PARTIAL REPLACEMENT OF CRUSHED AGGREGATE BASE COURSE MATERIAL WITH CINDER GRAVEL AND FINE SOIL

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ABSTRACT

Base course, the layer incorporating flexible pavements, is usually built directly under the asphalt-wearing course. The quality of base course materials is essential and is evaluated as per International and local specifications. Contrary to the usage of quality materials for better performance, it is equally important to use locally available and out of specification, materials if adequate performance and project cost reduction could be achieved. The objective of this study was partially replacing crushed aggregate base course materials by cinder gravel and fine soil. In this research study, sample of cinder gravel from location around Wolaita Sodo, was blended with fine soil and crushed aggregate for the base course layer. The laboratory experiments carried out using AASHTO procedures of testing materials. There were two phases of mix proportions. The first phase of blending was carried out by varying an amount of fine soil as 10%,20%,30% and 40% an optimum amount of fine soil needed to stabilize cinder gravel has been found to have 20% by weight proportion. The second phase of trial proportioning composed of the three blended components was starting from a proportion of crushed aggregate, cinder gravel and fine soil 100%: 0% :0%. An incremental of cinder gravel and fine soil and decrease of crushed aggregate revealed that the CBR value at the proportion 40%: 48%: 12% satisfies the minimum requirement of ERA specification for base course layer.

Keyword: - *Mechanical Stabilization, Cinder Gravel, Crushed Aggregates, Fine Soils, Soaked CBR, Trial, Proportioning*

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1. INTRODUCTION

Flexible pavement is commonly used all over the world whose design process has undergone through numerous phases of development, which resulted in the present-day design guidelines. The most widely used design method is based on the AASHTO Guide for the design of pavement structures. This method of pavement design is based on the result of the AASHO road test [2]. According to Araya, another design method that is widely used in (sub) tropical countries, including Ethiopia, is the Overseas Road Note 31 [1].

The two widely used types of flexible pavements are the conventional flexible pavement and the full depth flexible pavement. Conventional flexible pavements are layered systems with better materials on top where the intensity of stress is high and inferior materials at the bottom where the intensity is low. The design method incorporates the layers constructed one over the other to carry the traffic load, which is expected to use the pavement during the design period [8].

Base course materials are designed and built with materials having a better bearing capacity compared to the sub base and sub-grade soil. Different design manuals recommend the margin of specifications, which base course materials must satisfy. It is essential that the designer prepare special provisions to the standard specifications when circumstances indicate that nonstandard conditions exist for a specific project [2].

1.1 Objective of the study

The objective of this study is to partially replace crushed aggregate base course material with cinder gravel and fine soil using mechanical stabilization for asphalt cement pavements.

1.2 Statement of the problem

Currently cinder gravels are being used only as subgrade replacement, capping and sub-base materials on very few occasions. They are not being used in the road base layer of any roads. Thus, if the behavior of cinder gravels is understood to allow its use in road bases, then there is significant potential for road construction cost savings [5]. The pavement design manual of Ethiopian Roads Authority [3] specifies that cider gravels can be used as a road base material for low volume roads (T1 and T2). However, for roads with a design traffic volume of more than one million equivalent standard axles, the materials that are commonly used for base course construction are the high-quality crushed aggregates even if materials of marginal qualities exist in abundance quantities and at a near hauling distance. In Ethiopia, a huge amount of the budget is allocated for road construction every year. As a developing country, a significant reduction in the cost of road construction is necessary to satisfy the need of other sectors without affecting the road sector. Hence, an appropriate utilization of locally available cinder gravels for the base course instead of crushed standard base course would reduce the cost of the road project.

In this research study, an investigation of the partial replacement of crushed aggregate with cinder gravel and fine soil by mechanical stabilization was performed on samples extracted from Wolaita zone around Sodo, Southern Ethiopia

1.3 Scope of the study

This research focused on an investigation of the structural performance of crushed aggregate base course materials with cinder gravel and fine soil for AC pavement through using the physical and mechanical properties of different mix proportion of samples by conducting laboratory test. The relevant laboratory tests to characterize the materials performed as follows: Gradation, Atterberg's limit tests, California Bearing Ratio, and Compaction tests. The results obtained, were compared with the ERA specifications.

2. LITERATURE REVIEW

2.1 Definition and Location of Cinder Gravel in Ethiopia

The term cinder, commonly called volcanic ash (scoria) is used to describe a slaggy porous light material cooling from a volcano eruption. Volcanic cinders are pyroclastic materials associated with recent volcanic activity. With the aid of aerial photographs, a map was prepared to show the distribution of cinder gravels throughout Ethiopia. Cinder gravels were mostly concentrated in the Rift Valley, which extends from Tanzania and Kenya and bisects the country in an SSW-NNE direction; an indication of their frequency for each of the areas that were identified has been given [10].

2.2 Experimental Use of Cinder Gravel in Ethiopia

Cinder gravels typical of those used in the full-scale road trials and with particle size distributions similar to those shown in figure 2.1 can be used for road bases in lightly trafficked surface dressed roads. Such gravels have now been tested for carrying a traffic loading of 440,000 esa, which is close to the design for 500,000 esa included in Road Note 31 [9].

The Ethiopian Road Authority (ERA) and Cardno Emerging Markets and TRL have made a joint research project in Ethiopia and conducted laboratory investigation on the use of cinder gravels in pavement layers for Low-Volume Roads is [5]. It was a research project conducted laboratory tests on 56 samples taken from 30 locations of 13 cinder cones. The sample taken was up to three beings (50kg) from a single borrow pit. In this project, the samples were tested for Maximum dry density, California bearing ratio, gradation, 10% fines aggregate crushing test, aggregate crushing value. According to this report, a reluctance to use cinder (scoria) in the past has stemmed from the view that its properties, in terms of grading and CBR strength, are marginal and highly variable when compared to specifications for road materials. Some of these materials investigated can be used in each of the structural layers of the pavements of low volume roads [5].

As was found out by Gareth et al., blending cinder sample from one of the locations with fine materials and crushed stone by a proportion of 50%/20%/30% enhanced its soaked CBR from 46% to 55-60% and non-soaked CBR from 55% to 80%-85% [5].

One reason for the limited use of volcanic cinder gravels up to the present is that they are generally deficient of fine material and do not conform to the grading specifications for conventional crushed rock bases. Another reason is that they have a reputation for being difficult to compact [10].

2.3 Cinder gravel stabilized with other materials

According to Girma, stabilizing natural cinder gravel samples taken from Alemgena and lake Chamo with the optimum amount of 7% cement satisfies the UCS of 3.0 MPa as specified in ERA and AACRA pavement design standards for the heavily trafficked base course without adding fine soils. However, this high cement requirement was reduced to 5% cement, which is a practical value by mechanically stabilizing cinder gravel with 12 % of fine soils before cement stabilization [6]

Thomas, in his master's thesis, conducted a laboratory investigation on stabilizing cinder gravel with natural Pozolana (Volcanic ash). Maximum dry density and corresponding optimum volcanic ash amount for four, eight, twelve, sixteen, twenty, and twenty four percent of volcanic ash are used to determine the optimum amount of 20% [11]. Hadera also carried out laboratory-based investigation on cinder gravel and reported that neat cinder gravel had a 4-day soaked CBR of 72% at 98% maximum dry density. When blending cinder gravel with 22% volcanic ash, the soaked CBR increased to 145%. The cinder gravel was mixed with 20% volcanic ash and 2% lime, the 4-day soaked CBR increased to 184% [7]. Yitayehu in his laboratory experiment found out that an optimum amount of fine-grained soil required to improve its properties is 19% by mass proportion [12].

2.4 Base course Material specifications as per ERA Manual

The particle size distribution recommended by [3] for crushed stone base course materials (GB1) is shown in table 2.1

Table 2.1: Grading Limits for Graded Crushed Stone Base Course Materials (GB1) [3]

Test sieve (mm)	Percentage by mass of total aggregate passing test sieve		
	Nominal maximum particle size		
	37.5	28	20
50	100	-	-
37.5	95 – 100	100	-
28	-	-	100
20	60 – 80	70 – 85	90 – 100
10	40 – 60	50 – 65	60 – 75
5	25 – 40	35 – 55	40 – 60
2.36	15 – 30	25 – 40	30 – 45
0.425	7 – 19	12-24	13 – 27
0.075 (1)	5 – 12	5-12	5 – 12

Note 1: For paver laid materials a lower fine content may be accepted

Regarding the strength requirement for natural coarsely graded granular material, including processed, and modified gravels when compacted to maximum density in the laboratory, the material must have a minimum CBR of 80% after four days immersion in water [3].

3. RESEARCH METHODOLOGY

3.1 Location of the study area

Wolaita Sodo is found in average latitude of 6.48^0-6.53^0N and longitude of 37.44^0-37.46^0E with an elevation of 2056 meters above sea level which is located 387 km from the Capital, Addis Ababa City. The town lies in the climatic zone *dega* that is considered ideal for agriculture as well as human settlement

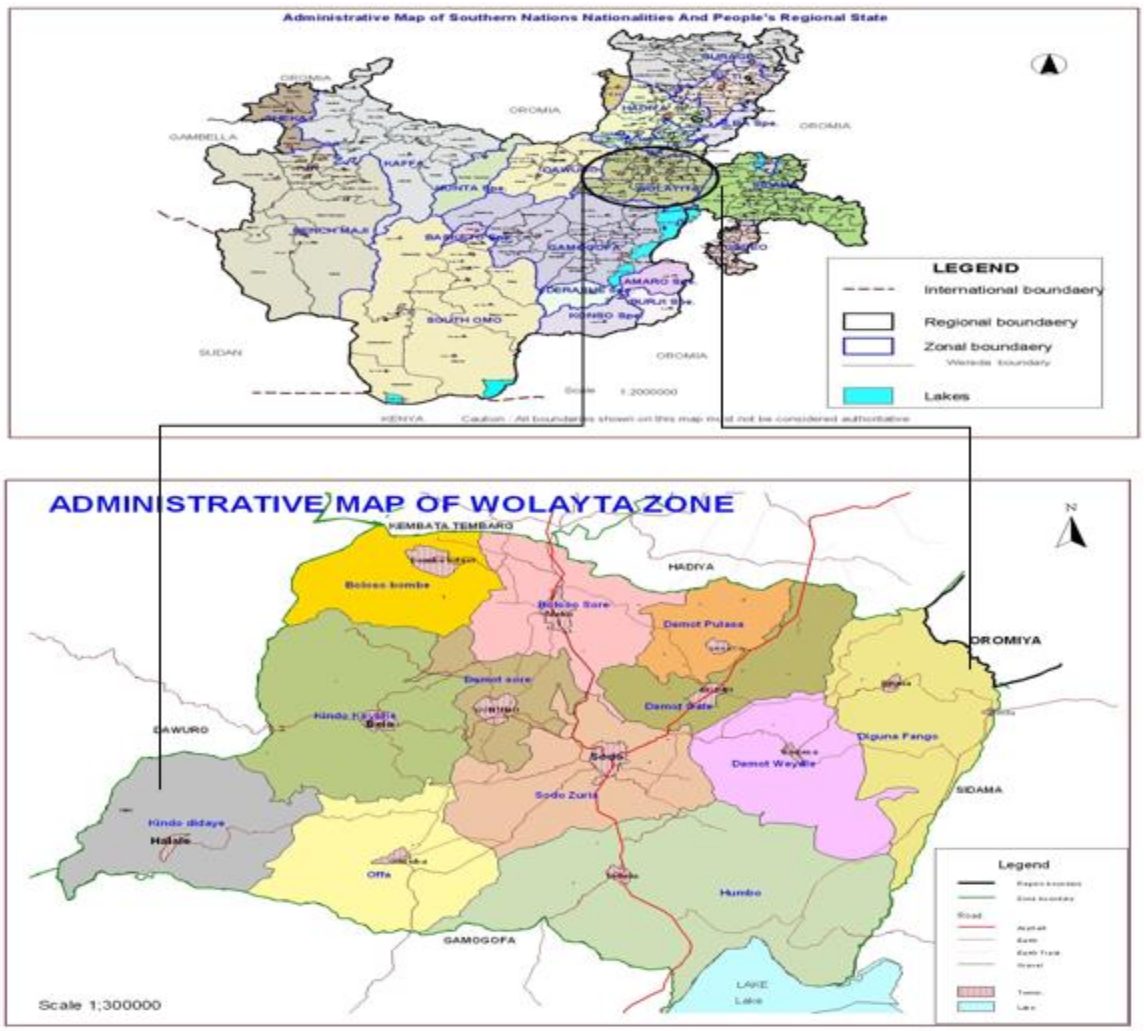

Figure 3.1: Location of Wolaita Zone Source: (Ethiopian map from GIS**)**

3.2 Sampling techniques and sample preparation

In this study, the researcher used AASHTO designation T-2 method to collect samples from crushed aggregate base course materials and cinder gravel. Before blending and testing, the samples were prepared according to AASHTO T 87. This method covered the preparation of oven dried disturbed soil and soil aggregate samples for Atterberg's limit, Permeability, Compaction, Californian bearing ratio, and other tests. Mixing cinder gravel with fine soil samples manually had been done to get the uniform mix for each proportion to determine the moisture density relation based on the sample requirement shown in table 3.1

Table 3.1: Sample requirement of cinder gravel and fine soil in the first phase of proportioning

Trial No	Proportion	Sample plan for 6000g of molding	
		Cinder (g)	Fine soil (g)
1	90:10	5400	600
2	80:20	4800	1200
3	70:30	4200	1800
4	60:40	3600	2400

4. RESULT AND DISCUSSION

4.1 Characterization of the Physical and Mechanical Properties before blending

4.1.1 Particle size distribution

The test was used to determine the grading of material's specimens for stabilization to be used as the base course layer. The particle size distribution curve was established to know the sizes passing within the lower and upper limits of the lines. The laboratory results had been used to determine compliance of the particle size distribution based on the specification requirements of ERA (2013).

Figure 4.1 shows the grading limits of ERA (2013) for the crushed stone base course (GB1) and mechanically stable natural gravels and weathered rocks (GB2, GB3). The grading limit (GB1) was used to evaluate the particle size distribution of the crushed aggregate, whereas the Grading limit (GB2, GB3) was used to evaluate the particle size distribution for the cinder gravel

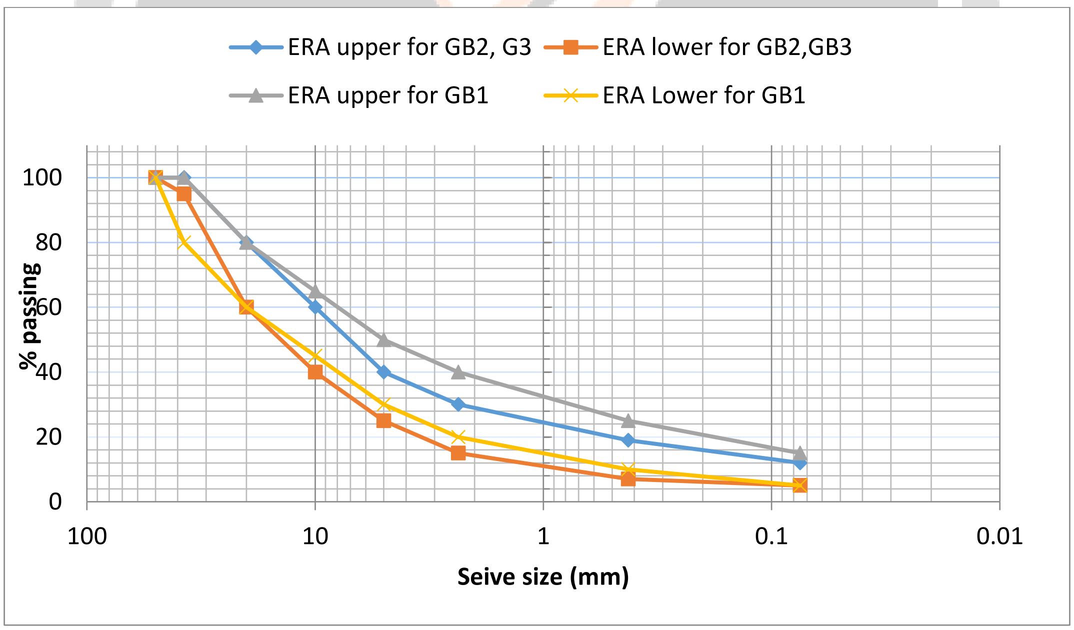

Figure 4.1: ERA specifications for crushed rock base and natural gravel base materials

The result of sieve analysis of crushed aggregate collected from the Bedessa crusher site indicated that it has a fair proportion of the particles of the content. Hence, it was considered in the evaluation for the gradation of base course material. This can be seen in figure 4.2, where the curve of crushed aggregate lies in the middle of the grading envelope.

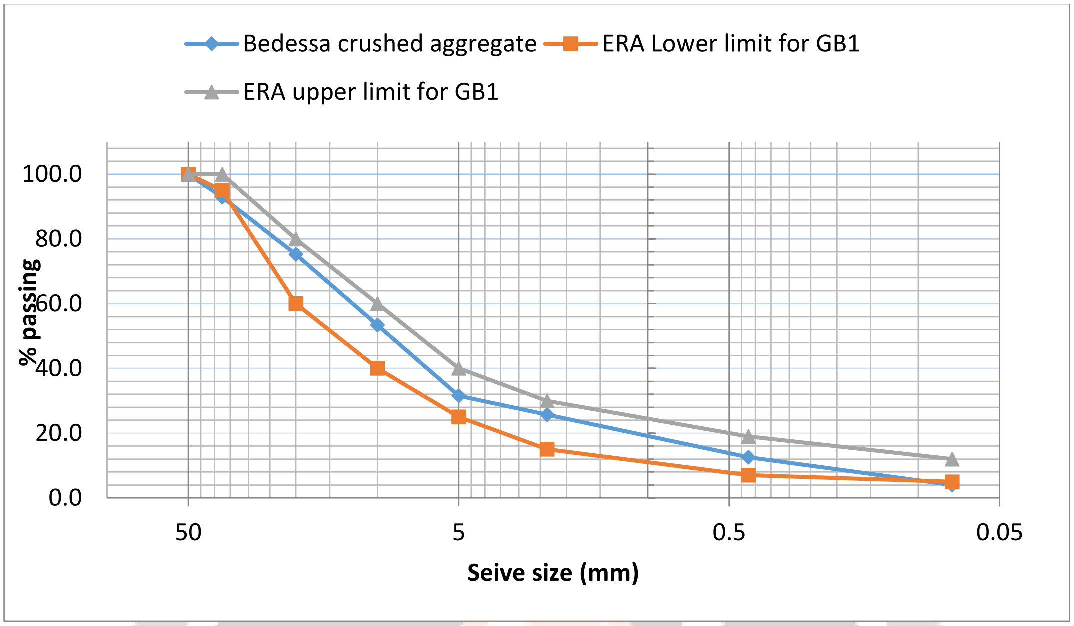

Figure 4.2: Particle size distribution of crushed aggregate from Bedessa along with its specification

The gradation test results of cinder gravels indicated that the sample collected from Tora Sadebo lacked fine materials, hence do not comply the grading limits of the ERA specification for mechanically stable natural gravels and weathered rocks (GB2, GB3). In order to check the effect of compaction on cinder samples, a compaction test was made according to AASHTO T180-D and sieved again. Then the result of sieve analysis indicated an improvement of gradation.

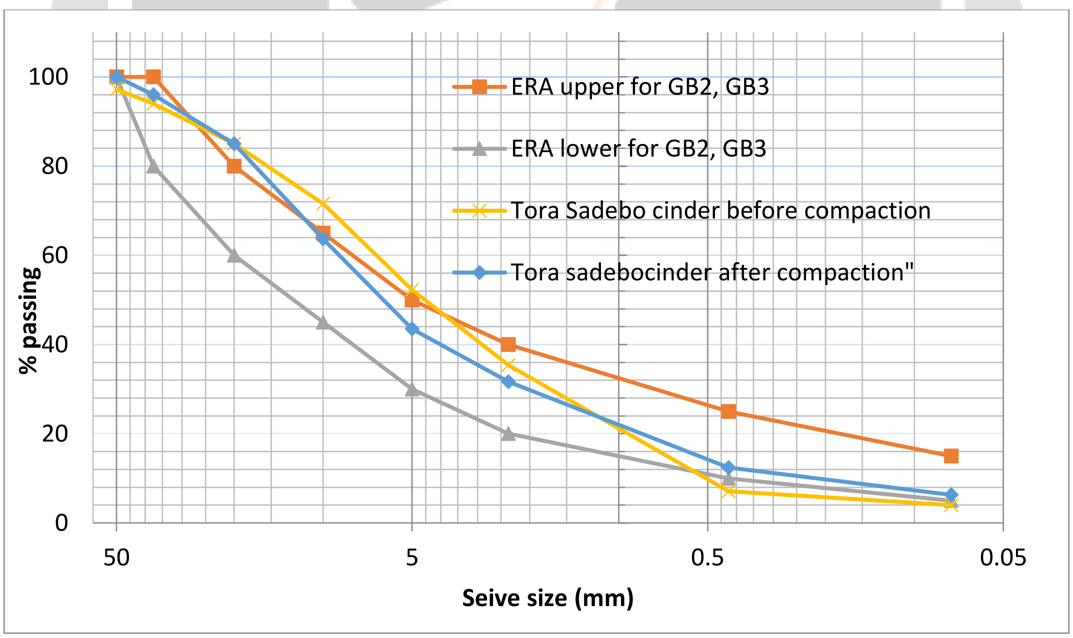

Figure 4.3: Particle size distribution of cinder gravel from Tora Sadebo along with its specification

The results of the particle size analysis indicated that the grading curve of the cinder gravel lies outside the specification envelop for sizes finer than 0.5mm. This indicates that the material lacks fine particles than the allowable limit of the specification.

4.1.2 Moisture density relationships

In this study, a laboratory procedure applied, based on ERA guideline for the use of cinder gravels in pavement layers for low volume roads. This guideline (ERA, 2018) pointed out that cinder gravels break down during compaction; hence, it is difficult to determine the accurate dry density and moisture content by a standard test method, AASHTO T180- method D. Hence, it was recommended to re-use a single molded specimen to obtain all five points of the compaction curve. This method is regarded as adjusted AASHTO T180-D. Therefore, the samples were re-used during the dry density-moisture content determination.

A modified Proctor test was conducted on a sample of crushed aggregate and fine soil, to find out the relationship between the moisture content and dry density for a specific compaction effort.

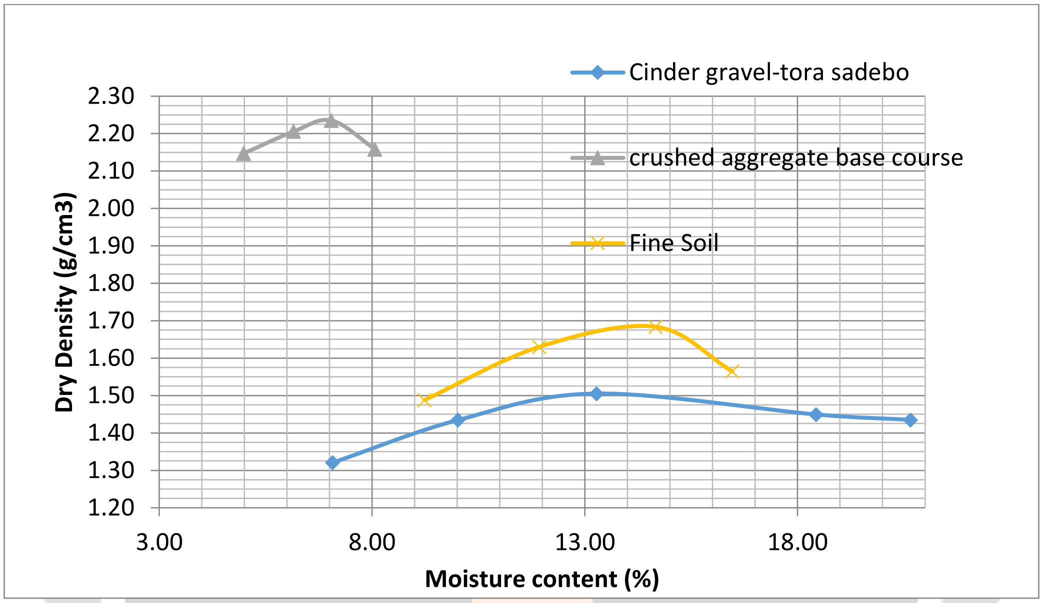

Figure 4.4: Relationship of moisture content and dry density

Results of OMC and MDD for three samples are shown in Figure 4.4. According to ERA specification, compaction requirement for base is a minimum of 98% as required for material not chemically stabilized. The result of OMC (%) and MDD (g/cm^3) cinder gravel specimen from Tora Sadebo, crushed aggregate from Bedessa and fine soil are (13.28 and 1.51), (7.05 and 2.24), (14.7,1.68) respectively.

4.1.3 California Bearing Ratio (CBR)

A three-point CBR was determined for the cinder gravel and crushed aggregate before any treatment, according to AASHTO T-193 using the moisture content as presented in section 4.1.2. The CBR value was obtained from 98% of maximum dry density with the corresponding Optimum Moisture Content (OMC). This was done to evaluate the compliance of the CBR value of individual material with the requirement of ERA manual.

Table 4.1 Summary of California bearing ratio Test of materials before treatment

Sample Location	Material type	Modified Proctor test		CBR				CBR @98% of MDD
		OMC (%)	MDD (g/cm^3)	No. of Blows	Dry density (g/cm^3)	CBR (%)	% Swell	
Tora	Cinder	13.28	1.51	10	1.23	30	0.47	55

Sadebo				30	1.43	45	0.31	
				65	1.70	62	0.00	
Bedessa	Crushed aggregate	7.05	2.24	10	1.93	51	0.1	153
				30	2.16	118	0.1	
				65	2.26	169	0.0	
Abela	Fine Soil	14.70	1.68	56	1.59	24	2.29	24

MDD=Maximum Dry Density, OMC= Optimum Moisture Content

The CBR of cinder gravel collected from Tora Sadebo cinder quarry sites indicated 55%. ERA specifies a minimum CBR of 80% for mechanically stable natural gravels and weathered rocks (GB2, GB3). The results showed that the cinder gravel used in this study did not satisfy the CBR requirement for base course materials. For the crushed aggregate, it indicated a CBR value of 153%, which was far beyond the requirement of ERA manual for freshly crushed rocks (GB1).

4.1.4 The Atterberg Limit tests

In this method of testing, determination of the liquid limit, plastic limit, and the plasticity index of soils was undertaken. The liquid limit is defined as the minimum moisture content at which the soil will flow under the application of a very small shear force. Atterberg limit tests were conducted on the samples prepared for blend. The results of the Atterberg limit test on cinder gravels and crushed aggregates revealed that these materials are non-plastic that of fine soil is shown in table 4.2.

Table 4.2: Result of atterberg limit test

Material description	Liquid limit	Plastic limit	PI	PP
Crushed aggregate-Bedessa	-	-	NP	Zero
Cinder gravel-Tora Sadebo	-	-	NP	Zero
Fine soil-Abela	41.4	29.5	12	588

PI= Plasticity Index PP= PI x percentage passing the 0.075mm sieve, NP= Non-Plastic

From the test results in table 4.2, it can be seen that, except fine soil, all other materials are non-plastic and the plasticity modulus and plasticity product are zero. The Ethiopian Roads Authority Manual recommends a plasticity product for crushed weathered rock a maximum of 60%. Therefore, the test result on two blend components revealed a plasticity product of zero, which conforms the specification.

4.2 Effect of Mechanical stabilization on material properties

The current study was aimed and undergone to partially replace crushed aggregate base course materials by cinder gravel and fine soil using mechanical stabilization for AC pavements. It was found out in section 4.1.1 that cinder gravels lack fine materials and fail to comply with the grading limit. As presented in section 4.1.3, cinder gravel does not satisfy the CBR requirement of greater than 80% to be used as the base layer. On the other side, crushed aggregate is well graded and satisfies the grading limits of ERA (2013) pavement design manual and its CBR value is also far above the requirement. Therefore, the purpose of mechanical stabilization of this study was to evaluate the effects of blending by comparing the results with the standard specification of base course requirements as per the standard.

4.2.1 Proportioning- Phase I

In this first phase of trial proportioning, cinder gravel and fine soil were involved by varying the percentage of fine soil in the mix. Compaction test was performed for cinder-soil mix by varying proportions of fine soil as 10%, 20%, 30%, 40%. The result of the modified proctor test showed that the maximum dry density of blending increases as the amount of fine soil increases and gets its maximum value of 1.67g/cm^3 when the soil content is 20%. Hence, it was taken as an optimum Soil Content that modifies the compact ability and the gradation problem of cinder gravels

4.2.2 Proportioning- Phase II

The second phase of trial proportioning was used to evaluate the effect of blending on the properties of the three components of the blending process. In this section, the result of the first phase of proportioning was used to obtain the quantity of crushed aggregate at which the CBR value of the mix falls and comes to the minimum requirement of ERA (2013) manual for road base. The trial proportions by weight of crushed aggregate, cinder gravel, and fine soil, and the corresponding weights of each component used to mold a 6000g of the sample are shown in table 4.3

Table 4.3: Sample requirement for second phase of trial proportioning

Blending phase II				
Trial No	Proportion (%)	Crushed aggregate (g)	Cinder (g)	Fine soil (g)
1	90:10(80:20) 90:08:02	5400	480	120
2	80:20(80:20) 80:16:04	4800	960	240
3	70:30(80:20) 70:24:06	4200	1440	360
4	60:40(80:20) 60:32:08	3600	1920	480
5	50:50(80:20) 50:40:10	3000	2400	600
6	40:60(80:20) 40:48:12	2400	2880	720

The proportion of cinder gravel and fine soil (80:20) found in section 4.2.1 was used for second phase of proportioning to incorporate third blend component (crushed aggregate). The values under the second column were determined based on this consideration.

4.2.2.1 Variation of Moisture-density with proportion

The result of moisture- density is essential to determine the CBR of the sample incorporating three blend components based on the sample requirement shown in table 4.3. The test was done according to AASTHO T-180 method-D. The optimum moisture content was then used to prepare the CBR specimens during the 1-point CBR test.

Table 4.4: Variation of MDD and OMC with different proportions

crushed aggregate: cinder gravel: fine soil (%)	MDD	OMC
100:0:0	2.24	7.05
90:8:2	2.24	8.29
80:16:4	2.00	10.32

70:24:6	1.93	10.52
60:32:8	1.87	10.53
50:40:10	1.85	12.58
40:48:12	1.80	14.02

The results of moisture-density tests indicated that maximum dry density (MDD) decreases as the quantity of cinder gravel and fine soil increases in the mix because neat cinder alone is a light material compared with crushed aggregate. On the other side, the test results showed that optimum moisture content required to achieve maximum dry density increases as the amount of cinder gravel and fine soil increases. This can be seen in table 4.5, where OMC gets up from 7.05% to 14.02%.

4.2.2.2 California bearing Ratio determination

The soaked CBR test was performed as per AASHTO T 193 to determine the strength of the compacted crushed aggregate, cinder gravel and fine soil mix. The test results revealed that the soaked CBR value decreases when the quantity of crushed aggregate decreases as expected. This is shown in figure 4.5

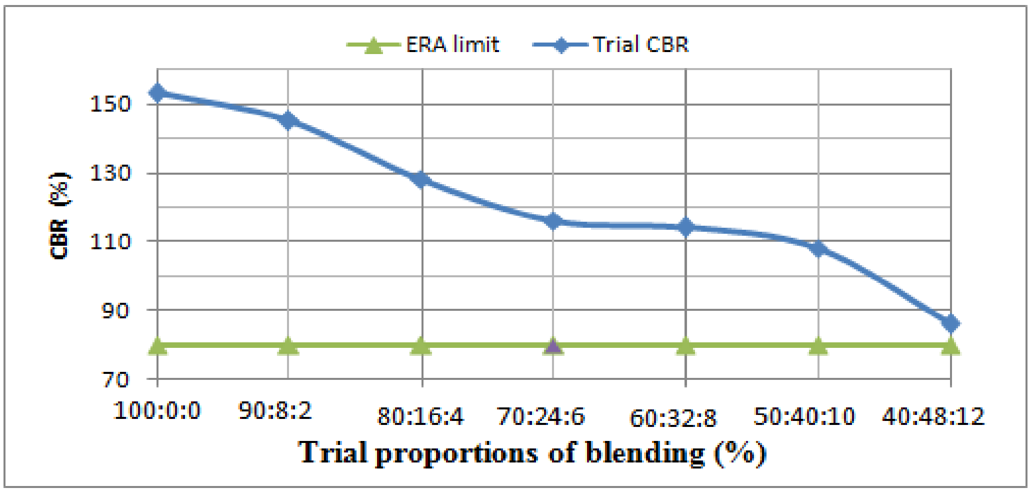

Figure 4.5: Effect of increasing Cinder gravel and fine soil on CBR value

In figure 4.5, the CBR value for different trials with increasing percentage of cinder gravel and fine soil in the blend caused a decrease from 153% to 86%. According to the requirement of soaked CBR value for road base as presented in section 2.2, it must be more than 80%. Hence, an acceptable mix ratio at which the strength requirement of ERA (2013) is 40% crushed aggregate base course, 48% cinder gravel, and 12% fine soil.

5. CONCLUSION

. Based on the results of this research, the following findings are deduced;

- Neat cinder gravels considered in this study have a low CBR value that did not comply with the requirement of ERA (2013) manual for base course construction materials
- The amount of fine soils required to improve the gradation and compaction problems in cinder gravels is 20% by weight proportion
- The proportion of crushed aggregate, cinder gravel and fine soil that satisfies the CBR requirement of ERA (2013) manual is 40%, 48%, 12% respectively. Hence, this proportion is an optimum proportion.
- At the optimum proportion of the three blended materials, the soaked CBR value obtained of about 86%, which was greater than the minimum requirement of ERA manual for base course.

Therefore, based on the results of the research study, fine soils typically can be used to stabilize cinder gravels with crushed aggregates, and it is suitable for base course construction if the mix proportion is determined by experiment.

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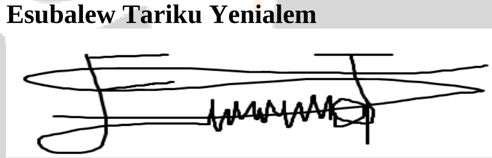
	**Esubalew Tariku Yenialem**  Graduated BSC in civil engineering from Debre-Markos university and Msc in geotechnical engineering from Arba-Minch university, Arba-Minch university institute of technology. *Wolaita sodo university*