STABILIZING CINDER GRAVELS FOR HEAVILY TRAFFICKED BASE COURSE

Girma Berhanu
Department of Civil Engineering
Addis Ababa University

ABSTRACT

Investigation into the improvement of natural cinder gravels with the use of stabilization techniques was made using samples collected from quarry sites near Alemgena and Lake Chamo. Mechanical and cement stabilizations were investigated in two subsequent phases. In the first phase, optimum amount of fine soils that makes up the deficiency of fine particles of natural cinder gravels was found to be 12 %. In the second phase, natural cinder gravel samples without, and with 12% fine soils were stabilized with 3, 5, 7, and 10% of cement by mass. The results of the investigation indicated that the optimum amount of cement required to achieve the minimum UCS of 3.0 MPa as specified in ERA and AACRA pavement design standards for heavily trafficked base course without adding fine soils is found to be 7 % cement. 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. Nevertheless, the performance of cement stabilized cinder gravel should be investigated in a full-scale road experiment against cracking due to stresses induced by thermal, shrinkage, and traffic.

Keywords: *Base course, Cement stabilization, Cinder gravel, Mechanized stabilization, Optimum cement content.*

INTRODUCTION

Natural gravels are abundant source of road building materials but do not always meet the quality requirements for bases and are frequently rejected in favour of expensive alternatives such as crushed stone. However, these alternatives are often not locally available and the transportation of large quantities in heavy vehicles is expensive and consequently large financial and environmental benefits can be achieved if the properties of locally available materials such as natural cinder gravels can be improved by stabilization techniques and used with confidence.

Natural cinder gravels are pyroclastic natural materials associated with recent volcanic activity. They vary in colour, often within the same quarry and may be red, brown, grey, or black. The particle sizes also vary from irregularly shaped lumps of 0.5 m in diameter to sand and silt sizes. Other characteristics features of cinder are their light weight, their rough vesicular surface, and their high porosity.

In a joint research project between the Ethiopian Roads Authority and Transport and Road Research Laboratory (UK), a preliminary investigation on the location and engineering properties and a full-scale road experiment of cinder gravels were undertaken. The preliminary study [1] involved field surveys, laboratory investigation, and investigation of a cinder gravel road. According to the study, the two most important factors that affect the engineering behaviour of cinder gravels are grading and the strength of the gravel particles. The particle size analysis carried out on 53 samples collected during the field survey indicated that the grading of natural cinder gravel is deficient in fine particles and do not satisfy the recommended grading limits for base course. The aggregate impact test carried out on 23 samples using a modified procedure for weak aggregates resulted values ranging from 46 to 177 which indicate that the cinder gravel is weak. The main findings from the investigation include:

- The importance of sampling below the weathered zone which can extend to a depth of two meters to obtain representative materials;
- Due to the weak nature of cinder particles, compaction causes the breakdown of particles which improves both grading and strength properties, and this is further confirmed on the gravel road study;
- Changes in moisture content do not affect the properties of cinder gravels; and
- The addition of locally available clayey soil to make up for the deficiency of fine materials improves the compactability and stability of cinder gravels.

The full-scale road experiment [2] was comprised of 20 different sections out of which six sections were gravel surfaced and the remaining 14 sections were bitumen surfaced. The results of the gravel surfaced experimental sections showed that improved performance can be obtained by mechanically stabilizing cinder with plastic fines. The findings from the surface dressed sections showed satisfactory performance of cinder gravels whether untreated or mechanically stabilized for use in base course for up to 440,000 ESA when designed according to Road Note 31. The road-mix surfacing was, however, not found a satisfactory method of providing a bituminous surface for cinder gravel.

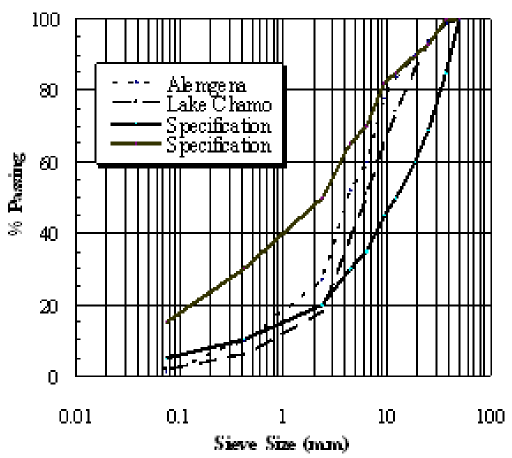
The results of the joint research work should be further taken up to investigate the potentials use of these abundantly available natural gravels in base course for heavily trafficked roads by improving their engineering properties. Both pavement design manuals used in Ethiopia, the Ethiopian Roads Authority Pavement Design Manual (ERA-PDM) [3] and the Addis Ababa City Roads Authority Pavement Design and Rehabilitation Manual (AACRA-PDRM) [4], recommend the use of stabilized locally available natural gravels when the cost of importing quality aggregate is expensive and hauling distance is far away. This paper presents the results of laboratory investigations made in improving the properties of cinder gravels by cement stabilization.

MATERIALS AND EXPERIMENTAL INVESTIGATIONS

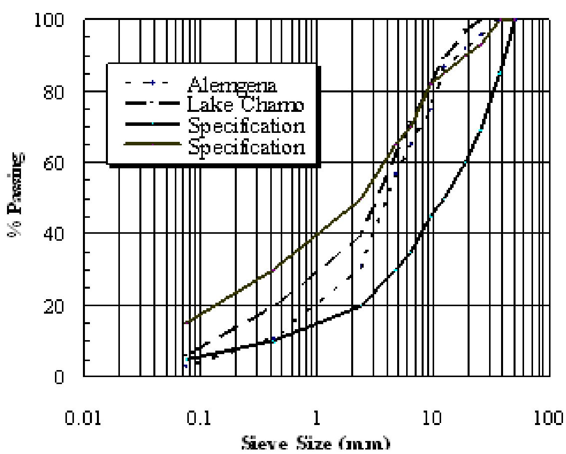
Sources and Descriptions of Materials

In this study, natural cinder gravel samples were investigated from two sites, near Alemgena and Lake Chamo. The samples near Alemgena were obtained from the freshly dozed stoke pile to be used for the subbase construction of Alemgena-Butajira Road while the samples from Lake Chamo were obtained from the quarry site which was used for the construction of unpaved roads in Arba Minch town. These samples were prepared for various tests after repeated quartering using sample splitter riffle box and studied in laboratories at Addis Ababa and Arba Minch Universities, respectively. In the presentation through out the paper, the samples are designated by Alemgena and Lake Chamo respectively.

Figure 1 depicts the gradation curves of the samples before and after compaction from both sites with desirable gradation specification limits specified for stabilised base materials in ERA_PDM and AACRA_PDRM. The gradation of cinder obtained from Alemgena is generally coarser than cinder from Lake Chamo. However, in both cases the gradation is almost within the specification limits except that the samples are deficient in fines before compaction and coarse particles are finer than the desirable limits after compaction because cinder particles break down during compaction due to their weak strength.



a) Gradation before compaction



b) Gradation after compaction

Figure 1 Gradation of cinder gravel samples before and after modified compaction

Table 1: Descriptive test results of natural cinder gravels used for the study

Type of test	Desirable limits	Test results	
		Alemgena	Lake Chamo
Los Angeles Abrasion	< 50 %	43 %	-
Aggregate Impact Value	< 35 %	44 %	-
Specific Gravity	2.5 – 3.0	2.26; materials > 4.75 mm and, 2.04; materials < 4.75 mm	1.89 materials > 4.75 mm and, 1.95 materials < 4.75 mm
Water absorption	1.0 – 2.0	6.0 %; materials between 37.5 mm and 10 mm, and 5.5%; materials < 10 mm	10.08%; materials between 37.5 mm and 10 mm, and 8.07 %; materials < 10 mm
Procter test	-	OMC = 24.8% MDD = 12.55 kN/m^3	OMC = 25.5% MDD = 12.75 kN/m^3
CBR		34 %	43 %

The descriptive test results in Table 1 shows that cinder gravel is a weak material and has high water absorption capacity because of its high porosity. The CBR value of the material is low for base course, but satisfies the requirements for subbase course materials.

As underlined in the previous studies, one can clearly observe in Fig. 1 (a) that the gradation of cinder gravel is deficient of fines particles. During this study, fine soils obtained near the quarry sites were blended with cinder gravel samples in order to make up for the deficiency of fine materials before cement stabilization. Table 2 shows the descriptive test results carried out on fine soil samples that were collected near the cinder gravel quarry sites for this purpose.

Table 2: Descriptive test results of fine soils used for mechanical stabilization

Type of test	Test Results	
	Alemgena	Lake Chamo
Gradation: % Passing - 4.75 mm	100	100
2.36 mm	88	86
0.425 mm	51	45
0.075 mm	17	10
Liquid Limit	55	39
Plastic Limit	39.5	30
Plastic Index	15.5	9
Specific gravity	2.7	2.7
Soil classification	A-2-7(0)	A-2-4 (0)

Experimental Investigations

In this study, cement stabilization of cinder gravels with and without the addition of fine soils to compensate for the deficiency of fine materials were investigated. Two series of trail mixes of cement stabilized cinder gravel were prepared three specimens for each percent of cement. The cement used was Ordinary Portland Cement. The first series of trail mixes are natural cinder gravel samples stabilized with 3, 5, 7, and 10 % cement by mass. The second series are mechanically stabilized cinder gravel samples (cinder gravels blended with optimum amount of fine soils) stabilised with 3, 5, 7, and 10 % cement by mass. Compaction and CBR testes were carried out on trial mixes prepared by blending 10 to 15 % fine soils by mass with natural cinder gravel samples to determine the optimum amount of fine soils required to mechanically stabilize cinder gravel samples.

The optimum moisture content pertaining to the maximum dry density for the range of cement content was determined according to ASTM D558. The specimens were then compacted using the optimum moisture contents determined in the standard mould following the same procedure as that used for proctor density. After compaction, the specimens in the mould were placed in a plastic bag, covered with wet cloth and kept in a humid room to cure for 24 to 48 hours.

The specimens were then removed from the mould carefully, labelled, put in plastic bag, covered with wet cloth, and kept in a humid room to moist cure until it was tested at the required curing period. Curing was necessary to ensure that there is always adequate water for the hydration reaction to proceed and to avoid the possible dry shrinkage while the reactions are proceeding. At the end of the moist curing period the specimens were soaked in water for four hours. Tests were conducted as soon as they were removed from the water bath.

After moist curing the specimens for 7, 14, and 28 days and soaking, unconfined compressive strength (UCS) test was conducted following ASTM

D1633-90 procedure. CBR tests were also carried out on trail mixes prepared with 3 and 5 % cement contents following ASTM D 1883-87.

RESULTS AND DISCUSSION

Stabilization of Natural Cinder Gravel with Cement

Table 3 shows the CBR test results carried out on cement stabilized cinder. The CBR values have increased by two folds for 3% cement in 7 days and almost four folds for 3% in 14 days and for 5% in 7 days. In general, CBR is not recommended [5] to be used when the strength of stabilised materials is more than 3 times that of the unstabilised materials. It is not also widely used to specify stabilised materials for road construction. This is because the strength of stabilised materials usually exceeds the limits of the CBR test procedure. CBR test is used here to indicate the general response of cement stabilization in cinder gravels.

The extensively used method to determine the relative response to cement stabilization and specify the strength of stabilised materials for pavement structure is UCS test. Table 4 shows the results of UCS tests carried out on cement stabilised cinder gravels with 7, 14, and 28 days of curing period. As shown in Fig. 2, the UCS test results clearly indicate that the strength of cement stabilised cinder shows a consistent trend of increase with both increase in stabilising cement and curing period. According to the results obtained, stabilised cinder gravel attains 3.0 MPa, which is the minimum strength requirement specified in ERA-PDM and AACRA-PDRM at 7% cement after 28 days of curing.

Table 3: CBR test results of cement stabilized cinder gravel

Cement by weight %	Alemgena				Lake Chamo			
	OMC (%)	MDD (kN/m^3)	Age (days)	CBR (%)	OMC (%)	MDD (kN/m^3)	Age (days)	CBR (%)
3	25.5	13.75	7	69	26.4	13.80	7	78
			14	111			14	-
			28	140			28	-
5	27.0	13.90	7	124	27.0	13.84	7	94
			14	134			14	-
			28	202			28	-

Table 4: UCS test results of cement stabilized cinder gravel in MPa

Cement by weight %	Alemgena			Lake Chamo		
	7 days	14 days	28 days	7 days	14 days	28 days
3	1.12	1.33	1.61	1.31	1.449	1.801
5	1.49	1.81	2.22	1.51	1.802	2.082
7	1.72	2.41	3.08	1.69	2.324	3.033
10	1.99	3.34	4.24	2.17	3.366	4.113

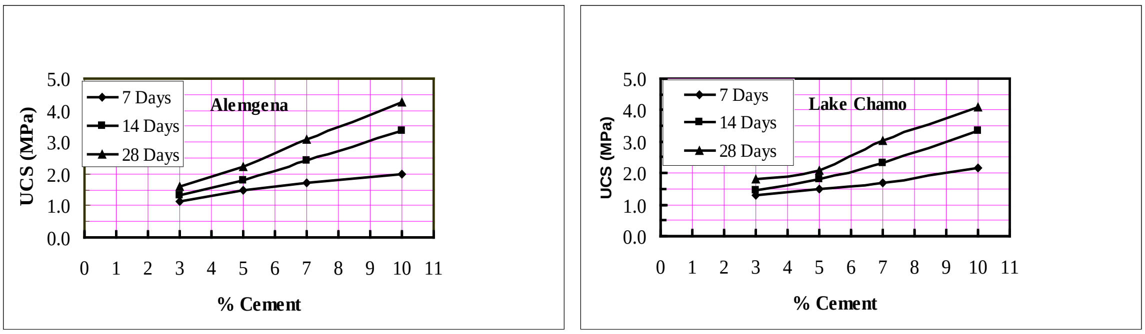


Figure 2 Variation of UCS with percentage of cement and curing period

Stabilization of Mechanically Stabilized Cinder with Cement

Because cinder gravel is deficient in fine particles, the amount of cement required to stabilise natural cinder gravel that satisfies the minimum strength requirement (as seen in Section 3.1) for heavily trafficked base course is generally high. In this section, the results of two series of tests: (a) to determine an optimum amount of fine soil required to compensate the deficiency of fines in cinder and (b) to investigate the cement stabilised cinder gravel blended with the optimum amount of fine soils determined are discussed. These are presented in subsequent subsections as "mechanical stabilization" and "cement stabilization" of cinder gravel below.

Mechanical Stabilization of Cinder Gravel

Table 5 shows the compaction and CBR test results conducted on mechanically stabilised cinder gravel with 10 to 15% fine soils by mass to determine the optimum amount of fines. Figure 3 shows the plots of these results. In both cases, the results consistently indicate that MDD and CBR increase with increase in fine soils up to 12%. However, beyond 12%, these values decreased.

This result indicates that the optimum amount of fine soil that makes up for the deficiency of fines in cinder gravel samples from both Alemgena and Lake Chamo areas is 12%. This optimum amount, 12% fine soils by mass, was mixed with the cinder gravel samples in order to investigate the improvement in strength that can be obtained when mechanically stabilised cinder is stabilized with cement.

Cement Stabilization of Cinder Gravel Blended with Fine Soils

Table 6 and Table 7 show the CBR and UCS test results carried out on cement stabilized cinder gravel with 12% fine soils respectively. The plot of UCS in Figure 4 shows that the strength of cement stabilised cinder blended with 12% fine soils has increased compared with that of stabilised cinder without the addition of fine soils. Accordingly, the minimum strength requirement specified in ERA-PDM and AACRA-PDRM is attained at 5% of cement by mass.

Table 5: Results of mechanical stabilization of cinder with fine soils

Fine Soil by weight	Alemgena			Lake Chamo		
	OMC (%)	MDD (kN/m^3)	CBR (%)	OMC (%)	MDD (kN/m^3)	CBR (%)
Cinder only	24.8	12.55	34	25.50	12.75	43
Cinder + 10 %	25.0	13.70	40	26.00	13.38	47
Cinder + 11 %	25.3	13.75	43	26.80	13.40	50
Cinder + 12 %	25.8	13.88	56	27.01	13.98	58
Cinder + 13 %	27.2	13.80	45	28.00	13.32	47
Cinder + 14 %	28.0	13.70	43	28.30	13.31	46
Cinder + 15 %	28.3	13.72	40	-	-	-

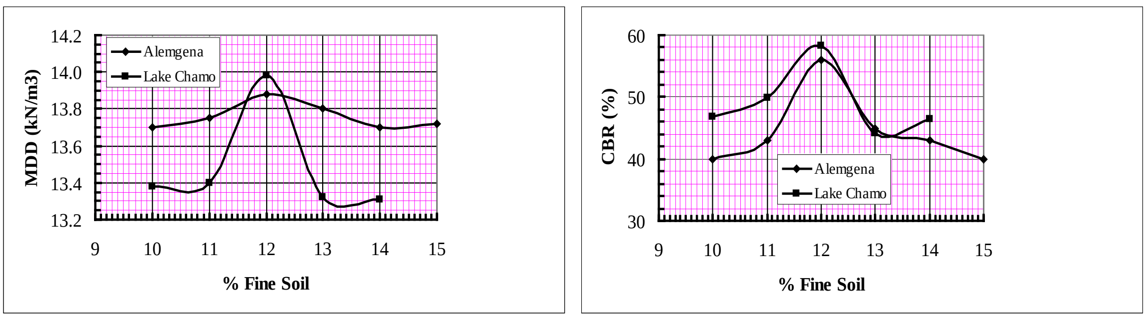


Figure 3 Variation of MDD and CBR with percentage of fine soil mixed with cinder

Table 6: CBR test results of mechanically stabilized cinder with cement

Cement by weight %	Alemgena		Lake Chamo	
	Age (days)	CBR (%)	Age (days)	CBR (%)
3	7	63	7	122
	14	74	14	-
	28	172	28	-
5	7	71	7	-
	14	112	14	-
	28	213	28	-

Table 7: UCS test results of mechanically stabilized cinder with cement in MPa

Cement by weigh %	Alemgena			Lake Chamo		
	7 days	14 days	28 days	7 days	14 days	28 days
3	1.56	2.21	2.73	1.623	2.138	2.596
5	2.23	3.17	3.91	2.336	3.282	3.934
7	2.63	3.40	4.69	2.695	3.573	4.332
10	3.27	4.24	5.59	3.126	4.027	5.23

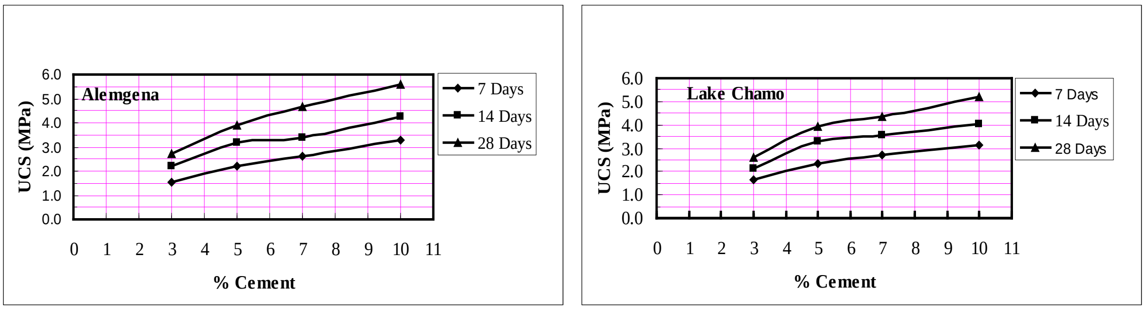


Figure 4 Variation of UCS with percentage of cement and curing period

The percentage increase in strength gained by adding fine soils was evaluated as shown in Fig. 5. As one can observe from the figure, the percentage increase in UCS gained as a result of adding fine soils has an increasing trend up to 5 % cement and then starts falling. This clearly indicates that 5 % cement by mass is an optimum amount to stabilise cinder gravel with sufficient fines.

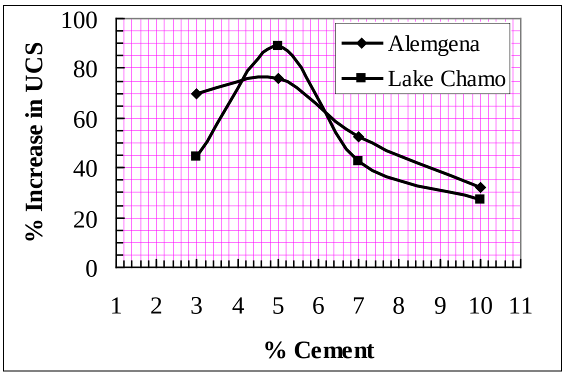


Figure 5 Variation of increase in UCS with cement content

CONCLUSIONS

Although cinder gravels occur extensively in Ethiopia, rarely support any vegetation other than grasses, and relatively easy to dig with shovel or hand tools, their use for road construction is limited for the reason that they do not meet the specification requirements. In this investigation, mechanical and cement stabilisation techniques were used to improve their properties so that they are used as base course materials for heavily trafficked roads. Based on the results obtained, the following conclusions are made:

- The gradation of cinder gravel samples lacked fine particles and 12 % of fine soil by mass was found to be optimum for making up this deficiency which confirms the results of previous studies.

- Cement stabilised cinder gravels without the addition of fine soils require 7 % of cement by mass to attain a UCS of 3.0 MPa which is the minimum specified strength in ERA-PDM and AACRA-PDRM for a base course in heavily trafficked pavement structure.

- With the addition of the optimum amount of fine soils to make up for the deficiency of fine particles, 5 % cement by mass is found to be optimum to achieve a UCS of 3.0 MPa, minimum specified by ERA and AACRA for a base course in heavily trafficked pavement structure for cement stabilised materials.

The results obtained in this investigation ascertained that the properties of cinder gravel can be improved by stabilisation and used for heavily trafficked base course. However, a full-scale road experiment is necessary in order to study the performance of stabilised cinder gravels against the possible detrimental effects of cracking due to stresses induced by thermal, shrinkage, and traffic. Moreover, the feasibility of cement stabilised cinder gravels should be checked for every project versus expenses related to getting quality aggregate and hauling distance.

ACKNOWLOGMENT

This investigation was carried out as students' final project at Addis Ababa and Arba Minch Universities. The Author wishes to thank all students who have been involved in this investigation.

REFERENCES

[1] Newil, D. and Kassaye Aklilu. "*The Location and Engineering Properties of Volcanic Cinder Gravels in Ethiopia*". Seventh Regional Conference for Africa on Soil Mechanics and Foundation Engineering/Accra, June 1980.

[2] Newil, D., Robinson, R. and Kassaye Aklilu. "*Experimental Use of Cinder Gravels on Roads in Ethiopia*". 9th Regional Conference for Africa on Soil Mechnics and Foundation Engineering / Lagos, September 1987.

[3] Ethiopian Roads Authority. "*Pavement Design Manual Volume I: Flexible Pavements and Gravel Roads*", 2002.

[4] Addis Ababa City Roads Authority. "*Pavement Design and Rehabilitation Manual*", 2003.

[5] National Association of Australian State Road Authorities. "*Guide to Stabilization in Road Works*". Sydney, 1986.