Journal of Civil Engineering, Science and Technology

Volume 10, Issue 2, September 2019

POTENTIAL USE OF CINDER GRAVEL AS AN ALTERNATIVE BASE COURSE MATERIAL THROUGH BLENDING WITH CRUSHED STONE AGGREGATE AND CEMENT TREATMENT

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Date received: 03/05/2019, Date accepted: 18/08/2019

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Doi: 10.33736/jcest.1465.2019

Abstract — Cinder gravels are pyroclastic materials associated with recent volcanic activity which occur in characteristically straight sided cone shaped hills. The aim of this study was to use this marginal material which is abundantly available in many parts of Ethiopia by modifying their properties through mechanical blending and chemical stabilization. Results of physical and mechanical test conducted on cinder gravel samples prove their marginality to be used as base course materials especially for highly trafficked roads. An experimental investigation was carried out by blending cinder gravels with conventional crushed stone bases course material, Crushed Stone Aggregate (CSA), in proportions of cinder/ Crushed Stone Aggregate (CSA) (10/90, 20/80, 30/70, 40/60 and 50/50) and treating with 6. 8 and 10% of cement. According to results of sieve analysis, Aggregate crushing value (ACV), flakiness index and California Bearing Ratio (CBR), 30% of Crushed Stone Aggregate (CSA) can be replaced by cinder gravels for use as Fresh, crushed rock (GB1) material and for cement treated cinder gravels adding 6% and 8% cement make them suitable for use as Stabilized base course (CB2) and (CB1) base course materials respectively, referring to their 14 day compressive strength as determined by Unified compressive strength (UCS) test.

***Keywords*:** Marginal materials, cinder gravel, conventional material, Crushed Stone Aggregate (CSA), cement treated, Fresh, crushed rock (GB1), Unified compressive strength test (UCS), stabilized road base (CB1),(CB2)

1.0 INTRODUCTION

The function of road pavement is to provide a safe, comfortable, convenient and economical running surface for the passage of fast-moving traffic [5]. Each layer has a specific function and the appropriate materials also the layer thickness has to be selected with regard to efficiency and economy. Pavement base course have generally been desired to be dense graded so that they achieve the maximum density and strength. The quality of the base depends on factors like Gradation, Angularity of the particles, Shape of Particles (flat and elongated particles should be avoided), Soundness of the aggregate particles and Resistance to weathering [7]. In Ethiopia materials to be used for base course construction have been specified which mainly include unbound granular materials (crashed stone and natural river gravels) as well as chemically stabilized materials (lime, cement or pozzolana-lime). However, availability of good quality aggregate may be a problem in some locations resulting in the haulage of alternative materials over increasing distances. This gives rise to the need for use of locally available marginal materials by modifying physical and engineering properties by conducting local experimental analysis which is recommend practice [4][3]. A broad definition of a marginal aggregate is any aggregate that is not normally usable because it does not have the characteristics required by the specification, but: could be used successfully by modifying normal pavement design and construction procedure [13]. Their marginality could be caused by their gradation, particle shape and strength or plasticity behavior. Too coarse materials generally tend to reduce stability, increase risk of shear and settlement, low in situ density and difficult to compact [18]. Gap-grade causes difficulty in compaction, dispersing of the compacted mass, moisture susceptibility and pumping of fines. Aggregate bases with high fines content are susceptible to loss of strength and load supporting capability upon wetting [6] [12].

For this study, marginal aggregates will be defined as aggregates that do not meet the ERA specification for flexible pavements base course materials. The marginal material used for the study was cinder gravels found extensively located in rift valley areas of Ethiopia, which are pyroclastic materials associated with recent volcanic activity occurring in characteristically straight sided cone shaped hills. Cones which commonly found in groups can extend to a height of 100meters and generate about 1 million metric ton of cinder gravel. Problems associated with cinder gravels are their gradation and weak particles that can be broken easily which make them unsuitable for base course construction [1][2]. The study indicated that cinder cones were found to be concentrated in the rift valley which extends southwards into Kenya and Tanzania. Laboratory studies on cinder materials collected from different areas of the country showed that cinders were found to possess dry modified aggregate impact values in the range 46 to 100 and on soaking no loss in strength occurred in addition it was observed that they may not have well-defined optimum moisture content. Repeated compaction test proves that depending on the amount of breakdown which could take place during field compaction then the material could be improved [1].

Full scale experimental investigation carried out using cinder gravels as a road base material with double surface dressing surfacing reveled they can perform satisfactorily for a traffic level up to 440,000ESAL based on measurement of surface measurements of rutting, cracking and deflection at yearly intervals [2]. Another study found out that using a thin asphalt surfacing and a thick cement treated cinder layer is required to withstand the stresses resulting from wheel loads in the order of 9 tones Based on the seven day strength of the cement treated cinder and a Pavement design for axle load data collected from Ethiopia [10].

Aggregate stabilization is a proven pavement construction technique which utilizes local aggregates to enable pavement construction at often significantly reduced costs and without adversely affecting the pavement's performance either through physical or chemical means [9]. Many researchers had made an attempt to partially replace scarce standard road construction materials with substandard materials and wastes including agricultural wastes like palm kernel shell, recycled asphalt pavements, broken ceramics, used rubber tires and industrial by products like fly ash and iron slag and obtain satisfactory result [8]. The mixing of one material with another is a direct means of creating improved grading and plasticity characteristics. Mechanically stabilized materials will have properties similar to any other unbound material and can be evaluated by reference to conventional granular pavement material requirements [16]. Any cement can be used for stabilization, but ordinary Portland cement is the most widely used throughout the world [14].

Cement treated aggregate is described as a mixture in which a relatively small amount of cement is used as a binder of coarse aggregates, and which needs proper water content for both Compaction and cement hydration [15]. Cement is most effective for low plasticity granular materials. The Unified compressive strength (UCS) test is the most common test performed on cement stabilized materials to determine the suitability of the mixtures for uses such as in pavement bases and subbases [15].

Studies conducted on samples of cinders from some location show that their property can be improved significantly by adding fine materials as well as treating them with cement.

Two methods were examined in this study for making use of these abundantly available resources which are partially replacing Crushed Stone Aggregate (CSA) with cinder gravels (physical stabilization) and treating them with cement (chemical stabilization). Physical tests were used on both methods to investigate the possibilities of both methods and results were compared with relevant specifications. The importance of this study to overcome problems regarding shortage of standard materials near to project site by making use of locally available materials. promote use of locally available marginal materials so that the government of Ethiopia will benefit from using abundantly available resources instead of exploiting scare standard materials which imply conservation of natural resources and Reduces cost and environmental benefit gained from using abundantly available cinder gravel for projects to be built in the study area will help the government to build more networks by eliminating extra costs of hauling from far distance and time delay which is one of the problem to the completion of the road construction at planned construction period.

Table 1 Desirable limits of Unified compressive strength test (UCS) for cement stabilized materials [3][11][17].

Standard		Strength requirements (MPa)
Road note 31 [ERA PDM]		3.0 – 6.0 for CB1 1.5 – 3.0 for CB2
US army and air force		5.2
National cooperative highway research program	Base course	2.1 – 5.17
	Soil types	2.1 – 4.2 for A-1, A-2, A-3
		1.72 – 3.5 for A-4, A-5
		1.4 – 2.8 for A-6, A-7

2.0 EXPERIMENTAL INVESTIGATION

2.1 STUDY DESIGN

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

- Taking samples
- Preparation of samples for each laboratory tests
- Laboratory tests to characterize natural untreated cinder gravel materials and CSA samples.
- Process of blending cinder gravel with CSA to find out maximum replacement amount that satisfy requirements of standard specification
- Process of chemical stabilization to determine amount of cement needed to be added to natural cinder gravels to satisfy strength requirements.

The laboratory investigation starts with examining the physical and mechanical properties of Crushed Stone Aggregate (CSA) and cinder gravel samples in as received condition which were Sieve analysis, Atterberg limits, Moisture density relation, California Bearing Ratio (CBR), aggregate crushing value (ACV) and ten percent value (TFV), Flakiness index (conducted only on Crushed Stone Aggregate sample), Water absorption and specific gravity

All above mentioned test except flakiness index was conducted on Crushed Stone Aggregate Crushed Stone Aggregate (CSA) - cinder gravel blends with varying proportions. The final stage of the laboratory work was determining the compressive strength of cement treated cinder gravel through Unified compressive strength test (UCS) in order to come up with optimum cement content satisfying specification for cement bound base course layer.

3.0 MATERIALS

Cinder gravel samples were purposively collected from three different areas namely Sallo, Tullu dimtu and Debrezeit based on the availability of materials and Crushed Stone Aggregates were obtained from Chinese railway building company in Ethiopia (CRBC) stock pile for base course Construction at ‘‘Jimma ber” quarry site and ordinary Portland cement was purchased from local construction materials shop.

4.0 RESULTS AND DISCUSSIONS

As shown in the graph below the gradation of all cinder gravel samples collected from Sallo, Debrezeit and Tullu dimtu or their blended prepared by mixing these samples in equal proportion by volume determined before and after compaction doesn't satisfy the requirements to be used as Ethiopian road authority manual of flexible pavement(ERAPDM) base course material in addition to the specification Table 2 shown below.

Table 2 Summary of Test Method

Type of test	Test method/ Designations
Sieve Analysis (Wet method)	AASHTO T - 27
Aterrberg Limits	AASHTO T 89-90
Water absorption and specific gravity	AASHTO T - 84
Moisture Density Relation	AASHTO T - 180
CBR	AASHTO T - 193
ACV	BS 812: part 110
TFV	BS 812: part 111
Flakiness index	BS 812: section 105.1: 1989
UCS	BS 1924-2:1990 part 2:

4.1 GRADATION CURVE

4.1.1 GRADATION CURVES FOR CINDER GRAVEL SAMPLES DETERMINED BEFORE AND AFTER COMPACTION

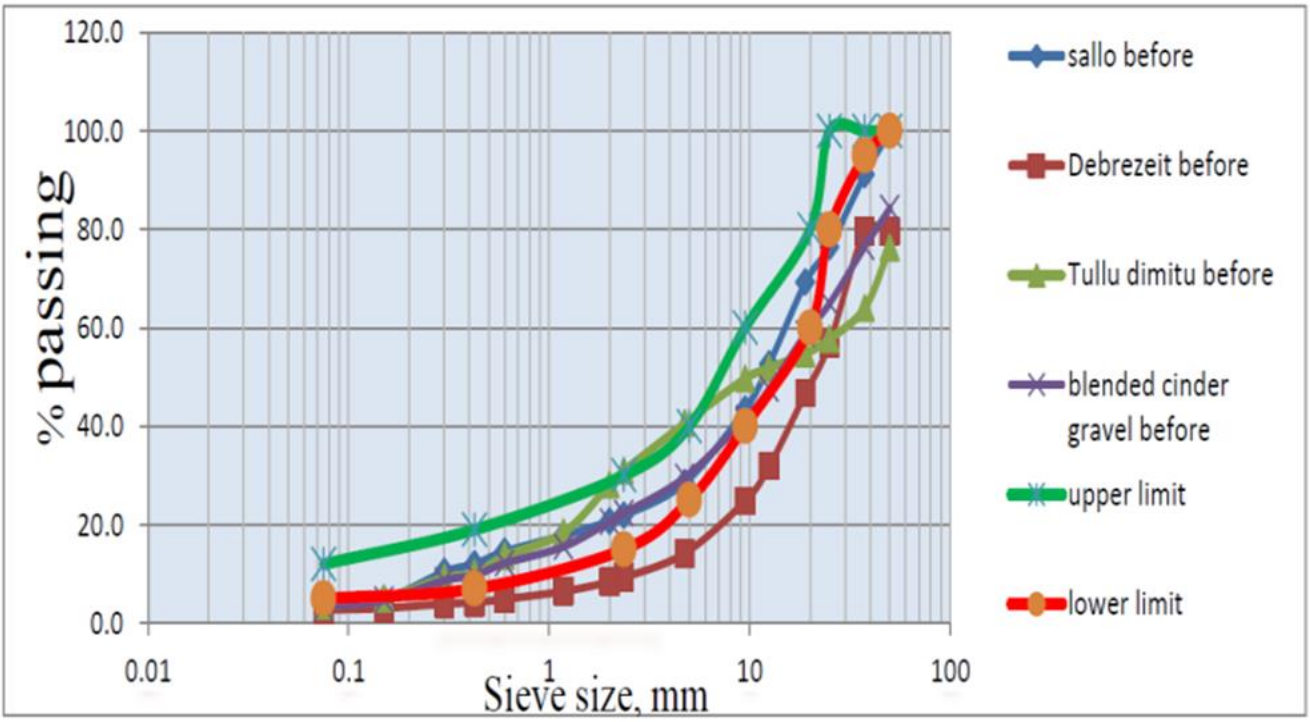

Figure 1 Gradation curves for cinder gravel samples determined before compaction

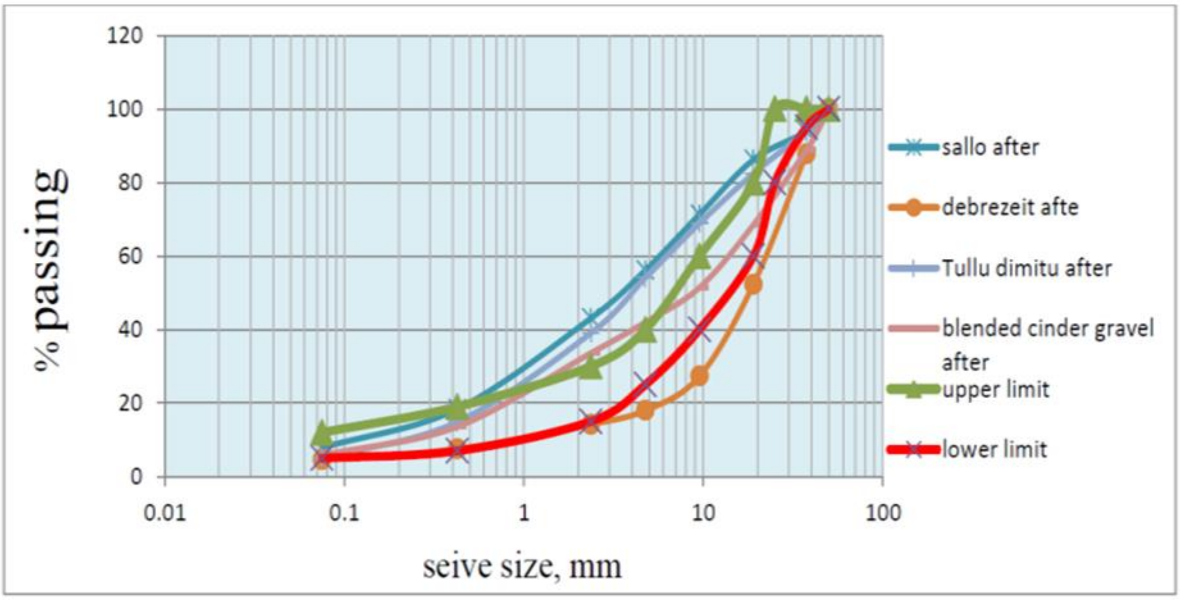

Figure 2 Gradation curves for cinder gravel samples determined after compaction

Results of physical and mechanical tests conducted on cinder gravels presented in Table 3 show that cinder gravel is a weak material and has high water absorption capacity because of its high porosity.

The California Bearing Ratio (CBR) value of the material is low for base course but satisfies the requirements for subbase course materials.

Table 3 Summary of results for tests conducted on cinder gravel and Crushed Stone Aggregate (CSA) samples.

Percentage of cinder gravel in the blend	0	10	20	30	40	50	100	Specification
OMC (%)	7.6	8.9	10.6	11.24	11.75	13.23	19.44	NS
MDD (g/cc)	2.32	2.19	2.15	2.13	2.08	2.05	1.77	NS
CBR (%)	162.5	155.42	135.67	121.43	104.89	89.54	32	>100
Water absorption (%)	0.55	4.55	4.67	4.82	5.03	5.17	ND	1.0 – 2.0
Specific Gravity	2.6	2.5	2.4	2.4	2.3	2.285	ND	2.5 – 3.0
ACV (KN)	18	21.2	23.2	26.3	29.4	33.5	35	<29
TFV (KN)	230	203	167	131	114	104	107	> 111
Flakiness index	18	ND	ND	ND	ND	ND	ND	< 30

*ND -not determined

*NS -not specified

4.1.2 CRUSHED STONE AGGREGATE (CSA) - CINDER GRAVEL BLENDS GRADATION

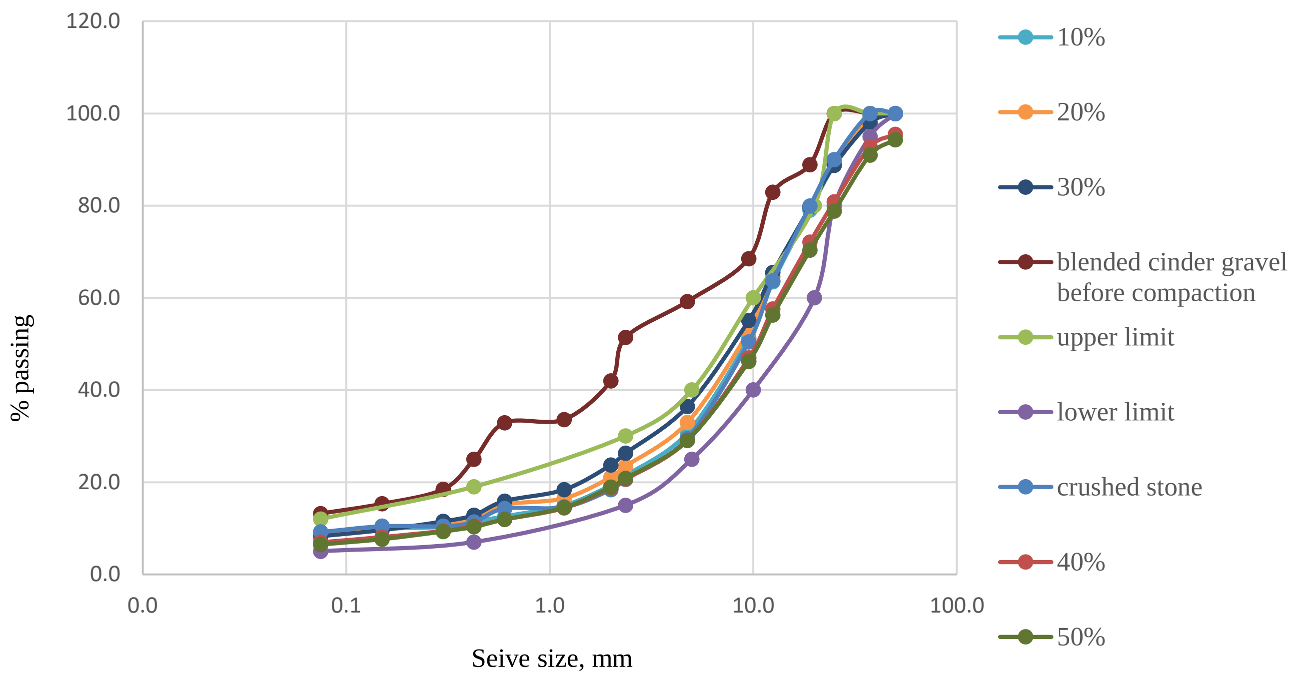

Figure 3 Gradation curves for Crushed Stone Aggregate-cinder gravel before after compaction

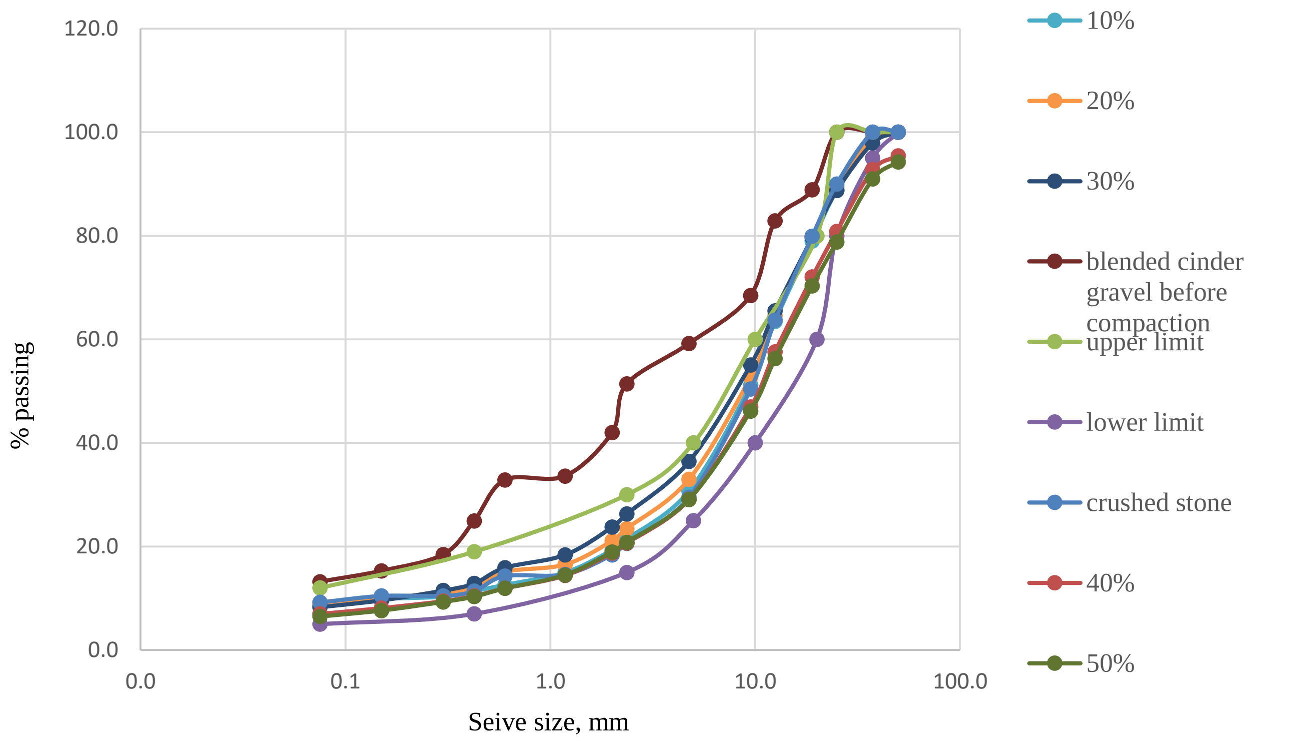

Figure 4 Gradation curves for Crushed Stone Aggregate-cinder gravel samples after compaction

From the results shown in Figure 3 and Figure 4 we can observe that for both before and after compaction condition as percentage of cinder gravel increase the gradation curve for the particular blend proportion will tend to move towards the lower limit curve for particles above 4.75mm and lower than 0.425mm whereas the curve move to upper limit for the range of particle sizes between 4.75mm and 0.425mm and this shows the open graded nature of cinder gravel samples.

Crushed Stone Aggregate (CSA) – cinder gravel blend up to 40% cinder gravel by volume satisfies gradation limits established by Ethiopian road authority (ERA) according to sieve analysis conducted before compaction. Compaction increases this value up to 50% as a result of additional fine and lesser coarser particles obtained by weak nature of cinder particles.

4.2 MOISTURE – DENSITY RELATIONSHIP

As it can be seen from the summary of the test results for Crushed Stone Aggregate (CSA) – cinder gravel blends with different amount of replacement of rate of cinder gravel for Crushed Stone Aggregate (CSA) (10 -50) in Figure 5 the moisture content increases from 7.6 to 13.23 and maximum dry density (MDD) decreases slightly from 2.32 for samples containing Crushed Stone Aggregate (CSA) only to 1.77 for samples that was prepared by blending cinder gravel samples from three different location. The change in moisture content was significant which may be caused by high absorption characteristics of cinder gravel materials in addition to their round particles which can decrease the grain to grain contact (shear strength) of the samples as % cinder material in the mix increases.

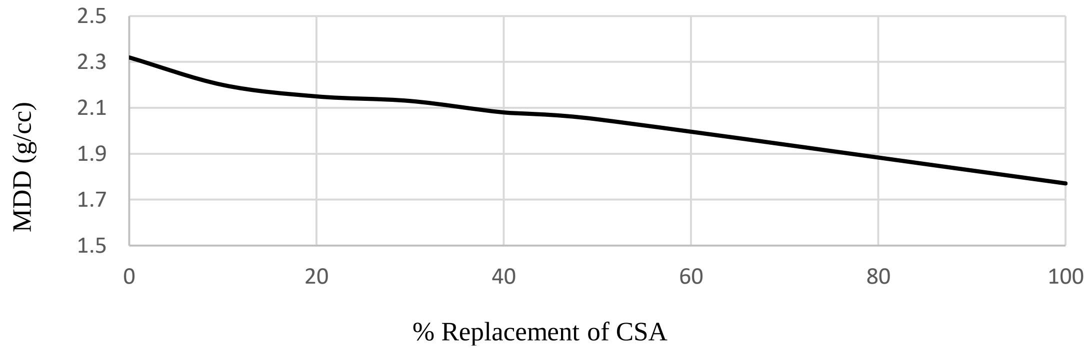

Figure 5 Results of moisture density relation test for different proportions of cinder gravel and Crushed Stone Aggregate (CSA) California Bearing Ratio (CBR) test.

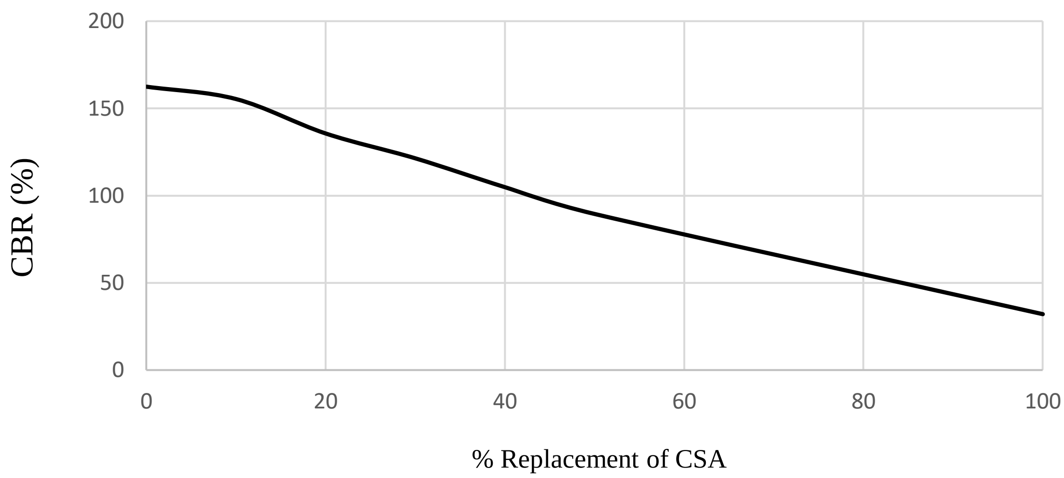

Figure 6 Percent cinder verses California Bearing Ratio (CBR) for different proportions of Crushed Stone Aggregate (CSA) – cinder gravel blends

From the Figure 6 we can see that as percentage of cinder gravel replacement for volume of Crushed Stone Aggregate (CSA) increases the California Bearing Ratio (CBR) also decrease by almost 50% from 162.5 for samples containing Crushed Stone Aggregate (CSA) only to 89.54 for mix having 50% cinder gravel and 50% CSA by volume of the total mix. The reason for this could be decrease due to the reduced workability to compact the material because of change in gradation due to stabilization and rounded particles of cinder which decrease the shear strength and California Bearing Ratio (CBR) can be taken as a measure of shear strength besides the increase in weak particles when volume of cinder increases in the mix increase from 10 – 50%

Analyzing the result replacing 40 % Crushed Stone Aggregate (CSA) with cinder can give a California Bearing Ratio (CBR) value of 100 even though one satisfying well above 100 requirement and safe with respect to National Cooperative Highway Research Program (NCHRP) criteria is blend containing up to 30% cinder gravel of having a California Bearing Ratio (CBR) of 121.4.

4.3 AGGREGATE CRUSHING TEST

Figure 5 showing the decrease in ten percent value (TFV) and increase in aggregate crushing value (ACV) as percentage of cinder gravel increase in the mixture which can be simply guessed because of weak nature of cinder gravels.

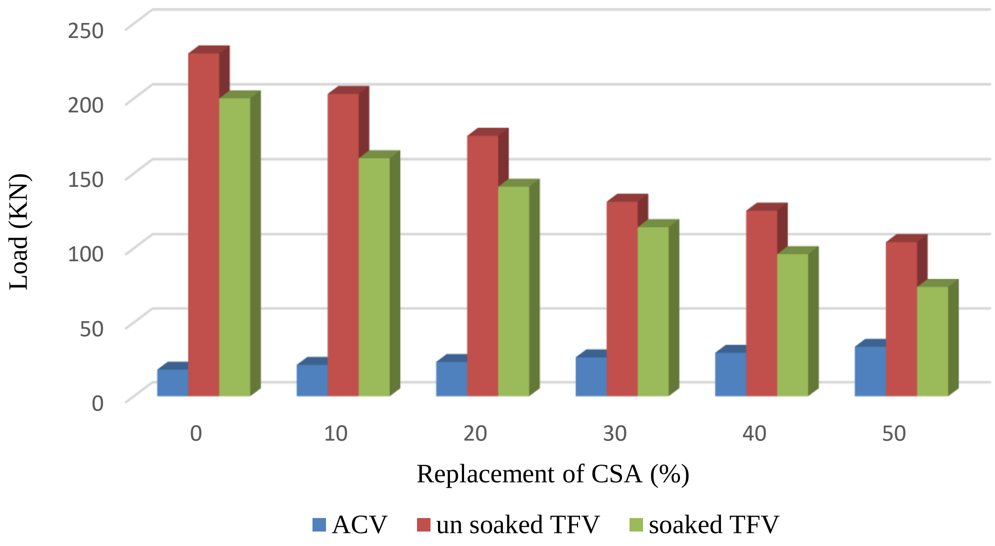

Figure 7 Percent cinder verses aggregate crushing value (ACV) and ten percent value (TFV) for different proportions of CSA – cinder gravel blends

Crushing tests were conducted on different proportions of Crushed Stone Aggregate (CSA) and cinder gravel with percentage replacement of cinder gravel for Crushed Stone Aggregate (CSA) varying from 10 -50%.from the results we can understand that replacing Crushed Stone Aggregate (CSA) with cinder gravels up to 30% by volume yields values below the maximum aggregate crushing value (ACV) and above the minimum ten percent value (TFV) specification for Fresh, crushed rock (GB1) material.

4.4 TESTS ON CEMENT TREATED CINDER GRAVEL

4.4.1 MOISTURE DENSITY RELATION OF CEMENT TREATED CINDER

Since the maximum density of a soil-cement mixture varies only slightly as the percentage of cement varies, a moisture-density test at the median cement content will suffice. In this study the median cement content was 8% so maximum dry density (MDD) and optimum moisture content (OMC) were determined by adding 8% of cement by dry weight of cinder gravel samples.

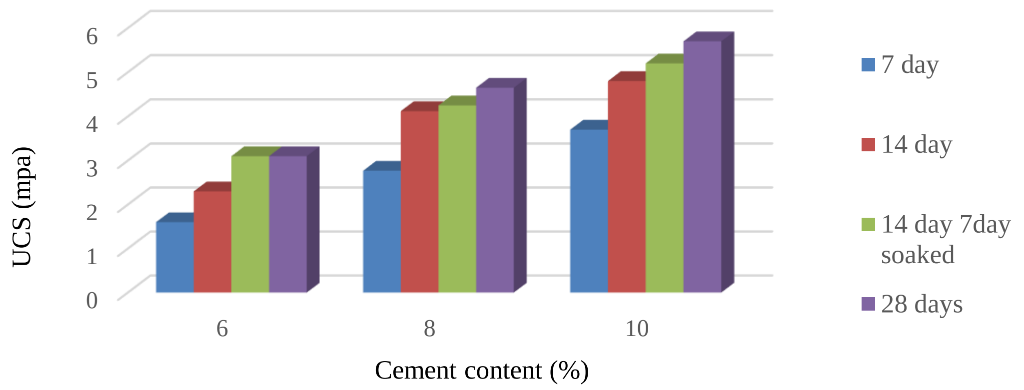

Figure 8 Compressive strength verses cement content

An optimum moisture content (OMC) of 17.28 and maximum dry density (MDD) 1.84 was obtained as in the compaction curve shown below in given in Figure 9 it has exhibited decrease in moisture content and increase in dry density which may be because of additional workability cement brings to the mix due to its grain size improving the gradation so as to achieve high maximum dry density (MDD) with reduced moisture content that needed for cinder gravel alone.

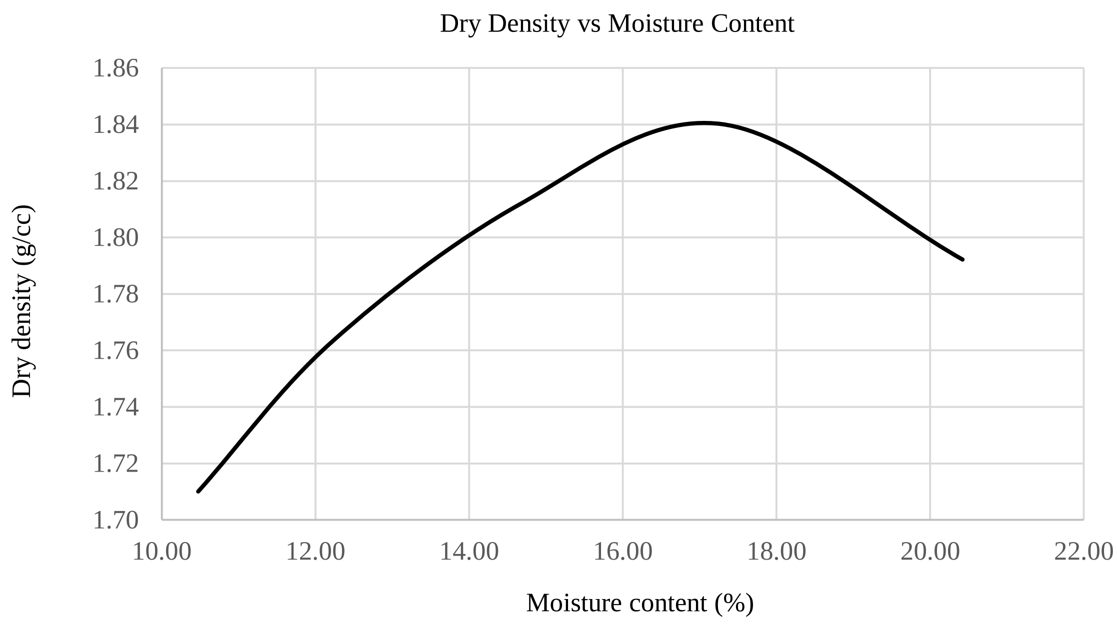

Figure 9 Moisture - density relation for cement treated cinder gravels with 8% cement content

4.4.2 DETERMINATION OF COMPRESSIVE STRENGTH

Using the predetermined optimum moisture content (OMC) and maximum dry density (MDD) values 15 cylindrical specimens of size 100mm x200mm were prepared by using split type of molds to make working with specimens smooth (when they were taken out of molds).

Table 3 Results of Unified compressive strength test (UCS) for three cement contents in each curing period.

Cement content (% by weight of cinder gravel)	Curing day	Curing condition	Dry density	UCS
6	7	Moist curing	1.7	1.6
	14	Moist curing	1.7	2.3
		7 day soaked	1.72	2.25
	28	Moist curing	1.7	3.1
8	7	Moist curing	1.79	2.77
	14	Moist curing	1.79	4.12
		7 day soaked	1.78	4.25
	28	Moist curing	1.79	4.65
10	7	Moist curing	1.8	3.7
	14	Moist curing	1.78	4.8
		7 day soaked	1.8	5.2
	28	Moist curing	1.8	5.7

The cylinder were crushed after a 7, 14 and 28 days of moist curing or soaking in water in order to compare with different specifications and examine the effect of curing time on the strength development of cement treated cinder gravels. Since Ethiopian road authority specifies UCS criteria for using cement stabilized materials namely CB1 and CB2 based on specimens tested after 7 days moist curing and 7 day soaked under water the cylindrical specimens was tested at this condition and resulted in a UCS of 2.28, 4.19and 4.48 for 6, 8 and10 % cement contents respectively.

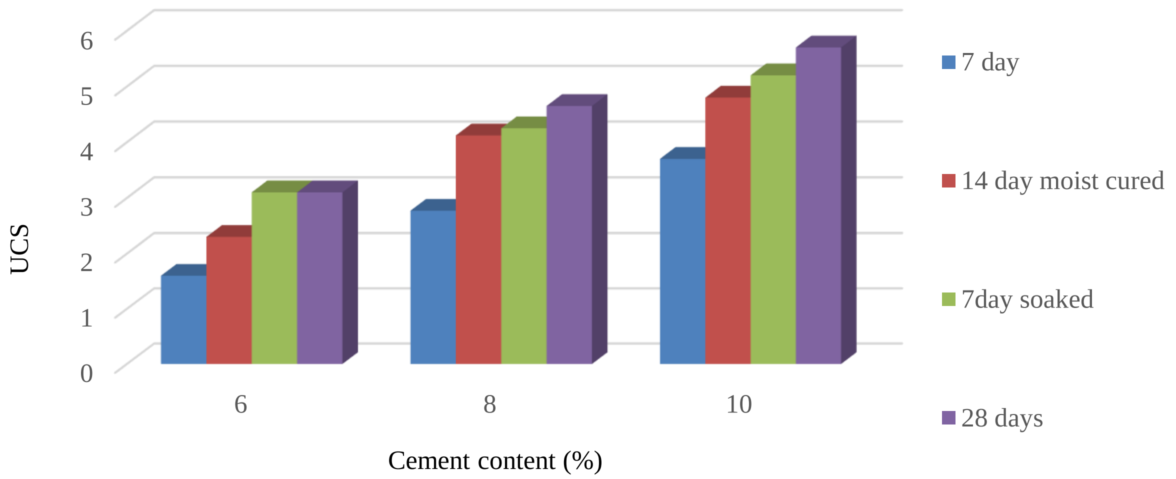

Figure 10 Showing comparison of strength achieved by cylindrical specimens casted @ different cement contents and tested@ certain duration and condition of curing.

To compare the strengths of the trial mixes with the requirements of ERA pavement design manual, the Unified compressive strength test (UCS) values of the trial specimens have to be converted to equivalent value of the 150mm cube specimen since the values in the Ethiopian road authority pavement Design manual has been established on the basis of 150 x150mm cubical specimens. Accordingly, the correction factors set by Ethiopian road authority pavement design manual in road note 31 were used to derive appropriate correction factor based on the height to diameter ratio of the specimens. The results of UCS tests obtained after 7 days moist curing and 7 days soaking in water as specified in Ethiopian road authority pavement Design manual (ERA PDM) were changed by multiplying with 1.25 to values supposed to be equivalent with 150mm cubic specimens.

Table 4 Adjusted unconfined compressive strength of cylinders

Cement content	UCS of 100 x 200mm cylinders (a)	Correction factor	Corrected value = (a*1.25)
6	2.25		2.81
8	4.25	1.25	5.31
10	5.2		6.5

From the results it can be stated that cinder – cement mix containing 6 and 8% satisfy the requirement for Crushed weathered rock, gravel or boulders (CB2) and Fresh, crushed rock (CB1) material while the National Cooperative Highway Research (NHCRP) specification is fulfilled by mix with 10% cement by dry weight of cinder gravel.

5.0 CONCLUSION AND RECOMMENDATION

From the results of this experimental study having above mentioned objectives the following conclusions are made.

1. The first part of laboratory investigation showed that cinder gravel is a weak material with an aggregate crushing value (ACV) >30KN and ten percent value (TFV)< 111KN also has high water absorption capacity because of its high porosity.

2. The gradation of natural cinder gravel doesn't fulfill the requirement, lacking sufficient fines and having coarser particles more than upper limit of gradation envelop for fresh, crushed rock (GB1) material as determined before compaction with Nom. Max. Size 37.5mm. Even if compaction produce fine grained materials to fill the gap it also make their gradation out of limit due to some fractions of particles were produced more than specified for base course material.

3. The California Bearing Ratio (CBR) value of the material is very low (< 40%) for base course. So natural cinder gravels can't be used as base course materials especially for high traffic unless modified in some way.

4. From Gradation point of view it has been seen that all the blend proportions satisfy requirements for dense graded base course as determined in after compaction state.

5. The results of particle strength and bearing capacity tests on Crushed Stone Aggregate (CSA) – cinder gravel reveal that 70/30 blend fulfill the criteria by attaining aggregate crushing value (ACV) of 26% <29KN and California Bearing Ratio (CBR) of 121% (satisfying well above 100 criteria). Thus is has been conclude that replacing 30% of conventional Crushed Stone Aggregate (CSA) with cinder gravel material is a possible alternative.

6. Optimum (minimum) cement content fulfilling strength requirement of Road note 31 (according to Ethiopian road authority pavement design manual there was table taken as a standard specification) for stabilized road base (CB1) is 6% and for crushed weathered rock, gravel or boulders stabilized road base

(CB2) 8%. The only mix satisfying criteria by US army was the one containing 10% cement by weight of dry cinder gravel.

7. The compressive strength of cinder– cement mix increases with curing age and also cement content. Soaking specimens in water decrease the strength of the mix only in the case of mix having 6% cement whereas for the others it was observed that the strength increase in small amount, which indicates cinder – cement mix with 8 and 10% cement are not susceptible to moisture change.

Based on literatures reviewed during the study and the outcomes of the study Based on the results of the research, it is recommended for consultants(designers) that utilization of the locally available cinder gravels shall be given due consideration for upcoming road construction projects in the study area or in other locations with similar characteristics.

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