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UTILIZATION OF CRUSHED STONE DUST AS A STABILIZER FOR SUB GRADE SOIL: A CASE STUDY IN JIMMA TOWN

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Abstract: Crushed stone dust is material obtained from aggregate crushing industries. Use of such stone dust materials creates lots of problems in environment and public due to excess storage and dust accumulation. Considering this aspect an experimental study was conducted on expansive soil by mixing it with locally available crushed stone dust. This paper reflects the visionary light on the suitability of crusher dust as soil stabilizer for use in pavement construction. The role of crusher dust in improving the characteristics of expansive sub grade material is analysed. The amount of cost savings for a pavement when it is stabilized with crusher dust is also studied. In order to realize the desired objective a purposive sampling techniques which is non probability method was adopted.in order to collect disturbed soil sample at depth of 1.5m at Ginjo kebele around Honey land hotel and a crushed stone dust from aggregate production area for the preparation of different lab tests. The lab work involves sieve analysis along the consistence test to classify the soil samples. The preliminary investigation of the soil shows that it belongs to A-7-5 class of soil in AASHTO & CH in USCS. Soil under this class was poor for sub grade construction. Atterberg limit, compunction and CBR test were used to evaluate the properties of stabilized soil. The soil stabilized with the crushed stone dust in stepped constration of 0, 5, 10, 15, 20, 25, 30, 35, 40, 45 & 50% by dry weight of soil. The analysis of the result shows the addition of crushered stone dust improve the geotechnical properties of soil. The addition crushed stone dust reduces PI, Swelling and the optimum moisture content with an increase in MDD& CBR with an increase of crushed stone dust.A considerable amount of cost savings is also possible when the expansive clay soil is stabilized with crusher dust.
Keywords: expansive sub-grade soil, crushed stone dust, stabilization, cbr, swelling index, cost

1. INTRODUCTION

— Background

The strength of flexible pavement normally depends on its subsequent layers for the load above is transferred to them. Due to the scarcity of high performance soil, highway agency enforced to construct road on weak subgrade by strengthening it. Road foundation contructed on problematc soil, creates problem in the long run and reduces the economic life by increasing the maintenance cost of the road. It is important to reduce failure by increasing the engineering properties of the subgarde especially the plastic property which in turn reduces the volume change of expansive soil. [1]

Almost 40% of the road expenditure in Ethiopia is allocated in rehabilitation of road for the last 13 years. This is due to the fact the most of Ethiopian land is covered by expansive soil. [2] This problem urges the need for wider application of cost effective and environmentally friendly technologies of improving soil properties, such as chemical stabilization, to be customized and adopted to the current road construction trend in the country[3] Avaiability of waste material such as fly ash, fond ash, dust for crusher encourage researcher to utilized these by stabilizing expansive solid for construction purposes, It was believed that these material can improved the needs of built structures that meet the demand of the population. [4]

Crusher dust is produced during the production of crushed aggregates. Its disposal in large quantities creates serious problem to environment, health in particular. This research will utilized these materials to improve the quality of the subgrade, it can also be a cost effective way of stabilizing the soil by reducing the cement stabilized soil in construction. [9] Since the introduction of crusher dust improves the engineering behaviour of soils, this review work exposes those qualities and applications that make quarry dust a good replacement or admixture during soil improvement and for a more economic approach [8].

The addition of crusher dust not only improve the swelling nature but also increases the CBR value which in turn reduces the thickness of pavement. [10].

— Statement of the Problem

Engineering problems related to expansive soils have been reported in many countries of the world as 3% of the world land area but are generally most serious in arid and semi-arid regions. As a result, highly reactive soil undergo substantial volume changes associated with shrinkage and swelling process.. Expansive soil are not as dramatic as hurricane or wide areas rather than being constructed in a small locality [2].

They are widely spread in the central part of Ethiopia following the major truck roads are covered by expansive soils. Soil stabilization is the alteration of one or more soil properties, by mechanical or chemical means, to create an improved soil material possessing the desired engineering properties. The process may include the blending of soils to achieve a desired gradation or mixing of commercially available additives that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil [2].

Accordingly roads in Jimma zone experienced many types of failures due to the above-mentioned cases. Therefore, to prevent the problems, it is essential for engineers to stabilize the existing weak soils before commencing the construction activities. One method to ensure that existing natural soil improved and suitable for construction is by mixing it with crusher dust as a cost effective stabilizer.

— Objectives of the Study

The main objective of this study was utilization of crushed stone dust as a stabilizer for sub-grade soil. Specifically, it aimed to identify the engineering properties of expansive soil and the crushed stone dust in the study area; determine the optimum crusher dust percentage to be added; quantify the amount of cost savings for sub grade formation; and compare the laboratory test result with standard specification

— Significance of the study

For sub-grade and foundation preparation, particularly in the road construction sector, expansive soil increases the initial cost of construction due to the need of improving its strength as foundation for pavement structure. This research served as guide for utilizing crusher dust as stabilizer. This is useful in the sense that, it can improve the quality of the subgrade and reduce initial costs of road construction.

2. MATERIALS AND METHODOLOGY

— Study Design

This research was designed to answer the research questions and meet its objectives based on experimental findings.

— Sample collection

The expansive soil sample used for this research work was collected from Jimma town, Ginjo Kebele. The soil was grayish black in color highly plastic clay. Disturbed and undisturbed sample were collected from the test pit at a depth of 2m.

The crusher dust was brought from local aggregate crushing industry near Bosa Kitto Kebele, Jimma town. The collected crusher dust separated from non-parental materials and subjected to geotechnical characterization as per standard specification such as AASHTO, ASTM and ERA

— Study Variables

The dependent variable of the study was applicability of expansive clay soil stabilized with crusher dust and the independent variables are engineering properties of the untreated and treated expansive soil, amount of crusher dust added, and its economic consideration.

— Sampling Techniques

The sampling technique applied for the collection of sample in the laboratory was quartering method.

— Methods for Preparing Specimens

Following a thorough laboratory procedure, the crusher dust was added to the soil at 5% increment to a maximum of 50% addition by weight. The engineering properties were determined according to standards. It was believed that in adding up to 50% is enough not to lose the plasticity of the soil.

— Laboratory tests

Given in Table 1 are the laboratory test employed to attain the objectives of the study.

Table 1. Standards and specifications - adapted AASHTO and ASTM

N/S	Laboratory test	Standard specification
1	Moisture Content	AASHTO T-80
2	Grain Size Analysis	AASHTO T-88&ASTM D422-63
3	Specific Gravity	ASTM D 854-00
4	Atterberg Limits	ASTM D424 or AASHTO T90
5	Soil Classification	AASHTO M-145
6	Procter compaction test	AASHTO T-180
7	California Bearing Ratio (CBR)	AASHTO T-193 and AASHTO T-180

— Design of Flexible Pavement

For economic comparison. T8 class was selected according to ERA Manual Volume I.

3. RESULTS AND DISCUSSIONS

— Geotechnical Properties of Soil Sample

To determine the quality of the materials, laboratory tests were carried out. The tests involved to identify the properties of the natural soil such as its physical and mechanical properties.

» Particle size distribution

Mechanical analysis for coarser material and hydrometer analysis for fine materials was performed for this particular test. According to Figure 1, the soil is classified as fine clay soil because almost 89 percent pass the #200 sieve.

» Atterberg's Limits

The Atterberg limits results are given in Table 2. The representative sample of the soil was very high plastic clay, liquid limit=80%, that makes the sub grade expansive and swell easily and does not satisfy standard specification of ERA. Therefore, it needs improvement to use for road construction as sub-grade material.

Table 2. 1Atterberg's Limit test result for natural soil

Atterberg's Limit's	Percentage. %	ERA(2002) requirement of PI for subgrade	Status for ERA Specifications
liquid limit, LL AASHTO T 89	80.08	PI≤30%	Fail for subgrade
Plastic limit. PL AASHTO T 90	35.27		
Plasticity Index, PI	44.81		

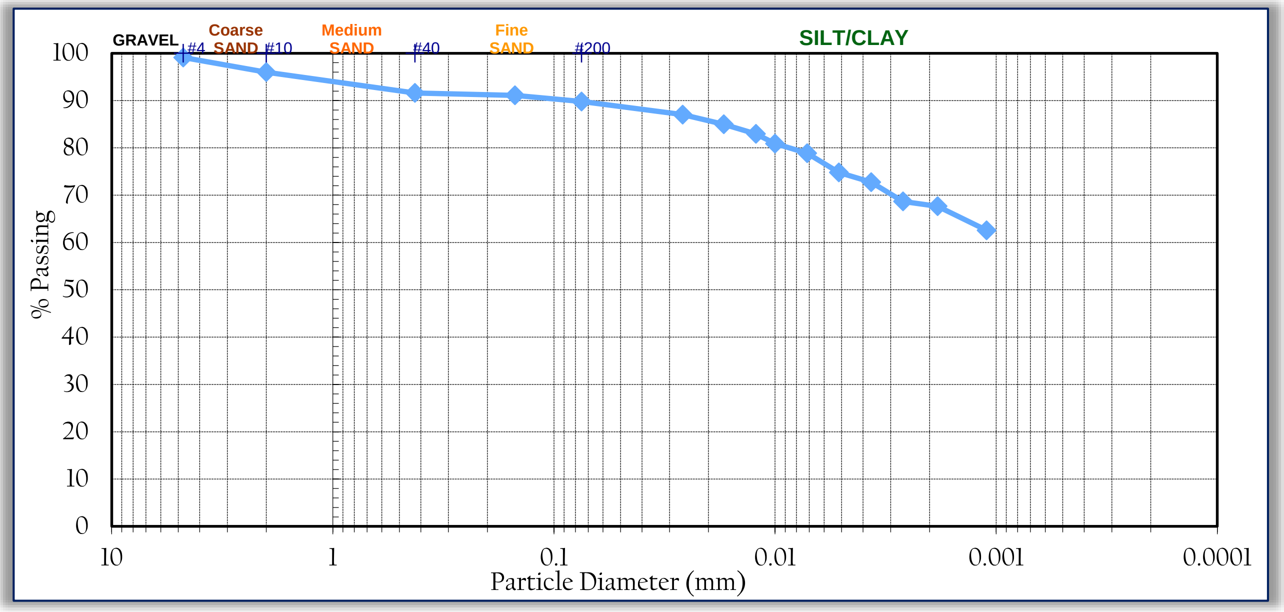

Figure 1. Particle size distribution curve of expansive soil.

» Soil Classification

The soils classification according to AASHTO system and USCS plasticity chart is as follows.

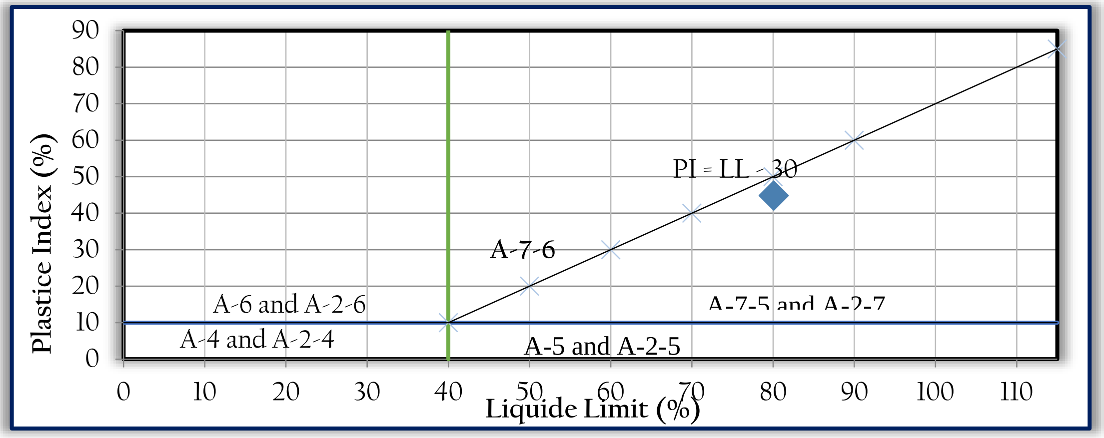

Figure 2. Soil classification according to AASHTO system

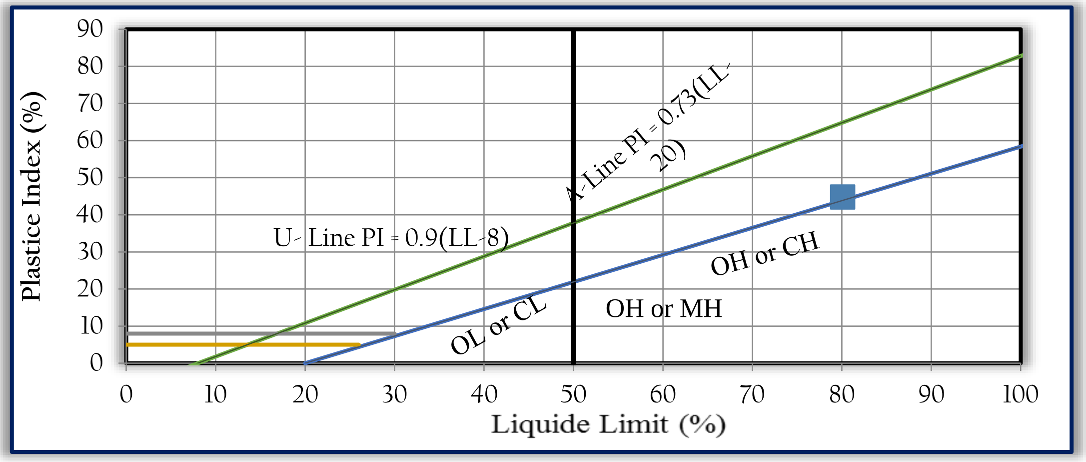

Figure 3.3 USCS plasticity chart of the studied soil

As a result of LL and PI the soil sample classified under group A-7-5. So that the usual types of significant constituent materials are clayey soils with fair to poor general rating of subgrade. Since soil sample has Liquid limit more than 50% and above A-Line, so they are classified under high to very high CH.

» Free swell index

This result indicated that the soils are highly expansive soils. Soils are called highly expansive when the free swell index exceeds 50%, and such soils undergo volumetric changes.

Table 3. Free swell index test result of Expansive Soil Sample

Additive content	Expansive soil		
Readings on the Glass Jar	S1	S2	S3
V_w = volume of soil specimen read from the graduated cylinder containing distilled water	19	18.5	19.5
V_k = volume of soil specimen read from the graduated cylinder containing kerosene	10	10	10
Free swell index= $[V_d - V_k] / V_k$ x 100%	90	85	95
Average Free Swell index	90%		

» Compaction Test

Proctor compaction test was conducted for the expansive soil under consideration to determine the maximum dry density and optimum moisture content of the soils.

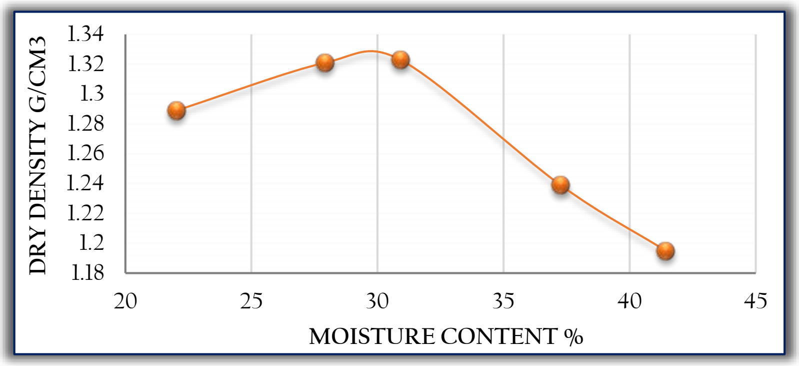

Figure 3. Shows a graph of moisture content and maximum dry density

Form Figure 3 it was shown that the soil sample has a maximum dry density of 1.323 g/cm^3 and the optimum moisture content of 30.91 %. During road construction the CBR value is obtained using the compaction test result. And these CBR results used to determine the thickness of the base layer of road.

» Soaked CBR and CBR Swell of soil sample

According to OMC and MDD of the expansive soil sample, the soaked CBR value is 1.817%. Table 4 showed CBR test was determined at 2.54 and 5.08 penetration at the given maximum dry density and optimum moisture content of original soil sample. Therefore, based on the ERA requirement, the soil was lower CBR value and it is not suitable for sub grade in road construction.

Table 4. CBR test result of the expansive soil sample

Compaction Data		OMC	30.913%	MDD	1.323g/cm3	
Blow	Dry density (g/cc)	Load(KN)		CBR (%)		Swell (%)
		2.54	5.08	2.54	5.08	
56	1.45	0.24	0.36	1.817	1.815	3.181
MDD		1.323g/cm3				
CBR at MDD		1.817%				

» Specific Gravity (ASTM D854-98)

The subgrade soil under study is expansive black cotton soil composed of different minerals. The average specific gravity of the soil under study was 2.69.

— Geotechnical properties of Crusher dust

The collected crusher dust separated from non-parental material and subjected to geotechnical characterization as per standard specification such as AASHTO, ASTM. The basic test such as sieve analysis, Atteberg limit, compaction, and CBR of crusher dust were investigated. Table 5 shows the geotechnical properties of the crusher dust.

Table 5. Geotechnical Properties of crusher dust

Properties	Observed Values
Grain size distribution	
Gravel (%)	7.6
Sand (%)	92.4
Fines (%)	0
Coefficient of Uniformity	4.7
Coefficient of Curvature	0.772
Consistency characteristic	
Liquid limit(%)=W_L	NP
Plastic limit(%)=W_P	NP
AASHTO Classification	A-1-a
Specific gravity	2.75
Compaction characteristics:	
OMC (%)	10.3%
MDD (%)	2.01g/cm3
Strength characteristics	
CBR (%)	11.8

— The effect Crusher dust on Expansive soil

» The effect of Crusher dust on Atterberg's limit

The results of expansive clay crusher dust mixes are shown in Figure 3.5 with varying percentages on addition. It shows the consistency limit such as Liquid Limit, Plastic Limit and Plasticity Index. It was found that as the percentage of crusher dust increases the liquid limit and plastic limit decreases. Consequently the plasticity index also decreased followed with increase in crusher dust content.

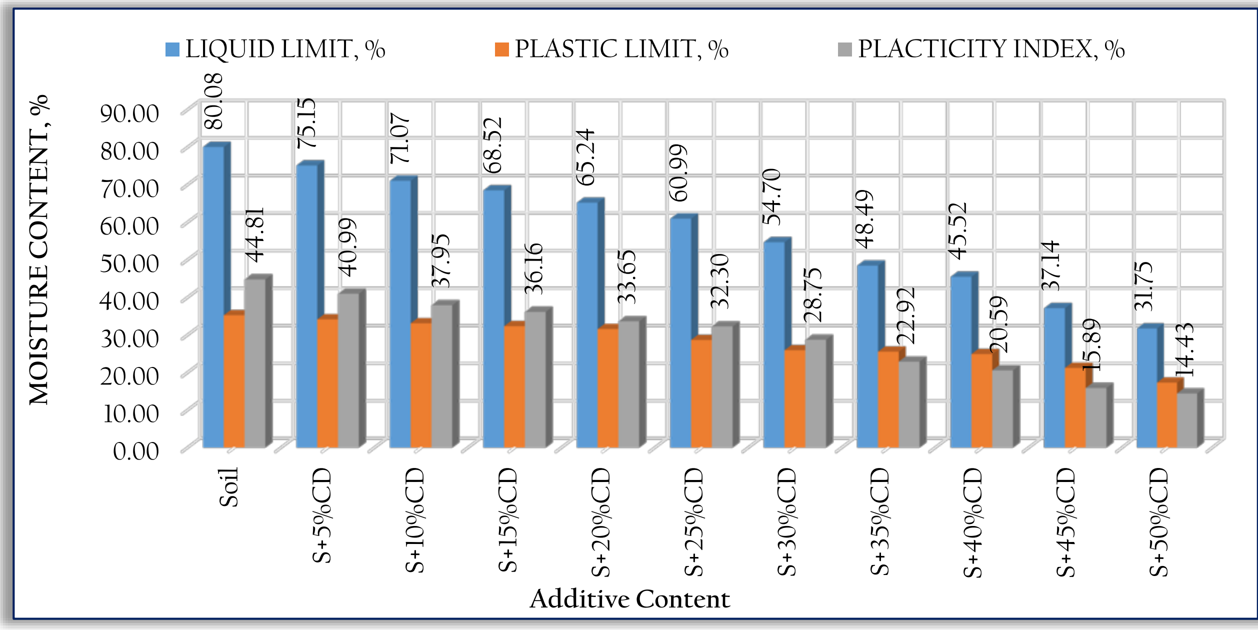

Figure 4. Effect of Crusher dust on Atterberg's limits

After modification PI reduced from a value of 44.81% to a value of 14.43% after an improvement with 50% crusher dust. Hence crusher dust has great impact in reduction of PI. The probable reason for reduction of liquid limit of modified soil may be due to mechanical stabilization and addition of non-plastic material.

Blending expansive soil with crusher dust was satisfying ERA standard specification for Sub-grade construction. Blending expansive soil with 30% crushed stone dust and above was satisfying ERA standard specification of for sub grade construction.

» Free swell index

The free swell index of expansive soil decrease when the ratio of Crusher dust increases. The free swell index result of stabilized soil is presented in Figure 5.

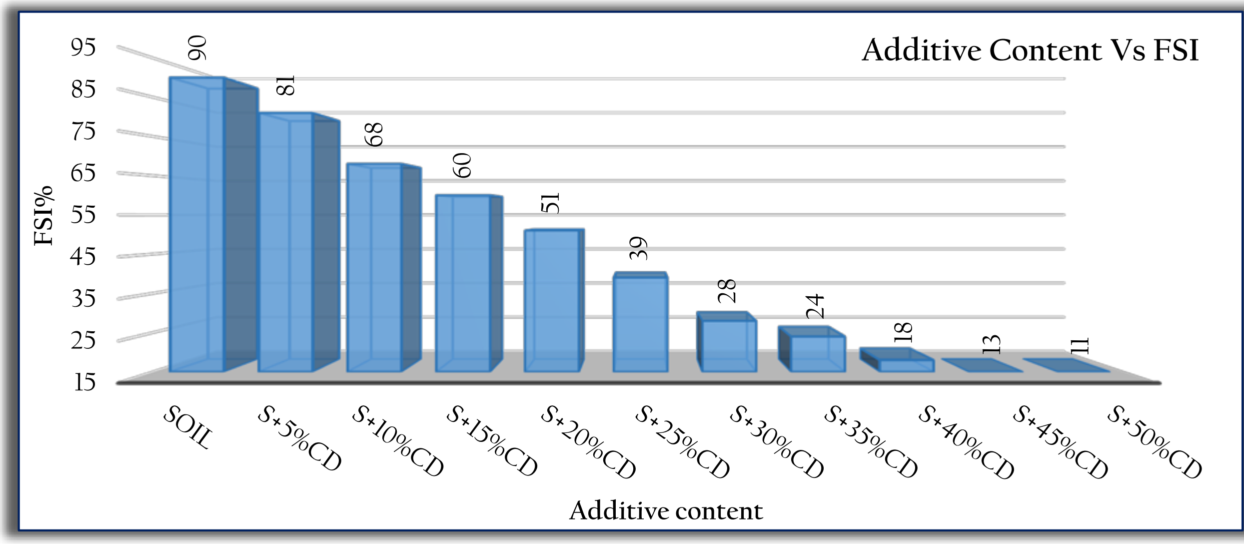

Figure 5. Free swell index of Expansive soil sample at different stabilizer ratio

As shown in Figure 5 above, the free swell of the samples has decreased with increase in Crusher dust ratio. But slight reduction is observed with higher ratio of Crusher dust added. Except 5%, 10%, 15% and 20% of Crusher dust soil mix all ratio were under the specification. As more percent of Crusher dust added to the soil the swell and shrink properties of the affected soil lower. Beside, more crusher dust content slightly reduces the expansiveness of the soil. As a whole the quantum of replacement of quarry dust is found to be in the range of 40% to 50 % in laying road pavements for the in-situ expansive clay soil which is marginally higher. For economic considerations and for laying local pavements inside streets and villages 30% replacement of clayey soil can be sorted.

» The effect of addition of Crusher dust on Compaction Characteristics

The results of standard Proctor tests on expansive soil treated with different percentages of crusher dust are shown Figure 6. The values for the maximum dry densities were noted to significantly increase with the addition of crusher dust from a value of 1.323 g/cm^3 to a maximum value of 1.735 g/cm^3 attained in the blend 50% crusher dust. Whereas, the optimum moisture content values are continuously decreasing. The Optimum Moisture Content (OMC) decreases from 30.91% to 18.16 % when crusher dust is increased from 0 to 50% as shown in Figure 7.

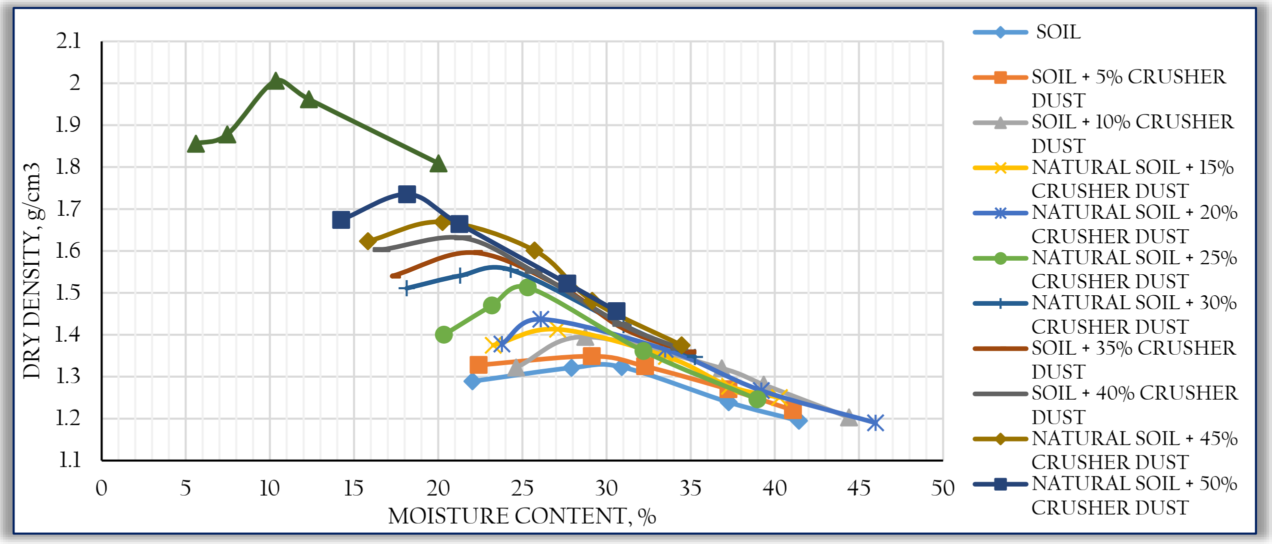

Figure 6. Effect of Crusher dust on Dry Density and Moisture Content

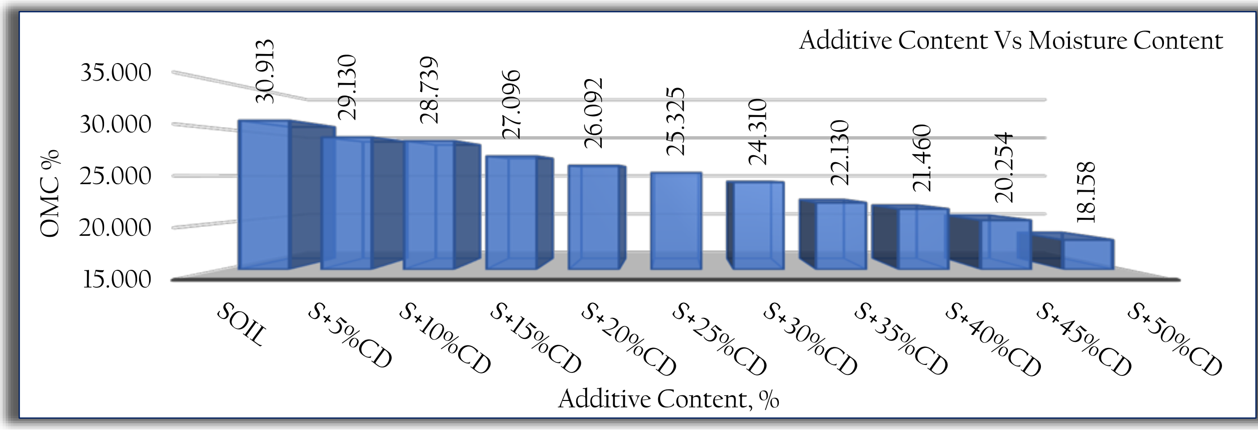

Figure 7. Variation OMC with percentage of Crusher dust

As the replacement of crusher dust is found to be in the range of 40%to 50 % in laying road pavements for the in-situ expansive soil which is marginally higher. For economic considerations and for laying local pavements inside streets and villages replacement of 30% crusher dust is practically feasible.

» Effect of crusher dust on CBR

The expansive soil was modified by addition of crusher dust in the proportion stated in the methodology as shown in the Figure 8 below. There is an increase in the CBr value as the dust percentage increases up tom 35% and slightly reduce when further increase the dust content.

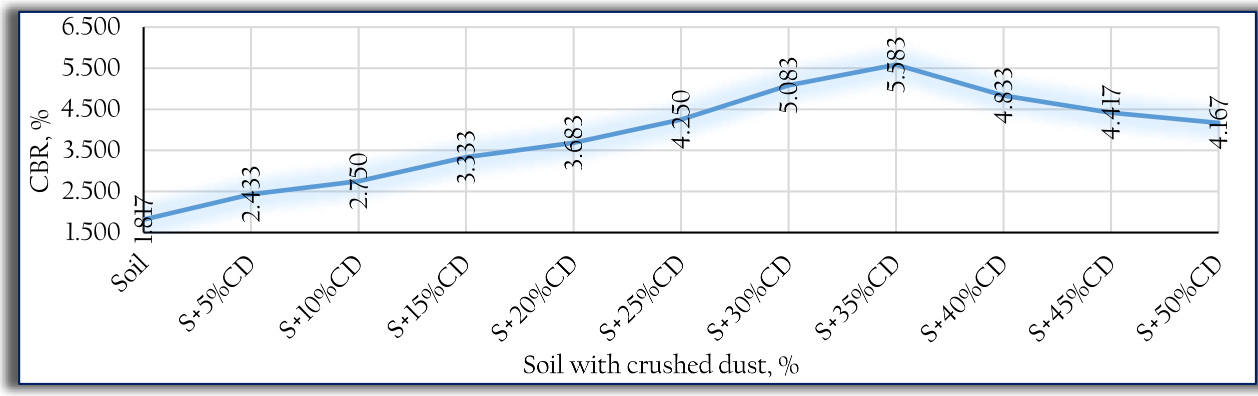

Figure 8. Shows the variation in soaked CBR value with Crusher dust

The probable reason for increase in CBR value of soil is by addition of stone dust in comparison with original soil may be due to increase in density of modified soil mass having more strength.

» Effect of crusher dust on CBR Swell

The crusher dust and soil mixtures compacted in CBR molds at optimum moisture content and maximum dry density gauged for swelling properties before and after soaking for four days to evaluate the percent swell. The test result at different ratios was illustrated in Figure 9. Soil sample had 3.181% value of CBR swell but when 30% crusher dust added it reduce to 1.478%. These indicate highly reduction in CBR swell. When it mix with crusher dust beyond 30% it improve the expansive soil strongly but there is slightly reduction was observed. Therefore using crusher dust stabilizers improve the stability and strength of the subgrade soils. The strength of subgrade is the principle factor in determining the thickness of the pavement, but deterioration due to frost action must also be taken into account. The strength of subgrade is associated on CBR scale.

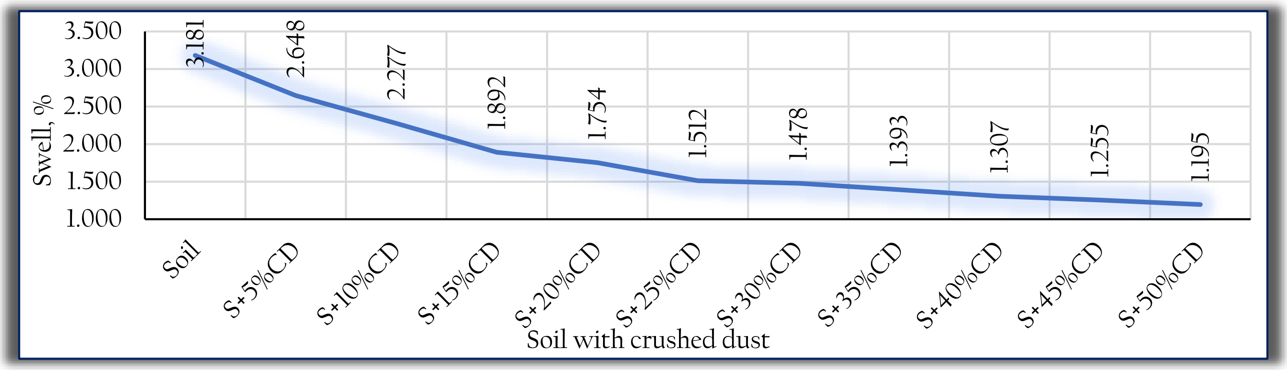

Figure 9. CBR Swell test result of stabilized and natural Expansive soil

– Design of Pavement structure

From conducted laboratory test the untreated soil has 1.817% of CBR, for the minimum CBR value of 2%, the subgrade strength class to be assigned to this project is therefore S1 As per ERA Pavement Design, Manual Volume 1,2001. The following preliminary information has been derived from material investigations

- ✓ The materials which may be considered for cement- or lime-stabilization have relatively low percentages of fines and low plasticity, thus making cement-stabilization more promising.
- ✓ Granular sub base materials are available in sufficient quantities and cement stabilization of the sub base is uneconomical when compared to bank-run materials. Stabilization of sub base materials will not be further considered.
- ✓ All other materials entering the composition of the possible pavement structures are available in various quantities and associated transport/construction costs.

Based on the above, and with the T8/S2 and T8/S3 combination of traffic and subgrade strength classes, the design charts 4 through 7 indicate the possible alternate pavement structures given in Table 6 and Table 7.

Table 6. Possible Pavement Structure before stabilization

Design Chart No.		4	5	6	7
Pavement Components and Selected Fill	Possible Alternate Pavement Structures	Alternate Structure No. 1	Alternate Structure No. 2	Alternate Structure No. 3	Alternate Structure No. 4
Surfacing (asphalt concrete) (1)		5 cm AC	15cm AC	15cm AC	5 cm AC
Roadbase: · Crushed Stone · Cement stabilized (e.g. 4 Mpa) · Cement stabilized (e.g. 2.5 Mpa) · Bituminous stabilized		 15 cm 15 cm 15 cm —	 25 cm — — —	 15 cm 12.5cm 12.5 cm —	 — — — 20 cm
Granular subbase		—	25 cm	—	25 cm (2)
Selected fill		20 cm	20cm	20cm	20cm (2)
Buffer layer		60cm	60cm	60cm	60cm

Table 7. Possible Pavement Structure after stabilization

Design Chart No.		4	5	6	7
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Surfacing (asphalt concrete) (1)		5 cm AC	15cm AC	15cm AC	5 cm AC
Roadbase: · Crushed Stone · Cement stabilized (e.g. 4 Mpa) · Cement stabilized (e.g. 2.5 Mpa) · Bituminous stabilized		 15 cm 15 cm 12.5 cm —	 25 cm — — —	 15 cm — 22.5 cm —	 — — — 20 cm
Granular subbase		—	27.5 cm	—	27.5 cm (2)
Selected fill		15 cm	—	—	— (2)

The alternate structures including cement stabilized layers appear prohibitive, and the alternate number two including only crushed stone road base and sub base also appear at a disadvantage. Since Granular sub base materials are available in sufficient quantities and cement stabilization of the sub base is uneconomical when compared to bank-run materials. Stabilization of sub base materials will not be further considered. Therefore the alternative 2 is best Alternate Pavement Structure. With these Alternative The total pavement thickness is 850mm and 675mm for untreated and threated sub grade respectively. The recommended pavement structure is given in Figure 10 and Figure 11.

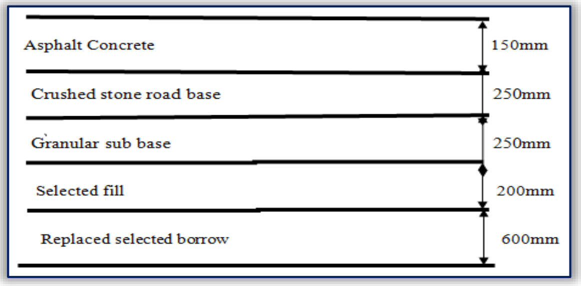

Figure 10. Pavement structure before stabilization

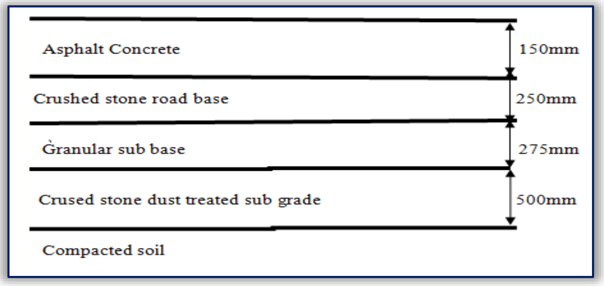

Figure 11. Pavement structure after stabilization

— Cost Estimation

The quantitative costs of pavement for untreated and treated sub grade are given in Tables 8 and 9 trough Table 10 respectively.

Table 8. Quantitative cost for untreated Expansive soil (Constractionethiopia.com, 2018)

Item No	Item description	Unit	Rate	Length (m)	Width (m)	Depth (m)	Amount
1	Sub Grade						
	Site clearing	m^2	15.49	1000	3.5	1	54215
	Balk excavation in expansive soil not exceeding 1.5m	m^3	99.58	1000	3.5	0.6	209118
	Disposal of excavated material (5KM hauling distance)	m^3	126.66	1000	3.5	0.6	265986
	Road bed preparation compaction to 93% MMD	m^2	58	1000	3.5	1	203000
	Selected material (5km)	m^3	145	1000	3.5	0.6	304500
	Placing and compacted selected material to 95% MDD	m^2	78.24	1000	3.5	1	273840
	Sub Total	1310659					
2	Capping layer/selected material	m^3	145	1000	3.5	0.2	101500
3	SUB BASE						0
	Gravel sub base 97%, MDD (MAT. From 5KM)	m^3	170.9	1000	3.5	0.25	149502.5
4	Base course						0
5	Crushed stone road base	m^3	469.19	1000	3.5	0.25	410541.3
6	15cm Asphalt Concrete	m^2	1500	1000	3.5	1	5250000
	Sub Total	5911544					
	Total Cost of Construction	7222203					

Table 9. Quantitative cost for crusher dust stabilized Expansive soil

I. Road Section	Unit	Unit price
Clearing and Grubbing within Road Prism	m^2	15.49
Purchase Cost of Stabilizer including transport		
Purchase Cost of Stabilizer from local crusher	m^3	456.25
For 1m^3 of Expansive soil, 0.39m^3 of crusher dust required(by using 30% CD wich is optimum)	m^3	177.94
Purchase Cost of Stabilizer of crusher dust	m^2	106.76
III. Placing of Stabilizer		
Hauling of Stabilizer	m^2	48.05
Mixing of Stabilizer	m^2	71.94
Placing of Stabilizer	m^2	54.19
Total Quantitative Cost	m^2	296.43

Table 10. Quantitative cost of pavement after stabilizing

Item No	Item description	Unit	Rate	Length (m)	Width (m)	Depth (m)	Amount
1	Stabilized Sub Grade	m^2	296.43	1000	3.5	1	1,037,505
2	Gravel Sub Base 97% MDD (MAT. From 5KM)	m^3	170.9	1000	3.5	0.275	164,452.8
3	Crushed Stone Road Base	m^3	469.19	1000	3.5	0.25	410,541.3
4	15cm Asphalt Surfacing	m^2	1500	1000	3.5	1	5,250,000
Total Cost		6,862,499					

The comparisons of the cost benefits were made from Tables 10. As shown in the tables, the total quantitative cost of crusher dust stabilized subgrade was estimated as 1,037,505 Birr/km against the cost of 1,310,659 Birr / km for replacing selective borrow material from a 5km distance. The saving in cost for crusher dust stabilization thus estimated to be 20.84% of construction cost of sub grade which is 5% of total construction cost.

4. CONCLUSION AND RECOMMENDATION

The study on stabilizing the locally available clayey soil in Jimma by crusher dust with the support of series of laboratory investigations in specific arrived at the following conclusions.

- This indicates that crusher dust can be used as an embankment material, backfill material for the lower layer of sub base. Also reuse of this waste material is economically advantages and does not bring any environmental hazards
- The test result showed that the subgrade soil considered for this study were A-7-5 as per AASHTO soil classification system and CH as USCS. The plastic index for soil sample is 44% and that MDD is 1.323 g/cm3. The soaked CBR value of soil sample is 1.86%. With this, the soil is classified as expansive clay soil and is unsuitable as subgrade materials.
- The addition of the crusher dust reduces the clay content and thus increases in the percentage of coarser particles, reduces the Liquid limit by 60.89% and plasticity index by 67.62%. With 30% of crusher dust, the liquid limit of expansive soil becomes 28.75% which makes it suitable for subgrade as per ERA specification.
- There is an increase in the maximum dry density and decrease in optimum moisture content
- The swelling characteristics of the samples have decreased with increase in Crusher dust ratio.
- The increase in percentage of CBR value for stabilized expansive were found to be 32.33%, 48.10%, 71%, 93.55%, 128.37% ,153%, 168.145%, 138.37% and 141.% at 5% increment of dust addition. The CBR value of expansive clay soil increases from 1.86% to 5.561% with increasing percentage of crusher dust from 0% to 35%, further increasing the content of crusher dust the CBR of treated soil slightly decreased as the CBR swell continuously decreasing with increasing of crusher dust from 0% to 50%. It is also identified that addition of 30% and 35% crusher dust yield high CBR value.
- It is observed that the mixture of the expansive clay mixed with 30% of crusher dust full fill the requirement for sub grade material recommended by ERA manual. The values at 35% crusher dust are also full fill the requirement of sub grade material.
- The study also reveal that the total pavement thickness can be reduced from 850 mm to 675mm by replacement of expansive clayey soil with 30 % Crusher Dust. The reduction of about 225 or 20.59% in pavement thickness will save substantial amount of money in construction.

According to the findings of this research, the following recommendations are forwarded to next researcher:

- This study was taken only one high expansive soil sample. It is recommended to take a large number of soil sample which characterizes the whole study area.
- It is recommended to test additional parameter like unconfined compressive strength and mineralogical tests should also be performed to have more realistic test results.
- The similar nature of investigation are also recommended for finding out use of existing plastic soil for other road construction material like, sub base, base and hard shoulder by adding suitable good engineering property material.

References

[1] S. P. V. ., “a Study on the Performance of Fly Ash and Sand Mixes As Sub-Grade and Fill Material,” Int. J. Res. Eng. Technol., vol. 05, no. 05, pp. 73–77, 2016.
[2] U. A. K., “Soft Subgrade Stabilization With Quarry Dust-an Industrial Waste,” Int. J. Res. Eng. Technol., vol. 03, no. 08, pp. 409–412, 2014.
[3] ASTM D422, “Standard Test Method for Particle-Size Analysis of Soils,” Astm, vol. D422-63, no. Reapproved, pp. 1–8, 2007.
[4] J. J. Bester, D. Kruger, and A. Hinks, “Aashto 1993,” Sustainable Waste Management and Recycling: Construction Demolition Waste:Proceedings of the international conference organised by the concrete and masonry research group. pp. 63–67, 2004.
[5] N. ChidozieMadu, “Influence of Spatial Variation in Subgrade Properties on the Design of Highway Flexible Pavements,” Am. J. Appl. Sci. Res., vol. 2, no. 6, p. 65, 2016.
[6] ERA, “Pavement Design Manual,” Roads Auth. Ethiop., vol. I, no. March, p. 281, 2013.
[7] M. N. Fatani and A. M. Khan, “Foundations on Salt Bearing Soils of Jizan,” Third Int. Conf. case Hist. Geotech. Eng., no. 1, pp. 79–83, 1993.
[8] A. Geremew, “Experimental Performance Studies on the Improved Expansive Subgrade Soil Formation by Using Mechanical Stabilization with Natural Gravel Around Jimma Quarry Sites,” Am. J. Civ. Eng., vol. 6, no. 5, p. 154, 2018.
[9] Q. S. Ghausuddin and S. S. Koranne, “Evaluation of soil-quarry dust mixtures reinforced with polypropylene fibers,” Electron. J. Geotech. Eng., vol. 16 I, pp. 1007–1017, 2011.
[10] A. Hefer and T. Scullion, “FHWA/TX-03/0-4358-1 Materials, Specifications, and Construction Techniques for Heavy-Duty Flexible Bases: Literature Review and Status Report on Experimental Sections,” vol. 7, no. 2, p. 144, 2005.

[11] C. O. Ken, F. Okafor, and D. Nwachukwu, "Geophysical Use of Quarry Dust (As Admixture) As Applied To Soil Stabilization and Modification-a Review," ARPN J. Earth Sci., vol. 1, no. 1, pp. 2002–2004, 2006.
[12] M. Mokhtari and M. Dehghani, "Swell-Shrink Behavior of Expansive Soils, Damage and Control," Electron. J. Geotech. Eng., vol. 17, pp. 2673-2682., 2012.
[13] A. A. of S. H. and T. Officials, "Standard Specifications for Transportation Materials and Methods of Sampling and Testing and AASHTO Provisional Standards," 2016.
[14] P. V. V. Satyanarayana, "Performance of Crusher Dust in High Plastic Gravel Soils As Road Construction Material," IOSR J. Mech. Civ. Eng., vol. 10, no. 3, pp. 01–05, 2013.
[15] V. R. Schaefer, D. J. White, H. Ceylan, and L. J. Stevens, "Design Guide for Improved Quality of Roadway Subgrades and Subbases," Iowa Highw. Res. Board (IHRB Proj. TR-525), vol. 7, pp. 8–72, 2008.
[16] B. U. Uge, "Expansive soils in Ethioipa : a Review," Int. J. Sci. Res. Eng. Technol., vol. 6, no. 5, pp. 429–439, 2017.
[17] B. U. Uge, "Performance , Problems and Remedial Measures for Roads Constructed on Expansive Soil in Ethiopia – A Review," vol. 9, no. 5, pp. 28–37, 2017.

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