Macro and Micro Level Investigation of Strength Enhancement of Expansive Soil Stabilized with Lime and Cement using Stone Dust as Additive

P.Samatha Chowdary, M.Rama Rao

Abstract:
Subgrade is an integral part of pavement and supports from beneath. This layer's properties are very important for the design of pavement and there is every chance of damage in a shorter period due to poor quality of the soil. Most of the rural areas of Deccan plateau covering entire Maharashtra, Gujarat, Central & Western Madhya Pradesh, and Southern part of Andhra Pradesh possess subgrade made of expansive soil. Experience has shown that pavements built on these soils often require costly procedures for making it vulnerable to be used as subgrade. In addition to this unfavourable economic condition to adopt high cost technology in subgrade treatment of rural roads becomes mostly non vulnerable, there by leaving rural roads with potholes requiring treatment after every season. Waste materials such as stone dust nowadays are posing a great environmental problem while being disposed into the air & water and onto the land. But, when these materials are properly utilized in making road pavements especially in subgrade would greatly help the society to have a better and pleasant environment. In this paper an attempt has been made to develop a low cost subgrade enhancement technique by using stone dust (Waste from stone milling industry) along with cement and lime separately. California Bearing Ratio test and Unconfined Strength tests were done on Soil-Lime -Stone Dust and Soil-Cement-Stone Dust mixes. It was observed that, as the percentage of stone dust increases the California Bearing Ratio (CBR) and Unconfined compressive strength (UCS) values also increase until a particular value and then decrease. Index properties, Atterberg limits for all the mixes stated above were studied. The results were on par with the CBR and UCS tests. Cementing bonds observed in Scanning Electron Microscopy (SEM) Analysis also strengthened the results obtained in UCS and CBR.

Index Terms: Atterberg limits, CBR, pH, SEM, Soil Stabilization, UCS, Waste material.

I. INTRODUCTION

India even after 66 years of being Republic, some issues of rural development continue to be relevant even today. Looking at the different components of the rural economy, transport remains the mainstay of the rural sector**.** To reduce this Pradhan Mantri Gram Sadak Yojana (or "Prime Minister Rural Roads Scheme"), was launched in the year 2000 by Indian government in order to provide connectivity to unconnected rural habitations. The main aim of this scheme was that these roads will be constructed and maintained by village panchayats. In some parts of India, where the government managed it directly has produced limited results and in other areas there was no difference, in either the quality or quantity of rural road network especially quality of road network. Expansive soils are termed as plastic clays that exhibit volume change when subjected to moisture variations due to the availability of montmorillonite and smectite which are often referred as vertosols. These expansive soils, when used as subgrade become highly unworkable and possess poor drainage due to the inherent property of less permeability. Substitution of waste materials will conserve dwindling resources, and will avoid the environmental and ecological damages caused by quarrying and exploitation of the raw materials. These waste materials can partly be used, or processed, to produce materials suitable as stabilizers, Drainage providers or fillers for subgrades of village roads were subgrade soil is subjected to alternate swelling and shrinkage, where ever year huge quantity of virgin soil has been consumed to fill these sub grades leading to enormous increase in cost and deterioration of natural available resources.

II. LITERATURE REVIEW

In India Rural roads have been built under various rural development programmes. Even serious efforts have been made these programmes to build rural connectivity, these could not provide all-weather roads to more than half of the villages in the country. On the other hand, many roads which have been built could not be sustained. Careful examination of these has revealed that most efforts have not been effective due to the fact that in those programmes, the roads were not understood to be engineering structures. These non-engineered structures without backup systems and facilities to sustain them with engineering inputs for repair and maintenance, limited financial resources and lack of capacities have led to disappearance of roads in no time. And this examination also showed that many failures were due to inadequate subgrade.

Many researchers had made an attempt to study the effect of stone dust on soil stabilization. In a study on the effect of quarry dust and lime mixture on expansive soil in terms of specific gravity, compaction CBR and UCS for varying proportions of lime and stone dust [16,21], observed that MDD increased and specific gravity decrease and stated that the decrease in specific gravity is due to the reduced plasticity characteristics of the soil. When effect of fly ash

Revised Manuscript Received on April 09, 2019.

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and quarry dust was studied for variations in liquid limit, plastic limit, compaction characteristics and strength characteristics on addition on expansive soil [18], it was observed that as fly ash and quarry dust is added alone liquid limit decreases and OMC decreases and MDD decreases and UCS increases. In a study on effect of quarry dust on CBR and compaction properties of expansive soil it has been observed that OMC of expansive soil [1], decreased with increase in percentage of rice husk ash and MDD decrease with increase in percentage of stone dust**.** In a study on [6] effect of quarry dust on index and engineering properties of expansive soil it has been concluded that liquid and plastic limit decreased with addition of quarry dust, while CBR and dry density increases with addition of quarry dust while cohesion decreased with addition of quarry dust.

In a investigation on the effect of 10% quarry fines and varying percentages of cement kiln dust on various curing periods of expansive soils [2], decrement in plastic limit and plasticity index. The decrease in liquid limit from 85% to 72.5%, when 10% quarry dust and cement kiln fines was added can be attributed to the effect of reduction in the diffused double layer thickness and effect of dilution of clay content of the mix. And increase of maximum dry density and CBR was attributed to the formation of time dependent pozzolanic reactions that produced cementation products, the slow rate of increase in strength between 7^{th} day and 14^{th} day followed by steeper increase that extended till 28^{th} day was due to the seeming delay of strength in initial days and that of 28 days was due to the formation of CSH, CAH and CASH gels.

A study on effect of using HDPE waste fibres, Stone dust and lime on index and engineering properties expansive soil [3] by mixing each ingredient separately resulted in decrement of liquid limit, plastic limit, plasticity index, followed by increment in CBR, UCS and permeability as on stone dust percentage increases. A study on effect of addition of stone dust on compaction strength and cohesion characteristics of expansive soil [6,24] revealed that liquid limit decreased, while plastic limit decreased from 20% to 16% and plasticity index decreased from 24% to 18%, MDD and UCS increased with increase in stone dust from 0 to 25%. When effect of combination of stone dust and polypropylene fibers on compaction parameters, UC strength and CBR on expansive soil [19], was investigated, the results concluded that there was an increase in MDD, UCS and CBR with increase in percentage of stone dust and fibers. Study of effect of stone dust on various properties of expansive soil when compared with results of expansive soil enhanced with cement and lime [14] observed that stone dust addition resulted in increase of liquid limit, CBR and strength properties of soil and decrement of plastic limit when compared with soil mixed with only lime and cement and this may be probably due to decrease of the plasticity characteristics due to excess alumina present in stone dust that resulted in the formation of additional cementitious gels. A study of effect of mixing quarry dust with moorum on index properties, compaction characteristics and CBR parameters blended with various percentages of stone dust [20],was conducted, it was observed that liquid limit, plasticity limit, OMC were decreasing while MDD and CBR were increasing as stone dust fills the voids of the coarse grained particles of murrum. In a study made on expansive with varying quarry dust percentages in increment of 10% [17] it was found that atterberg limits decreases with increment in stone dust percentage, and 2% lime was fixed as optimum for stone dust percentage of 38% were strength was maximum. In a study made to compare improvement of expansive soil characteristics with stone dust cement and lime [22], it was observed that the improvement was more fruitful while compared to only lime and cement since alumina is present in stone dust. It was also concluded that addition of stone dust gives the same level of enhancement when mixed with lower quantities of cement and lime compared to the expansive soil stabilized with only lime and cement, thus reducing cost of stabilization. Experimental investigation conducted to study the effect of lime and stone dust on CBR of black cotton soil [4], revealed that MDD increases as lime increases since lime causes soil particles to coagulate , aggregate and flocculate making soil more workable,. MDD of soil lime mix further increases due to heavy particles of stone dust till 20% and then it decreases since stone dust particles segregate. CBR value of soil lime mix increases with increase in percentage of stone dust till 20 % then it decreases as the addition of stone dust becomes counterproductive. In a research on crusher dust addition to expansive soil [23], it has been observed that OMC of soil reduced while, MDD, CBR was increased significantly when the amount of crusher dust was 30%, which was attributed to the increased of coarser particles in the mix supplied by the addition of crusher dust.

Experimental investigation of expansive soil with stone dust and fly ash in equal proportions ranging 10, 20, 30, 40 and 50% on Atterberg limits, Strength and Swell Index [15], revealed that there was considerable decrement in liquid and plastic limit as the percentage of admixture increases due to gradual decrement in flow characteristics with increase in percentage of stone dust and fly ash. This study also revealed decrease in OMC, Swell Index and increase in MDD, UCS with increase in percentage of fly ash and stone dust admixture is due to the replacement of clay particles by the admixture that reduces swelling and shrinkage of treated clay and enhances strength of the mix. Optimum values in this study conducted were obtained when fly ash and stone dust were taken in equal proportions of 30%. In a study by mixing 7.5% lime and 25% dust with marine clay[5], it has been observed that liquid limit reduced by 37% while plasticity index reduced by 67%. However the studies stated above were only partial and a lot of research need to be done still. This paper envisages an attempt made to study the macro effect of using stone dust as an additive to lime and cement treated soil separately, all the results obtained from macro analysis of Atterberg limits, Strength (UCS, CBR),Differential Free Swell index are explained with reasoning for the changes occurred and in turn Scanning Microscopy Analysis was also done to strengthen the results obtained by properly discussing the mineralogical changes occurred in the mix due to addition of stone dust.

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III. MATERIALS AND METHODS

A. Materials:

Soil: In the present study soil was collected from Nurukullapu Village, Amravathi Mandal, and the fast growing capital of divided Andhra Pradesh. Most of the soils in the region are clay soils.

Lime and Cement: Lime used for the present study was collected from Ravi Teja Lime industries Piduguralla, Andhra Pradesh .Cement was collected from KCP Cements and the cement used for the study is OPC 53 grade cement from Sree Shakthi Cement suppliers in Guntur.

Stone Dust: Stone dust was collected from Srinivasa crushers, near Amravathi

IV. METHODOLOGY

This is divided in to three parts

Part I deals with methodology for determination of optimum Lime and Cement.

This is basically decided by conducting compaction test by adding lime to virgin soil varying lime in increments of 2%. Then UCS samples are made at Optimum Moisture Content (OMC) +2% .Then UCS test is done. pH test is also done on the samples by means using pH meter and adding lime to virgin soil varying lime in increments of 2%. The optimum lime is taken as that percentage of lime where UCS attained maximum value. The same methodology was followed for cement by varying cement in increments of 2%. But for cement while mixing extreme care has to be taken that the water content is OMC+2% since cement at a later stage is not expected to develop shrinkage cracks if the OMC stated is perfectly maintained .All the methods of the basic experiments as compaction and unconfined test where done.

Part II covers the methodology for determination of optimum stone dust after fixing of optimum lime. This is basically decided by conducting compaction test by adding stone dust to virgin soil with optimum lime UCS and varying stone dust in increments of 2%. Then UCS and CBR samples are tested. pH test is also done on the samples by means using pH meter. SEM analysis and atterberg limits and differential free swell index tests are also conducted at each percentage variation of stone dust. The optimum stone dust was taken as the percentage where UCS and CBR was maximum.

Part III covers the methodology for determination of stone dust after fixing of optimum Cement. The method followed is same as optimum stone dust determination followed with optimum lime. But here optimum cement content is fixed and all other tests are conducted similar to that with lime.

All the above mentioned tests were carried according to IS: 2720 –Methods of test for soils. ([7], [8], [9], [10], [11], [12], [13]).

V. RESULTS AND DISCUSSIONS

A.Properties of Materials

The soil which is considered for the study is highly expansive with liquid limit of 86.27% and a free swell index of 140% having a clay content of 72% and soaked CBR of 0.85%.The higher value of differential free swell index and liquid limit makes the soil highly non workable. The properties of natural soil are summarized in Table I. The SEM image of soil is given in Fig.1

Table I: Properties of natural soil

Property	Value
Specific gravity	2.5
Particle size distribution a)Sand (%) b) Silt (%) c) Clay (%)	 24 3.2 72.8
Liquid limit (%)	86.27
Plastic limit (%)	36
Plasticity Index (%)	50.27
IS Classification of soil	CH
Maximum Dry Density (kN/ m^3)	14.4
Optimum Moisture Content (%)	23
Soaked CBR value (%)	0.85
Differential free swell index (%)	140

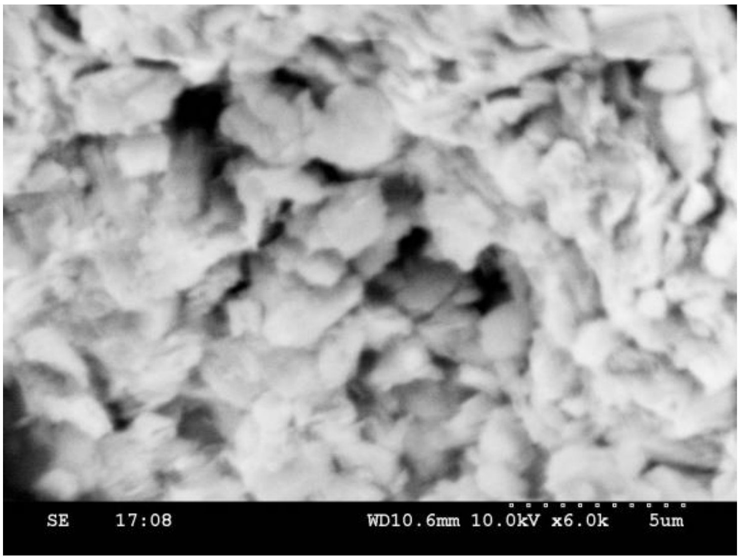

Fig. I: SEM image of expansive soil without treatment

The chemical composition and physical properties of stone dust are summarized in Table II & Table III. The SEM image of Stone dust is given in Fig. IIa & Fig. IIb.

Table II: Chemical Composition of Stone Dust:

S.No	Constituents	(%)
1	Silica – SiO_2	95
2	Alumina – Al_2O_3	1.59
3	Carbon	1.45
4	Calcium Oxide – CaO	1.2
5	Magnesium Oxide – MgO	0.4
6	Potassium Oxide – KaO	0.2
7	Ferric Oxide -Fe_2O_3	0.16

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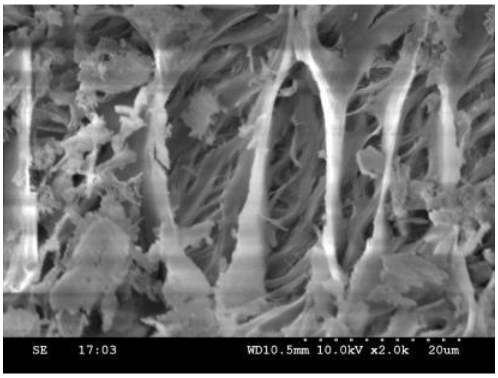
Table III: Physical Properties of stone dust

Property	Value
Specific gravity	2.77
Maximum Dry Density (kN/ m^3)	20.1
Optimum Moisture Content (%)	9.4
Particle size distribution : Gravel size (%) Sand size (%) Silt size (%)	 3 81 16
IS Classification	SM



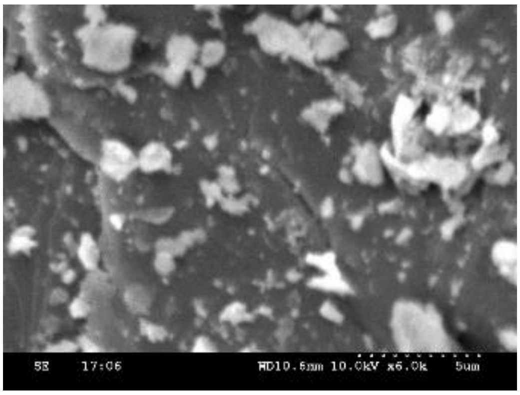


Fig. IIa & Fig.IIb: Scanning Electron Microscopy Images of Stone Dust under different magnifications.

It can be seen from SEM image Fig. IIa & Fig.IIb that Stone Dust particles were spherical in shape. The particles had shiny surfaces without any dust over them.

A. Optimum lime and cement determination

Results of Optimum moisture content (OMC), Maximum dry density (MDD) and Unconfined Strength (UCS) on variation of lime percentages are given in Table IV and that of cement are given in Table V.

Table IV: OMC, MDD, UCS on variation of lime percentages.

Sl.No	Lime (%)	OMC (%)	MDD (kN/m^3)	UCS (kN/m^2)
1	2	24	14.35	37.69
2	4	25	14.26	46.1
3	6	25.92	14.25	65.63
4	8	26	14.21	89.21
5	10	24	14.5	78.45
6	12	23.92	15.1	61.26

Table V: OMC, MDD, UCS on variation of cement percentages

Sl. No	Cement (%)	OMC (%)	MDD (kN/m^3)	UCS (kN/m^2)
1	2	23	13.87	46.88
2	4	24	14.6	62.56
3	6	24	14.7	63.44
4	8	26	15.1	99.45
5	10	25	14.8	86.71
6	12	22	14.7	65.63

In **Table IV**, the initial increase in OMC values may be attributed to the development of flocculated structure which resists the compaction effort and the decrease in dry density may be attributed due to less due to occupation of less space by soils as a result of change of soil structure. In **Table V,** the increase in MDD with cement content may be due to the relative higher specific gravity of cement to that of the soil. The increase in OMC with cement content was as a result of water needed for the hydration of cement. The constant increase in UCS (**Table IV & Table V**) can be due to the formation of cementious compounds between clay & lime or clay & cement particles due to increase in shearing resistance at inter particle level. From the above results optimum lime is 8% and optimum cement is 8%.

A. Optimum stone dust determination for optimum lime

Results of OMC, MDD, UCS and California Bearing ratio on with different percentages of stone dust and optimum lime are given in Table 6.

Table VI: OMC, MDD, UCS, CBR values with different percentages of stone dust and optimum lime

Stone dust (%)	OMC (%)	MDD kN/m^3	UCS (kN/m^2)	CBR (%)
Soil+8%lime+2% SD	30	14.45	95.49	4.5
Soil+8%lime+4%SD	27	14.50	109.02	7.43
Soil+8%lime+6%SD	25	14.52	115.56	13.9
Soil+8%lime+8%SD	25	14.60	131.17	15.6
Soil+8%lime+10%SD	24	14.71	148.28	21.4
Soil+8%lime+12%SD	26	14.43	135.35	19

From Table VI, the initial increase in MDD may be attributed to mixing of heavy particles of stone dust in soil. After which dry density decreases as large stone dust particles segregate while the initial decrease in OMC may be attributed to mixing of coarser particles of stone dust having less affinity towards water. UCS and CBR, the strength increases upto 10% addition of stone dust in lime stabilized soil. The reason of this effect was due to the pozzolanic reactions of lime with the amorphous silica and alumina present in soil and stone dust.

Results of Atterberg limits, Differential free swell index (F.S.I), pH on variation of different stone dust percentages and optimum lime are given in Table VII.

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Table VII: Atterberg limits, F.S.I, pH on variation of SD percentages and optimum lime

SD (%)	L.L (%)	P.L (%)	P.I (%)	S.L (%)	F.S.I (%)	pH
Soil+8%lime+ 2% SD	78	45	33	25	80	13
Soil+8%lime+ 4%SD	67	40	27	27	61	13.3
Soil+8%lime+ 6%SD	61	37	24	31	57	14
Soil+8%lime+ 8%SD	50	35	15	32	50	14.2
Soil+8%lime+ 10%SD	42	N.P	N.P	33	48	14.2
Soil+8%lime+ 12%SD	40	N.P	N.P	33	45	14.2

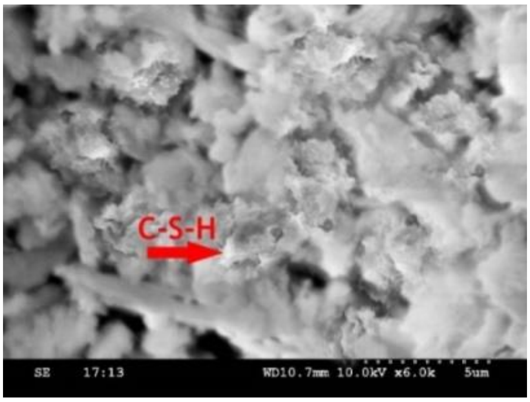
From Table VII, It can be observed that as the percentage of Quarry dust increases, Liquid Limit and Plastic Limit decreases. This may be attributed to reduction in Diffused Double Layer thickness and Clay percentage. The reduction in Plastic Limit of soil admixtures is due to filling of voids of flocculated soil there by reducing water. Differential Free Swell Index is observed to decrease with increase in percentage of admixtures due to prevailing of Divalent and Trivalent cations (Ca^{2+}, Al^{3+}, Fe^{3+} etc.,) and also due to increased flocculation of clay particles leading to reduced surface area and water affinity of the soil sample. Increase of pH indicates minerals formed due to pozzolanic reactions between soil, lime and stone dust. Increase in the shrinkage limit may be attributed to the replacement of cohesive soil with quarry dust which has very low cohesion value and very high angle of internal friction than soil which decreases the cohesion and increases the angle of internal friction.

A. SEM analysis of Soil-Lime –Stone dust mix

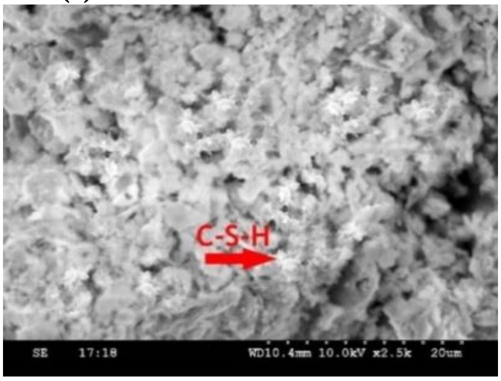
All these above statements are well supported by SEM analysis as given below.

From SEM analysis of various mixes of soil-lime-stone dust (fig.4 (a)-4(f)) and comparing with fig. 3, it can be seen that with varying percentages of stone dust, as on stone dust percentage increases, till optimum there is considerable improvement in C-S-H gel crystals. From SEM images it is clear that addition of quarry dust results in flocculated structure with voids filled by stone dust resulting in decrement of plasticity characteristics, Optimum Moisture Content and Differential Free Swell Index and increment in Maximum Dry Unit Weight.

Fig. 3: SEM image of CSH gel taken from literature

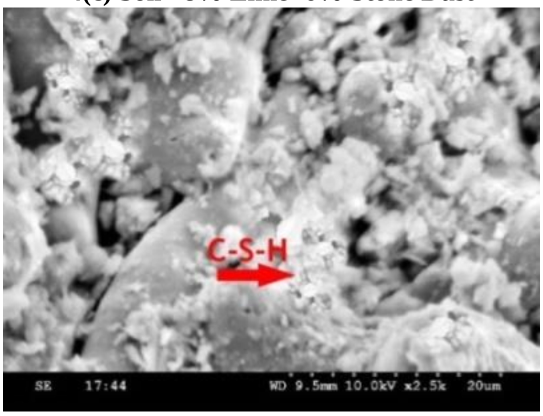


4(a) Soil +8% Lime+2% Stone Dust

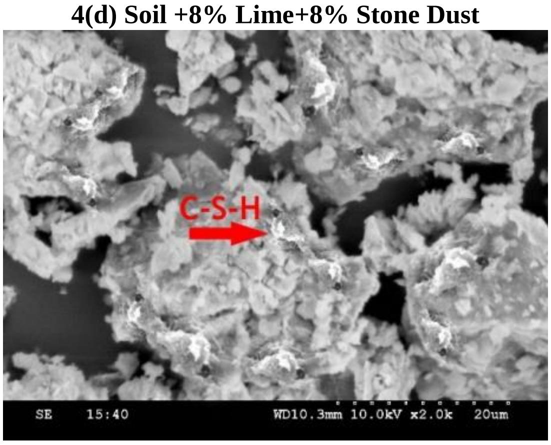


4(b) Soil +8% Lime+4% Stone Dust

4(c) Soil +8% Lime+6% Stone Dust



4(d) Soil +8% Lime+8% Stone Dust



4(e) Soil +8% Lime+10% Stone Dust

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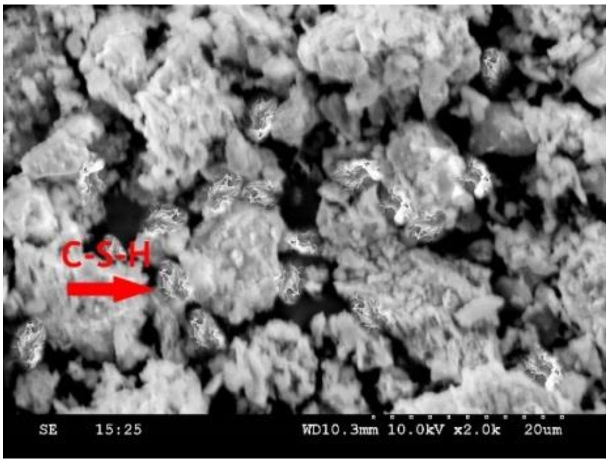

4(f) Soil +8% Lime+8% Stone Dust

Figure 4(a)-4(f): SEM Images of different percentages of stone dust added to optimum Lime.

Hence from all the results and discussions stated above the optimum stone dust for Soil –Lime –Stone dust mixture is considered to be 10%.

A. Optimum stone dust determination for optimum cement

Results of OMC, MDD, UCS and California Bearing ratio values with different percentages of stone dust and optimum cement are given in Table VIII.

Table VIII: OMC, MDD, UCS, CBR values with different percentages of stone dust and optimum cement

Stone dust (%)	OMC (%)	MDD (kN/m^3)	UCS (kN/m^2)	CBR (%)
Soil+8%cement+2% SD	26	14.6	103.57	6.7
Soil+8%cement+4%SD	25.81	14.7	114.87	9.9
Soil+8%cement+6%SD	25	14.8	123.86	15.9
Soil+8%cement+8%SD	22.68	14.8	135.82	17.3
Soil+8%cement+10%SD	20	15	142.69	21.0
Soil+8%cement+12%SD	22	14.7	121.28	17.3

From Table VIII stated above, The increase in maximum dry density with increasing quarry dust content occurs due to the reduction in percentage of voids owing to replacement of clay with quarry dust having a higher specific gravity and The reasons for reduction in optimum moisture content by addition of stone dust are due to proper rearrangement of modified soil and reduction in surface area of modified soil mass. Increase in percentage of quarry dust the optimum moisture content of soil goes on decreasing. This is attributed to the reduction in clay content of soil by replacement with quarry dust which has less attraction for water molecules and the increase in UCS till 10 % addition of stone dust may be due to addition of stone dust in comparison with original soil may be due to increase in density of modified soil mass, having more strength. After that the decrease in UCS may be attributed to more increase in coarser particles of stone dust and the less availability of calcium ions for reaction to occur. The increase in CBR till 10 % addition of stone dust may be attributed to reduction in percentage of voids. There after it reduces as the stone dust particles increase they segregate and create soft pockets inside. Hence CBR value is slightly decreased compared to optimum.

Results of Atterberg limits, Differential free swell index (F.S.I), pH on variation of different stone dust percentages and optimum cement are given in Table IX.

Table IX: Atterberg limits, F.S.I, pH on variation of SD percentages and optimum cement

SD (%)	L.L (%)	P.L (%)	P.I (%)	S.L (%)	F.S.I (%)	pH
Soil+8%cement+2% SD	72	45	27	20	80	12.9
Soil+8%cement+4%SD	65	43	22	25	70	13.2
Soil+8%cement+6%SD	52	40	12	29	65	13.9
Soil+8%cement+8%SD	42	36	6	32	47	14.2
Soil+8%cement+10%SD	36	32	4	36	45	14.2
Soil+8%cement+12%SD	35	31	4	38	45	14.2

From Table IX, as the percentage of stone dust increases in the soil, liquid limit is decreased. The decrement in liquid limit cab be attributed to poor liquid limit of stone dust and reduction in the diffused double layer thickness as well as due to the effect of dilution of the clay content of the mix, since liquid limit of the black cotton soils is essentially controlled by the thickness of the diffused double layer and the shearing resistance at particle level. marked reduction in plastic limit of clay was due to gradual decrease in flow characteristics and plastic characteristics of the soil sample with increase in the percentage of stone dust .This reduced plasticity of clay is very much required to avoid the failure patterns in the road construction over the expansive sub grade soils. The decrease in free swell of soil-cement-stone dust may be the same as that of soil-lime-stone dust mix.

A. SEM analysis of Soil-Cement –Stone dust mix

From SEM analysis of Soil-Cement –Stone dust mixes stated below **(Fig. 5(a) –Fig. 5(f)),** it can be clearly seen that with varying percentages of stone dust as on stone dust percentage increases, Pozzolanic reaction is carried out in the pores of cement-stabilized soil. Some researchers have shown that the small pore (<0.1 micron) volumes of the cement-stabilized clay mixed with fly ash are higher than those of cement-stabilized soil and since stone dust has the similar pozzolanic effect as fly ash, so it can also reduce the large pore space and the hydration products both filled with and split the original lager pore, reducing the porosity and improving the cementation. Then it can improve the strength and compactness there by increase in Strength of Soil-Admixtures compared to soil alone. When soil cement and

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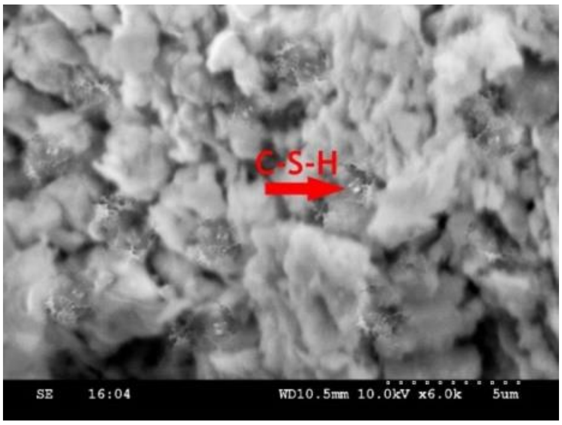
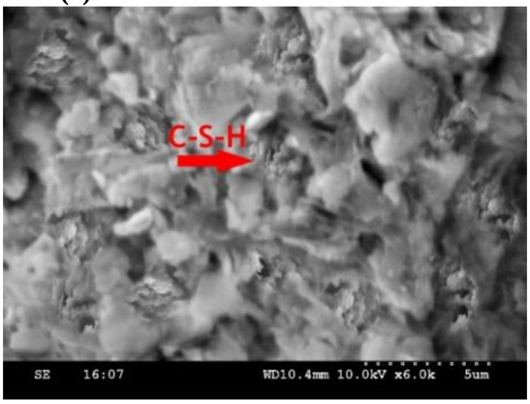
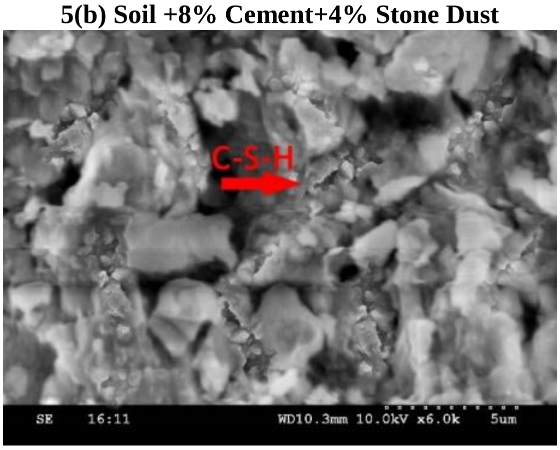
Stone Dust mix has reached its optimum when dust further increases the particles of dust create larger and larger voids and there by a slight reduction in strength occurs.



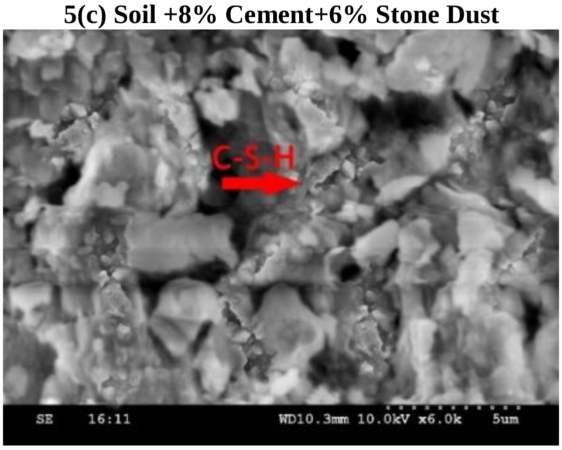
5(a) Soil +8% Cement+2% Stone Dust



5(b) Soil +8% Cement+4% Stone Dust



5(c) Soil +8% Cement+6% Stone Dust



5(d) Soil +8% Cement+8% Stone Dust
5(f) Soil +8% Cement+12% Stone Dust

Figure 5(a)-5(f): SEM Images of different percentages of stone dust added to optimum Cement.

VI. CONCLUSIONS

- CBR increased from as low as 0.85% to 21.4% in case of soil-lime-stone dust mix and 21% in case of soil-cement stone dust mix.
- According standards in construction of subgrade for hard shoulder CBR should be more than 12%. Hence both the optimum mixes can safely be used as hard shoulders.
- As per Ministry of Rural Development (MORD) specifications the granular sub base should have a CBR greater than 20 %. Hence from the results obtained both the optimum mixes can also be used as treated subgrade and sub base and directly if it is cement concrete road with granular sub case base can be directly laid without adding additional thickness in case of low volume roads.
- The reduction in plastic and flow characteristics of the soil with different percentages of stone dust result in change of soil structure from a plastic state to non-plastic, which is very important to avoid failure patterns on the road.
- Optimum lime and cement determined from the study was 8%.
- For both Soil-Lime-Stone dust mix and Soil-Cement –Stone dust mix the optimum was obtained to be 10%
- Environmental concern of disposal of this waste disposal can be solved. Stone dust proves to be efficient waste materials to treat soil subgrade

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