, and water absorption values are decreased.

Table 3.6: Specific gravity and Water absorption of aggregate results.

Samples Designations	Specific gravity			Water absorption (%)
	Apparent	Bulk(dry)	Bulk(SSD)	
RAP-0 (Neat RAP)	2.4	2.31	2.34	0.92
RAP-1(Neat CSA)	2.86	2.78	2.81	1.44
RAP-2	2.81	2.72	2.75	1.35
RAP-3	2.79	2.70	2.73	1.27
RAP-4	2.76	2.67	2.71	1.24
RAP-5	2.76	2.66	2.70	1.23
RAP-6	2.67	2.61	2.64	1.20

The general procedure and test result of RAP – CSA mixes and its natural state were described in Table 3.6.

3.4 Flakiness index Effect

As explained in Section 2.5.8, Flakiness index is usually conducted for checking the suitability of material produced by crushing operation to avoid flaky materials because they offer reduced resistance to traffic load during their service life. RAP used in this tested was mostly rounded particles; hence visual inspection was enough to determine as it has no problem on natural RAP aggregate. According to Table flakiness index conducted for fresh stone aggregate that used for this tested indicate that the aggregate sample used were suitable for base course ma%, which having flakiness index about 13.94% which is much less than the maximum limit of ERA specification, that does not exceed 30%.

Table 3.7: Results of Flakiness index for CSA samples.

Sieve Analysis			Gauging		Remarks
Sieve size (mm)	Wt. Ret consists of at least 200 pieces (w1) g	% Ret	Gauge range	Wt. of sample passing the gauge (w2) g	ERA specification
50	1350	25.96	63-50	190	Maximum limit of Flakiness index in %, Not to exceed 30%
37.5	1150	22.11	50-37.50	165	
28	900	17.31	37.5-28	120	
20	600	11.54	28-20	80	
14	550	10.57	20-14	65	
10	350	6.73	14-10	60	
6.3	300	5.78	10-6.3	45	
Total	5200	100		725	
Flakiness index (%)		13.94			< 30%

3.5 Effects of Aggregate Impact values

Aggregate impact value tests were conducted for RAP sampled from two sites (Jimma-Agaro and Jimma-Sokoru road site), mixing samples of two sites in one to one ration by weight (blended neat RAP), neat CSA samples and on a sample prepared by RAP blended with CSA samples to determine its strength under impact wheel load.

3.5.1 AIV test Result of unblended RAP and natural CSA Material

Table 3.8 result showed that RAP cothe nearly similar AIV testent road site have nearly similar AIV test while CSA attained higher value than RAP contents. This laboratory result shows at natural state RAP aggregate were good resistance to sudden shock or impact occurred due to vehicles than that of CSA tested here. This could be occurred because the aggregate used in RAP during construction has good resistance to impact and the RAP was covered by asphalt content that would resist to crushed under sudden force.

Table 3.4: Results of AIV test for RAP and CSA samples.

Samples	AIV (%)	Specification
Jimma-Agaro site RAP	10.4	AIV<30 %
Jimma-Sokoru site RAP	9.35	
Blending both site RAP	9.5	
CSA	18.7	

3.5.2. Result of blended RAP- CSA Materials.

The summary of test result for RAP-CSA blends with a different replacement rate of RAP with crushed natural aggregate (10% to 50%) shown in nce under sudden traffic force.

Table 3.5 explains that AIV were decreased slightly from 15.8% to 12.5%the proportional percentcontents increased in proportional percent to CSA samples. Hence, as per ERA specification, both RAP and blended RAP-CSA proved good resistance under sudden traffic force.

Table 3.5: Results of AIV test for Blends of RAP with CSA samples.

% of RAP added to AIV test	10	20	30	40	50	CSA-only	RAP-only
AIV (%)	15.8	14.2	12.8	13.7	12.5	18.7	9.5
Specification	AIV≤30%						

3.6 Effects of Los Angeles abrasion test

All quarried RAP samples, CSA and samples prepared by blending of RAP with CSA in different proportion by their weight were tested for LAA to evaluate the Mechanical strength of the material and judge their suitability according to ERA specification for base course material.

3.6.1 LAA test Result of unblended RAP and natural CSA Material

Table 3.6: Results of LAA test for neat RAP and CSA samples.

Samples	**LAA (%)**	**Specification**
Jimma-Agaro RAP	6.2	LAA ≤ 51%
Jimma-Sokoru RAP	10.1	
Neat blended RAP	7.8	
Neat CSA	27.0	

The result of the material test shows that even before blending RAP with CSA all samples of RAP were within the allowable ERA specification requirement. This implies that RAP material is so hardest material to resist wearing load happen on it, and it was covered by asphalt that would resist as it was not crushed under any load. Hence the material has higher resistance to abrasion than the tested CSA.

3.6.2 The LAA result after RAP Blended with CSA Material

LAA test was conducted on different proportion with the percent of RAP and natural CSA replaced by a percent of RAP varies 10%-50%. The results of the test were summarized in ere tested and had 27% values.

Table 3.7. The result shows that all RAP-CSA blended aggregate are satisfying ERA specification for GB1 base course material and RAP blends are appropriately used in high traffic conditions. The five blended RAP-CSA sample average a loss of 11.6% with a minimum and a maximum of 25%. The RAP sample proved to be more durable than CSA materials that were tested and had 27% values.

Table 3.7: Results of LAA test after Blends of RAP with CSA samples.

% of RAP added to Test for LAA	**10**	**20**	**30**	**40**	**50**
LAA (%)	25.0	21.5	16.5	15.9	11.6
ERA specification	LAA ≤ 51%				

This was LAA test procedure and test result for RAP and CSA samples and blends of those materials within the replacement rate to determine its characteristics and engineering properties.

3.7 Effects of Aggregate crushing value and Ten percent fines value tests

To evaluate the strength of RAP and CSA it is important to carry out ACV and TFV tests for RAP, CSA, and RAP-CSA blend in different proportion by their weight. The recommendation should be given depending on ERA specification manual.

3.7.1 Results of the test conducted on natural RAP and CSA material samples

The table is shown in **Table 3.8** is the result of ACV and TF in restablishing RAP from two sites and CSA into establish baseline data before blended to each other. The average ACV of RAPs samples was smaller than that of CSA base course material, i.e., RAP samples are more durable to resist crushing load that CSA base course materials with a minimum of 7.1 to 10.6 % maximum respectively. There was a small decrease in TFV between on soaked and soaked condition which point out the less sensitivity of RAP to moisture change which may be due to RAP was covered by asphalt and their ability to lose water quickly. Whereas CSA sample attains an ACV of 19.9% and TFV of 192 well achieving the requirements showing strong and tough nature of the CSA. But RAP materials were having less TFV than a requirement in a maximum of 115% and a minimum of 86.7 % with an average of 95% which less toughness of RAP. Requirements of values in the pavement design manual to be used as road base GB1material are maximum 29% of ACV and minimum 111Kn TFV with minimum wet to dry ratio of 65%. In this regard, RAP samples do not satisfy the requirements of ERA concerning the values obtained in TFV to be used as GB1 material although they were behind the specification in a small amount. ERA states that for materials whose stability decreases with a breakdown, an aggregate hardness based on a minimum soaked 10%fine value of 50 KN may be specified to categorize materials under GB2 and GB3 group. Accordingly, all samples satisfy this.

Table 3.8: Result of ACV and TFV test for RAP and CSA samples.

Samples	ACV (%)	TFV (KN)		ERA specification
		Soaked	Unsoaked	
Jimma-Agaro RAP	7.1	84.6	69.2	TFV>111KN ACV<29%
Jimma-Sokoru RAP	10.6	115	86.7	
Neat blended RAP	7.9	95	71	
Neat CSA	19.9	192	171	

3.7.2 Results of the test conducted on blended RAP with CSA material samples

The result of laboratory tests **Table 3.9** is conducted for crushing test on specimens prepared by combining CSA ofh a RAP of 50%, 40%, 30%, 20%, and 10% for base course. The ACV result shows that replacing CSA with all RAPs is not out of ERA standard specification requirement for GB1 base course material which requires a maximum value of 29%. As the percentage RAPs increase the loss due to crushing were decreased with a maximum and minimum of 18.1% to 12.8 % respectively.

It provides RAPs material is more hard material to stand under crushing force than natural CSA material. Contrary to the strength behavior, it was found that as the amount of recycled material in the blend increased, the TFV of the blended material was decreased, since the RAPs materials were partially coated with asphalt and rounded in shape made supple rather than breaks into small pieces, so it crashed before reaching the maximum load in the compression machine.

Table 3.9: Results of ACV test after Blends of RAP with CSA samples.

Percent (%) of RAP added to Test for ACV		**10**	**20**	**30**	**40**	**50**	**ERA specification**
ACV (%)		18.1	16.3	15.7	14.2	12.8	ACV<29%
TFV (KN)	Soaked (a)	185	158	143	132	119	TFV>111KN
	Un soaked (b)	164	136	114	111	104	
Ratio a/b (%)		89	86	80	84	87	Ratio >75

3.8 Summary

The tested RAP content material was satisfying principal mechanical properties of stone materials, which are satisfactory resistance to crushing under the roller during construction of the road and adequate resistance to surface abrasion under traffic loads due to vehicles. The RAP- CSA blends aggregate tested in replacement of unbound base course GB1 with 10%, 20%, 30%, 40% and 50%of RAP with its complement of CSA indicated (15.8% - 12.5% for AIV), (18.1% - 12.8% for ACV) and (25% - 11.6% for LAA) as the maximum and minimum value of the test. It implies that all mixes were strong enough used for the base course layer of GB1 layer according to ERA specification.

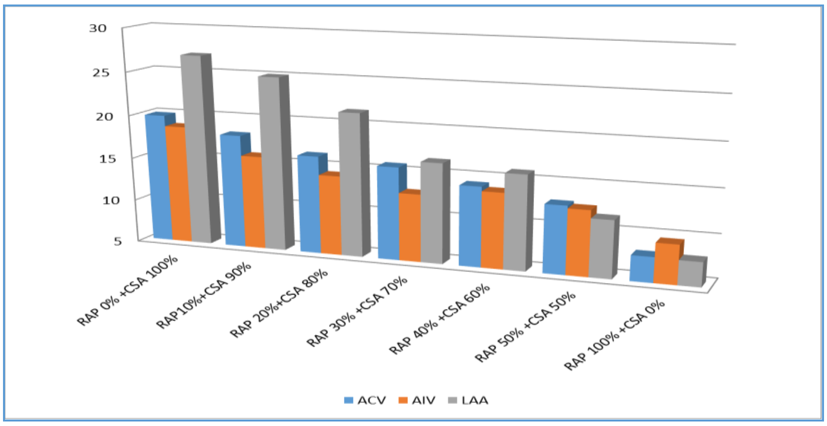

Figure 3.4: Value of parameter at various compositions of RAP and CSA.

As shown in Figure 3.4, the low values indicated that the fraction of aggregate crushed is low and hence stronger and tougher the aggregate and it can capable of withstanding on higher wheel loads due to traffic. The best combination was observed on every combination of RAP and CSA; even natural RAP samples provides to be more durable than CSA materials that were tested. Since all test results are within ERA specification.

3.8.1 Laboratory Compaction Tests

Important properties that need to be determined are OMC and MDD of the CSA and RAP aggregates in natural and blended proportional. A specimen of the two quarry site, Jimma-Agaro and Jimma-Sokoru, recycled asphalt concrete, and natural CSA and the blend with CSA at different percent proportion by weight were tested. A batch of five samples was tested for each blended and unblended RAP and natural CSA samples. Specimens prepared for CBR and Procter compaction tests used the materials with maximum particle size of 19 mm according to AASTHO T180 procedures to determine the optimum water contents and maximum dry densities. The summary of the test results was shown in the tables below, and individual results of all samples were included in appendix A-2 of this paper.

3.8.2 Results of the test conducted on natural RAP and CSA material samples

Table 3.14 indicated the effect of recycled content on MDD and OMC of samples content RAP sample collected from Jimma-Sokoru and Jimma-Agaro roads. The samples have a similar result of MDD and OMC while CSA has higher MDD and OMC when related to RAP since the presence of coated asphalt reduces the amount of water needed to achieve the required compaction level of the RAP mixture, because of the surface coating of stone particles. CSA had an average maximum dry density of 2.22 g/c^3 with minimum and maximum values of 2.18 g/c^3 and 2.26 g/c^3 respectively. On the other hand, neat RAP had an average maximum density of 1.83 g/c^3 with values ranging from 1.72 g/c^3 to 1.96 g/c^3. It was found that CSA had a higher MDD than pure RAP (100% RAP) materials. It was further assumed that the partial coating reduces the RAPs water absorption, which leading to a reduction water to achieve maximum dry density.

Table 3.10: Result of compaction test on Natural CSA and RAP samples.

Samples reference	Material Descriptions	OMC (%)	MDD (g/cc)
Jimma-Agaro	RAP	6.77	1.81
Jimma-Sokoru	RAP	6.45	1.82
Neat Blended	RAP	6.64	1.83
CSA	Basalt stone	7.46	2.22

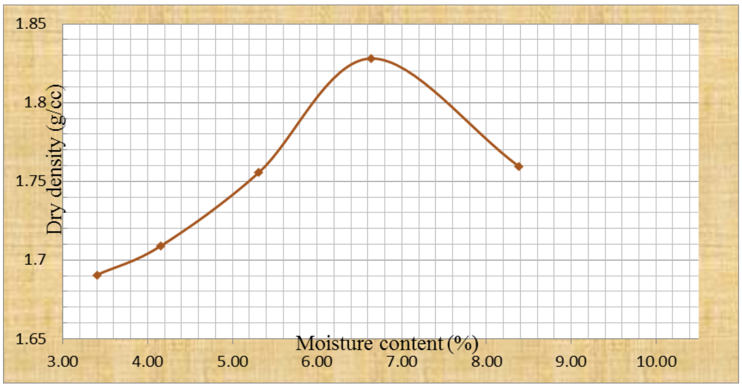

Figure 3.5: Dry density vs. Moisture content curve for blended neat RAPs.

3.8.3 Results of the test conducted on blended RAP with CSA material samples

For various blends of RAP with pure aggregate, some trends were noted Regarding the effect of RAP content on the MDD and OMC of material. From the result, we observe that the increase in RAP content of the blend leads to a decrease in maximum dry density and OMC values this is due to the coat on asphalt concrete prevent compaction by consolidation and minimizing the number of fines in RAPs particles. Hence, as the RAP contents in CSA-RAP blends by weights were increased, the density was decreased, and its permeability was increased that were from 2.20g/cc to 1.98g/cc as RAP contents increased from 10% to 50% respectively. The increased permeability also limits the soil's ability to hold enough water to allow the soil particles to easily shift and properly interlock during compaction. Which has led to a reduction in the required water to achieve MDD. Therefor CSA had a higher density (2.22g/cc) an average value of 2.18 g/cc minimum and 2.26g/cc maximum values than pure and blended RAP (1.83g/cc) in average values in mixes.

Table 3.15: Result of compaction test on blended CSA and RAP samples.

Samples Designations	Material Descriptions	OMC (%)	MDD (g/cc)
RAP-1	Neat CSA	7.46	2.22
RAP-2	CSA- RAP blend	7.35	2.20
RAP-3	CSA- RAP blend	7.21	2.17
RAP-4	CSA- RAP blend	7.13	2.09
RAP-5	CSA- RAP blend	6.94	2.05
RAP-6	CSA- RAP blend	6.88	1.98
RAP-0	Neat RAP	6.64	1.83

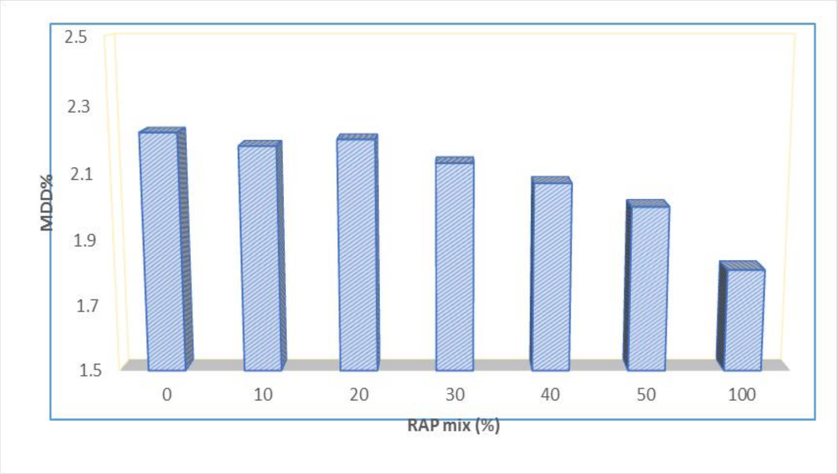

Figure 3.6: Result of MDD vs. RAP-CSA blends in percent.

3.8.4 Result of CBR test

Jimma-Agaro road RAPs, Jimma-Sokoru road RAPs, neat blend of Jimma-Sokoru and Jimma-Agaro roads RAPs, neat CSA, and the mixing of RAP-CSA materials are experimental tested for CBR at a different rate. Using three way method, 12 test batch of CBR was conducted on neat RAP and neat CSA in a natural state, and 15 test batch was conducted on mixes of RAP-CSA in weight basis. The stability and strength of asphalt concrete construction material layers are evaluated by CBR parameters. Hence to investigate the possibility use of RAP for base course material as a partial replacement CBR test is performed on natural neat RAP, neat CSA, and a blend of RAP-CSA materials in proportion of 0%, 10%, 20%, 30%, 40% and 50% of RAP and its complements percent of crushed stone aggregate collected from CCCC Jimma industrial Park quarry site. The CBR results obtained from each sample of RAP, CSA and blends of them were under specific and on specific. The laboratory test results for each blended and unblended was listed in Table 3.19 and Table 3.20, respectively.

3.8.5 Test Result on natural CSA and RAP samples

In the study area the CBR of the natural aggregate was shown in **Error! Reference source not found.** The result show that CBR values of RAP were ranging from 22.5% to about 78.3%. The reason between higher difference can be the compaction test of density attained during a compaction test. From compaction laboratory test result, it can observe that there is a big difference between natural neat RAP material and virgin stone aggregates at the same compaction effort. More specifically, the maximum dry densities of compacted RAP have an average of 1.83 g/cc with that of CSA were 2.22 g/cc. When comparing with ERA specification swelling factory is so small, ranging from 0.01% to about 0.03% minimum and maximum value respectively. But for GB1 unbound base courses less or equal to 2% were recommended ERA specification accordingly.

Table 3.11: Result of MDD and OMC for blended neat RAPs.

Modified Proctor: T 180	
MDD (g/cc):	1.83
OMC(%):	6.6
98% of MDD(g/cc)	1.79

Table 3.12: Result of DD and MC before and after soaking for blended neat RAPs.

	Before Soaking		**After Soaking**	
Blows	**DD**	**Moisture**	**DD**	**Moisture**
	(g/cc)	**(%)**	**(g/cc)**	**(%)**
10	1.74	2.75	1.72	5.07
30	1.77	4.91	1.78	5.19
65	1.89	2.58	1.89	4.06

Table 3.13: Result of CBR and swelling value for blended neat RAPs.

Blow	**LOAD (KN)**		**CBR (%)**		**Swell %**
	2.54mm	**5.08mm**	**2.54mm**	**5.08mm**	
10	3.17	4.63	24.37	23.17	0.02
30	5.43	7.33	41.73	36.63	0.01
65	8.40	11.52	64.58	57.62	0.01

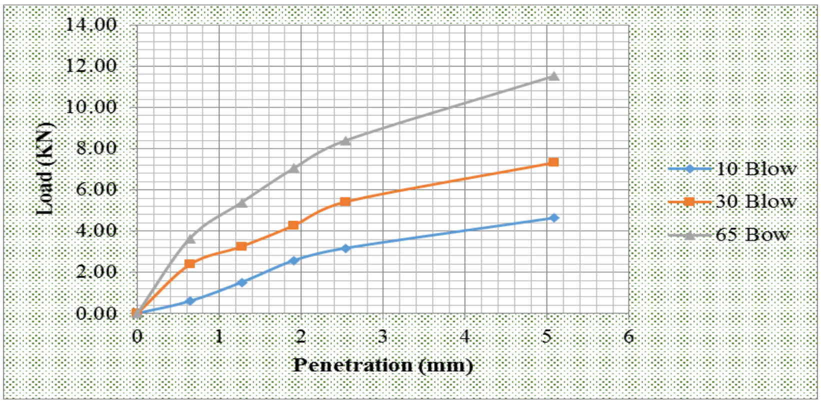

Figure 3.7: Load- penetration curve for three methods of blended neat RA.

Table 3.14: Result of CBR test for natural materials.

Sample Designations	Compaction test			CBR test results				CBR @ 98 % of MDD
	OMC (%)	MDD (g/cc)	98% of MDD	# of blow	DD (g/cc)	swell	CBR %	
Jimma-Agaro	6.77	1.81	1.77	10	1.35	0.24	22.54	43.2
				30	1.72	0.21	38.99	
				65	1.83	0.15	56.05	
Jimma-Sokoru	6.45	1.82	1.78	10	1.86	0.32	33.51	34.1
				30	1.90	0.20	49.96	
				65	2.17	0.12	78.29	
RAP-1 (CSA only)	7.46	2.22	2.17	10	2.10	0.22	67.0	176.9
				30	2.15	0.16	160.8	
				65	2.21	0.08	205.3	
RAP-0 (Blended neat RAP)	6.64	1.83	1.79	10	1.74	0.02	24.4	42.1
				30	1.78	0.01	41.7	
				65	1.89	0.01	64.6	

3.8.6 Test Result on Blended RAP-CSA samples

As shown in Table 3.20, when RAP content wreduced, whichin the mixes CBR values were reduced which imreducedthat Blending RAP with CSA leads to reduce CBR values of the mixes. It showed that by adding RAP as low as 30% into CSA can reduce the CBR value below GB1 base course material expansiveness of the materials, is also measured by swelling properties. It can be concluded that the higher the compaction effort (dry density), the higher CBR that can be achieved. It means the maximum and minimum swelling were ranging from 0.24 to 0.11 respectively. But the ERA specification for base course material gives maximum swelling of 2<=. Therefore, the material was not expansiveness properties when blended.

Table 3.15: Result of CBR for RAP-CSA blended samples.

Sample Designations	Compaction test			CBR test results				CBR @98 % of MDD
	OMC (%)	MDD (g/cc)	98% of MDD	# of blow	DD (g/cc)	Swell	CBR %	
RAP-2	7.35	2.20	2.16	10	2.06	0.16	59.1	169.4
				30	2.08	0.20	136.2	
				65	2.15	0.12	166.9	
RAP-3	7.21	2.17	2.13	10	1.93	0.24	57.0	129.52
				30	2.05	0.20	104.2	
				65	2.20	0.11	160.8	
RAP-4	7.13	2.13	2.05	10	1.82	0.22	69.8	107.63
				30	2.02	0.20	94.6	
				65	2.16	0.16	135.6	
RAP-5	6.94	2.05	2.01	10	2.02	0.19	60.3	98.03
				30	2.09	0.12	93.5	
				65	2.18	0.12	125.3	
RAP-6	6.88	1.98	1.94	10	2.02	0.21	51.8	80.1
				30	2.09	0.20	82.2	
				65	2.07	0.12	111.7	

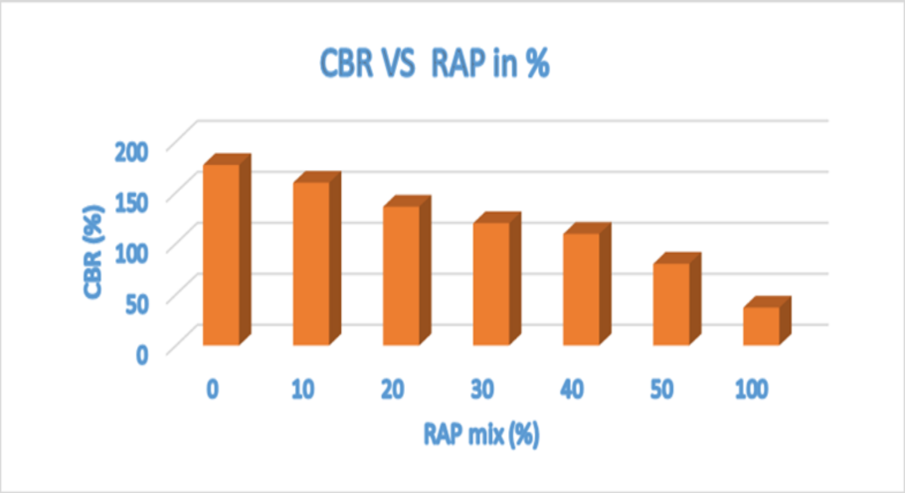

Figure 3.8: Effect of RAP-CSA blends on CBR values.

Table 3.16: Summary of all laboratory tests results.

Material descriptions		**RAP-0**	**RAP-1**	**RAP-2**	**RAP-3**	**RAP-4**	**RAP-5**	**RAP-6**	**ERA specification values**
Material Reference		**Neat CSA**	**10%**	**20%**	**30%**	**40%**	**50%**	**Neat Blended RAP**	
ACV (%)		19.9	18.1	16.3	15.7	14.2	12.5	7.9	< 29%
AIV (%)		18.7	15.8	14.2	12.8	13.7	12.5	9.5	< 30%
LAA (%)		27.0	25.0	21.5	16.5	15.9	11.6	7.8	< 51%
TFV (Kn)	soaked	192	185	158	143	132	119	95	>111kN
	Un soaked	171	164	136	114	111	104	71	
	Un Soaked/ soaked	89	89	86	80	84	87	74.7	>75 %
CBR (%)		176.9	169.4	129.52	107.63	98.03	80.1	42.1	>100%
Sp. gravity		2.78	2.72	2.70	2.67	2.66	2.61	2.31	>2.65
Water Absorption (%)		0.92	1.08	1.20	1.24	1.27	1.35	1.61	< 2%
Flakiness index (%)		13.94	Not determined						< 30%
Atterberg's limit	LL (%)	3.42							< 25 %
	PI	3.42							< 6%

4. CONCLUSION

This study is essential to deal with the use of marginal aggregates, RAPs material, the wasted and environmentally friendly construction materials, specifically in unbound granularly GB1 base course layer. Several experimental findings were evaluated on the mechanical and physical properties of a granulate material (i.e., Natural aggregates, RAPs, and various RAP-CSA blends) under different laboratory tests. Based on those laboratory results, the following conclusions were drawn.

The engineering properties evaluation results show that neat RAP material has less loose and excellent resistance to crushing under the roller during road construction and when it was opened to traffic with ACV in the range of 7.1% and 10.5%, AIV of 9.3% and 10.4%, LAA of 6.2% and 10.1%, in maximum to minimum values respectively. However, the CBR of neat RAP aggregate was low with a value of 42.1%. The maximum particle size ranged from about 0.425mm to 19mm that would provide more course particle than the recommended and lacking course material make as a gradation of RAP doesn't fit the requirement for the GB1 base course layer. The specific gravity of testing RAPs was ranging 2.3 to about 2.4, and water absorption was very low due to covered by asphalt contents in the range of 0.83% to 1.05%. However, some properties were PL<25%, PI<6% and the ACV and AIV<30%, LAA<51% of RAPs aggregates were very tough and good strength under crushing during construction and sudden traffic load and low Water absorption, the CBR <80%, TFV<111KN, SG <2.65 gradations are not in the range of ERA specification. Therefore, natural neat RAP aggregate can't be used for high traffic roads GB1 base course layer of Asphalt concrete without modifying of their properties.

As investigating the results of modified aggregates based on weight gives, ACV was varying from 18.1% to 12.8%, AIV (15.8%-12.5%), LAA (25%-11.6%), Specific gravity (2.78-2.61), CBR value (169.4%-80.1%), TFV (185kN-119kN when soaked and 164kN-104kN when unsoaked), and PI (3.92%) when mixed in respecting from 10%-50% RAPs material and its complements CSA. According to the ERA specification for GB1 unbound base course materials to be used for base course of highly trafficked roads, the laboratory test results of ACV<29%, AIV<30%, TFV>111kN, LAA<51%, CBR >100%, Specific gravity >2.65, and PI <6%.

The use of RAPs in unbound road base layers Asphalt concrete after blending with CSA as per ERA specification for GB1 base course standard is technically viable. CBR, Specific gravity, water absorption and loss due to crushing stress were decreased with increasing RAP content in blending proportion. It was observed that 30% by weight replacement of CSA with RAPs aggregate was successfully used for GB1 base course layer as CBR and TFV test results, and all RAPs aggregates have good strength and toughness to standing under sudden wheel load and crushing force during construction applied than natural aggregates were tested, as ACV, AIV, LAA tests were investigated on RAPs samples. Even though, RAP content in the RAP-CSA mix has the strongest impact on the properties of individual blends.

As it was seen from Gradation and Specific gravity results from 40% of blended and also from water absorption, liquid limit, plastic limit and plasticity index show that all (50%) the blended RAP-CSA percent can be easily used for GB1 base course layer accordingly ERA standard. As it measured by standard laboratory tests, it could be concluded that replacing 30% RAPs contents by weight with CSA can be the optimum contents that suitable to be used in pavements base course layer.

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