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Use of Nanolime & Fly Ash Mixture to improve Consistency Limits & UCS of Rajkot Soil

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Abstract. Expansive soil is present in arid and semi-arid regions across the globe. This soil is one of the problematic types and unfit to support any engineering structures. The basic characteristics of this type of soil is high shrinkage and swelling, high liquid limit, higher quantity of fines available in it. Rajkot is situated in western most part of India and Gujarat, which has geology of basaltic rock formation and highly expansive montmorillonite clay. In this study on Rajkot soil, micro particles of fly ash (class F) were mixed with nanolime derived by direct thermal decomposition method was utilized to alter soil properties. Wherein, fly ash with percentages of 20 and 40% replaced virgin Rajkot soil and lime nanoparticles with percentages of 0.5, and 1 were mixed with it. The prepared samples were put for curing period of 1, 7 and 28 days and soil parameters in terms of engineering properties such as changes in Atterberg limits, free swell index and unconfined compressive strength tests were investigated. Based on test results, the optimum quantity of fly ash and Nanolime for Atterberg limits, free swell index test, and Unconfined compressive strength (UCS) test, was 80% Rajkot soil, 20% fly ash and 0.5 % nanolime. The swell behaviour was restricted in moderate range and it may be attained by flocculation and agglomeration of clayey size particles by nanolime. The UCS strength improvement for 1, 7, and 28 days curing was 148%, 231%, and 270% respectively. The C-S-H gel formed by chemical reaction between nanolime, soil and fly ash was reason behind improvement in UCS strength.

Keywords: Nanolime, Expansive soil, Fly ash, Soil Stabilization, Unconfined Compressive Strength, Nanotechnology

1 Introduction

Black cotton soils usually have the potential to demonstrate undesirable geotechnical properties, such as low bearing capacity, high compressibility, shrinkage and swell characteristics and high moisture susceptibility. Several methods have been adopted to improve the geotechnical properties of such soils so that the stability and serviceability requirements can be met. Among these methods, stabilization of the black cotton soil using different additives can basically be considered, because the replacement of the unsuitable soil with good quality soils becomes more and more uneconomical and nonecological practice. In addition, cement stabilization is nowadays not preferable because of the increasing cost of cement and the environmental concerns related to its production [4]. In many places in Rajkot, these black cotton soils caused severe damage to infrastructures. In view of this, the need to improve these soils is necessary. Urban areas of the Rajkot district nowadays experience a considerable development because of a constantly increasing demography, from where its extension towards virgin zones often less favourable than those already urbanized.

Using by-products and waste is a necessity of the day, many researchers are trying to reuse the waste and try to improve the soil Several projects have also attempted to use plastic waste to improve the sandy soils [14] The lime is used for stabilization of clayey soil [2, 4, 15]. The type of lime commonly used to stabilize fine-grained soils are hydrated high-calcium lime, calcite quicklime, monohydrated dolomitic lime, and dolomitic quicklime [2]. When lime is added to clayey soils, many chemical reactions occur: cation exchange, lime carbonation, pozzolanic reaction and flocculation-agglomeration [2, 4]. Since the properties of soil-lime mixtures depend upon the character of the clay soil, and the type and period of curing, the method and quality of construction and the proper amount of lime to be used should be investigated before the application of the lime-soil mixture technique [15].

Fly ash is a by-product of the pulverized coal combustion process usually associated with electric power-generating plants. It is a fine-grained dust and is composed primarily of silica, alumina, and various oxides and alkalies. Fly ash generation and utilization during the year 2017-18 shows that, unutilized amount of fly ash of last year is 64.57 Million Tons, it is the key issue to find way of convert it in serviceable one [6]. The effect of fly ash on the strength of expansive soil is depend on many factors such as type of fly ash and particle sizes of it [7, 8]. The optimum amount of Neyveli fly ash and Badarpur fly ash is 10% and 40% respectively to minimize swell potential. The permeability of soil-fly ash mixture is increased because of void ratio increased, further with increase in curing time of Neyveli fly ash, permeability decreases due to cementation of free lime. The maximum unconfined compression strength gained for Badarpur fly ash, Badarpur fly ash + Ca (8.5%) and Neyveli fly ash is, 0.414 kg/cm2, 1.05kg/cm2, and 44.95 kg/cm2 respectively for 28 days test [7].

The reduction in liquid limit with 10-12% lime or by adding 50-60% fly ash is similar. The soil is more workable and desired density can be achieved over a wider range of moisture content with addition of lime and fly ash. The optimum dosage of lime with fly ash for plasticity index, compressibility, and strength parameter is, 2 to 3, 5 and 13% respectively [7].

There are many methods to improve the soil with help of Stabilization – used in the field from many years successfully. The available methods to dealt with clayey soil/Expansive soil are Compaction Grout, Stone Columns, Preloading and Surcharge Piles, Lime Stabilization, Electro kinetic Injection and Electro osmosis. Majority of the methods are either considering micro dimension of the soil particles and voids in between them. The methods are very time consuming or costly. This era since last 20 years, researchers are trying to find the solution of different characteristics and required properties of soil by "Nanotechnology" [1, 2, 10, 19]. In general, as the size of particles is reduced to the manometer scale, they usually exhibit dramatically different or enhanced properties, compared with their counterparts at a larger size. This change in behaviour is caused by two main reasons: much increased surface area and the dominance of quantum effects [19]. As a particle decreases in size, a greater percentage of atoms and molecules become exposed at a surface. Therefore, their surface properties (e.g., physical, chemical electrical, and reactivity) become more important and even dominant, while their mass property becomes much less important. The nanoparticles exist in the form of nanoplatelets, nanowires and nanodots have different properties than clay size particles because of their extremely small size, higher specific surface area, surface charges and Nano porosity. The presence of even small amount of these nanoparticles can influence the soil engineering properties [19]. There are researchers across the globe have tested different Nanomaterials like Nano Silica [12], Nano Copper [17], Nano Clay [3], Nano Alumina [17] etc. and results of these materials on the laboratory/field tests shows that the future of the problems related to problematic soils/require properties of soil, might be addressed by this technology as well.

The nanomaterial **-** Nanolime firstly investigated and used for conservation of artefacts, tackling the degradation processes affecting cultural heritage objects and structures, without altering the physical and chemical properties of the treated works of art (stone, wall paintings, paper and wood). As the effectiveness of Nanolime is dependent on the quality/purity and the size of the particles, still it is in progress of optimization of the synthesis methods of these nanoparticles (lime slaking, sol-gel and solvothermal synthesis, aqueous homogeneous precipitation routes, etc). The Nanolime do not require a special application method, and can be applied by brushing, spraying, injection, pouring, immersion, vacuum impregnation or systematic dripping techniques, and it is environment friendly, non-hazardous material as well [5].

In the field of geotechnical engineering, Nanolime shows superiority in soil improvement compared with lime even at the dosage of 0.5%. The UCS of treated soil increased over time with increasing percentage of Nanolime from 0.2 to 0.5% due to higher ability to flocculate and agglomerate [11]. The PI of treated soil with Nanolime decreases and this reduction is in proportion with curing time and surface area of Nanolime. The maximum dry density was obtained for soil mixed with only 0.3% and 0.5% Nanolime at curing period of 1 day and 60 days respectively. The chemical reactions between calcium oxides and dissolved silica present in the soil mineral are able to produce CSH gel for pozzolanic reactions which could be seen clearly by FESEM analysis [9]. The application of lime and CaCO3 -Nanomaterial decreasing the value of liquid limit and plastic limit. The effect of this mixture on the unconfined compression strength is maximum at 4% lime and 0.5% CaCO3 – Nanomaterial at all ages test [18]. The effect of micro and Nanolime particles on the kaolinite clay soil and the investigation is, the addition of small amounts of lime nanoparticles, the liquid limit decreased on the first days of curing time. The addition of lower percentage of lime nanoparticles compared with lime power, increased the compressive strength of clay in a shorter time. The same trend shown in the CBR test results [13].

The objective of the present work is to study the effect of nanolime & fly ash mixture on the strength, swelling properties, and consistency limits of expansive Rajkot soil.

2 Materials and Experimental Procedures

2.1 Materials

Experimental studies were performed using a problematic local soil collected from campus area of Marwadi University, Rajkot, Gujarat. The soil obtained from the site was dried in an oven at 110 ± 5° C for 24 hours, crushed, pulverized, and finally homogenized. The basic soil characterization tests were performed in accordance with the respective IS standards and, the results are provided in Table 1. The untreated soil was classified as CH as per IS 1498 - 1970, with a PI of 46 (high PI clay), free swell index of 70% (very high swelling clay), unconfined compressive strength of 60 kN/m^2, and shrinkage limit value of 8.11 reflects higher amount of montmorillonite content in the soil.

The fly ash used in this research work is Micropozz 20, manufactured by Suyog Suppliers, Vadodara, Gujarat. The fly ash is classified as Class F fly ash as per standard specifications mentioned in Table 2. The fly ash is also named ‘pulverized fuel ash’ or ‘non-reactive type fly ash.

Nanolime was manufactured by direct thermal decomposition method at the Nano-science laboratory, department of physics, Marwadi University. The sample then send to the laboratory for material characterization tests. The X-Ray Diffraction (XRD) graph confirmed CaO atomic composition when compared with ICDD library. According to FESEM images of CaO particles, the particles are nearly spherical in morphology and size of agglomerated cluster is in the range of 1 -100 nm size, hence it proves that the prepared material is CaO nanoparticles.

2.2 Sample Preparation

Compaction Test. The light compaction test was performed in accordance with IS: 2720 (part VII) – 1980. The test was performed on virgin Rajkot soil, and Rajkot soil replaced with 20%, 40% 60%, and 80% fly ash. The oven-dried soil, passing through 1.18 mm IS Sieve size, was used with fly ash, mixed thoroughly until it turns homogeneous coloured, water was added to mix the sample.

Consistency Limits, Free Swell Index Test & UCS Test. The pulverized soil, passing 425 µ IS sieve size was mixed with different percentage of fly ash and mixed thoroughly until consistent sample achieved then nanolime was added and further mixed. For UCS Test, the sample were prepared in accordance to OMC-MDD value derived from compaction test. The prepared samples were put in air tight polythene bag for 1, 7 and 28 days of curing period and the tests carried out as per the standards.

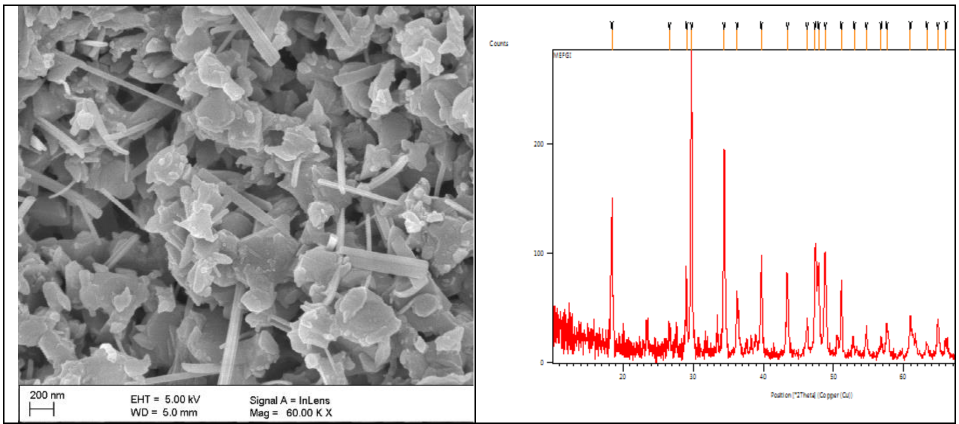
Table 1. Basic soil characterization test results of Rajkot soil

S. no.	Properties	Particulars
1	Particle size distribution	
	% Gravel size	0
	% Sand size	3
	% Silt size	54
	% Clay size	43
2	Specific gravity	2.411
3	Atterberg's limits	
	Liquid limit (%)	80
	Plastic limit (%)	34
	Plasticity Index (%)	46
	Shrinkage limit (%)	8.11
	IS classification	CH
4	Compaction characteristics	
	Maximum Dry Density, (g/cm^3)	1.48
	Optimum Moisture Content, (%)	24
5	Unconfined Compressive Strength (kN/m^2)	60
6	Free Swell Index (%)	70
7	pH	8.25

Table 2. Properties of fly ash

Specification	International Standards				Suyog Suppliers
	ASTM 618	BS EN 450		IS 3812	Micro Pozz 20
		S	N		
Fineness (min), m^2/kg				320	330
ROS 45 (max), %	34	12	40	34	20
LOSS on ignition (max), %	6	7	7	5	2
Water requirement (max), %	115	95	95		95
Moisture content (max), %	3			2	0.5
Soundness by Autocalve, %	0.8	10mm	0.8	0.8	0.2
28 days strength (min), %	75	75	75	80	80
Lime reactivity (min), N/mm^2				4.5	4.5
Chemical Analysis					

SiO_2+Al_2O_3 + Fe_2O_3 (min), %	70	70	70	70	85
SiO_2, (min), %				35	45
Reactive Silica (min) %				20	28
CaO (max), %	10	10	10		6
MgO (max), %		4	4	5	3.5
SO_3 (max), %	4	3	3	3	2
Na_2O (max), %		5	5	1.5	1.5
Total chlorides		0.1	0.1	0.05	0.05



(a) (b)

Fig. 1. (a) FESEM & (b) XRD images of nanolime

3 Analysis and Discussion of Results

Consistency Limit Test. With addition of nanolime and fly ash, the sample was found more workable. The liquid limit value decreased with increased curing period, plastic limit and also decreased but less compared to liquid limit, so overall plasticity index fell down. The soil designation of modified sample was observed to MH (Silt with High Compressibility), this could be happening due to flocculation and agglomeration of clayey size particles to silt size. These results also show that, nanolime could capable of reacting with montmorillonite particles and hence less efficacy of soil particles to water molecules.

Free Swell Index Test. It is observed from Table 4 that when higher amount of soil replaced with non-cohesive fly ash, the free swell index value is 0%. Here results of 80% BCS + 20% FA + 1% NL shows with increment in curing time, more soil particles processed with Nanolime and hence declination in the value of expansion. The expansive characteristics of modified soil when compared with virgin Rajkot soil, it turns from very high expansiveness to moderate to low expansiveness.

Compaction Test. The virgin black cotton soil tested for light compaction test, observed 24% OMC and 1.48 gm/cm^3 MDD. The addition of 20% of fly ash shows huge decrement in OMC while slight improvement in MDD but further addition of fly ash there was very less difference was observed in OMC and MDD.

UCS Test. The nanolime and fly ash mixture shows positive response to the strength parameters. The tested specimens, as shown in the picture depicts very less to no bulging, this might happen due to replacement of cohesive soil with non-cohesive fly ash and chemical reaction with soil-nanolime-fly ash. The specimens of 60% BCS + 40% FA mixed with 0.5 & 1% NL shows very less strength compared to virgin soil, because of higher dosage of non-cohesive material replacement, but with curing period, strength increment was observed that shows chemical reaction took place. For 80% BCS + 20% FA and 0.5 & 1% NL, within one day of curing, it shows around 150% increment in strength compared to virgin soil. After 7 and 28 days of curing, the 0.5% nanolime sample shows higher increment in the strength compared to 1% nanolime mixture as shown in the figure 3. For every sample mixture, the trend of strength gained with different curing period was same.

Table 3. Results of Atterberg Limit Test

S. no.	Soil sample	Nanolime (%)	Maturing (days)	LL	PL	PI	Soil designation
1	Pure BCS	0	0	80	34	46	CH
2	20% BCS + 80% FA	0	1	32	21	11	CL
			7	31	21	10	CL
			28	33	20	13	CL
3	60% BCS + 40% FA	0	1	54	29	25	CH
			7	50	34	16	MI
			28	51	35	16	MI
		0.5	1	49	34	15	MH
			7	47	26	21	CI
			28	62	32	30	MH
		1	1	59	34	25	MH
			7	55	32	23	MH
			28	51	27	24	CH
4	80% BCS + 20% FA	0	0	65	35	30	MH
		0.5	1	65	36	29	MH
			7	60	40	20	MH
			28	68	42	26	MH
		1	1	69	38	31	MH
			7	67	37	30	MH
			28	66	38	28	MH

Table 4. Results of Free Swell Index Test

S. no.	Soil sample	Nanolime (%)	Maturing (days)	FSI	Degree of expansion
1	Pure BCS	0	0	70	Very High
2	20% BCS	0	1	0	Low
	+		7	0	Low
	80% FA		28	0	Low
3	60% BCS	0	1	33.33	Moderate
	+		7	7.14	Low
	40% FA		28	4.76	Low
		0.5	1	0	Low
			7	0	Low
			28	0	Low
		1	1	0	Low
			7	0	Low
			28	0	Low
4	80% BCS	0	1	27.27	Low
	+	0.5	1	7.14	Low
	20% FA		7	7.14	Low
			28	27.27	Moderate
		1	1	27.27	Moderate
			7	16.66	Low
			28	16.66	Low

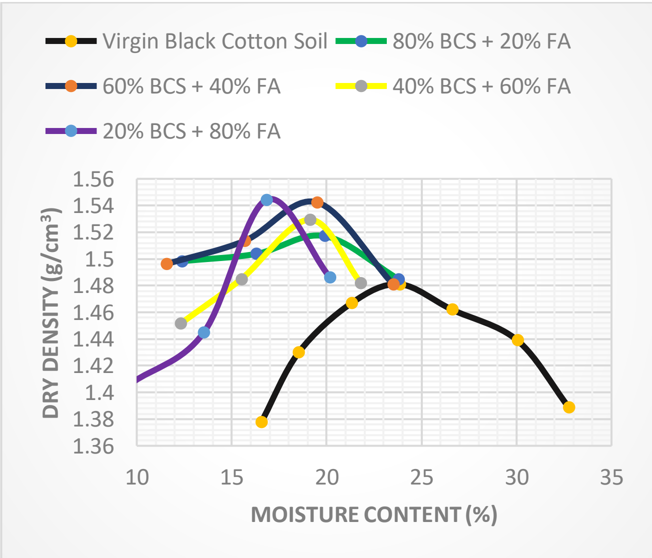


Fig. 1. Compaction curves for different soil-fly ash mixes

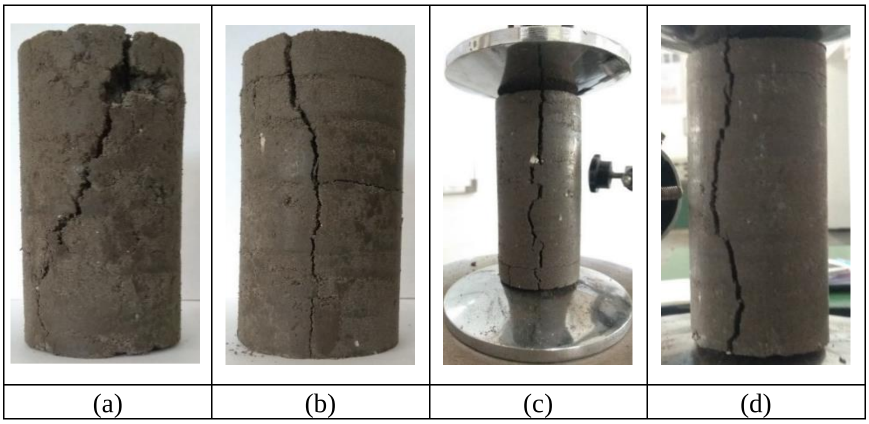


Fig. 2. Failure patterns under unconfined compression of 28 days cured specimen for (a)60% BCS + 40% FA + 0.5% NL sample, (b) 60% BCS + 40% FA + 1% NL sample, (c) 80% BCS + 20% FA + 0.5% NL sample, (d) 80% BCS + 20% FA + 1% NL sample.

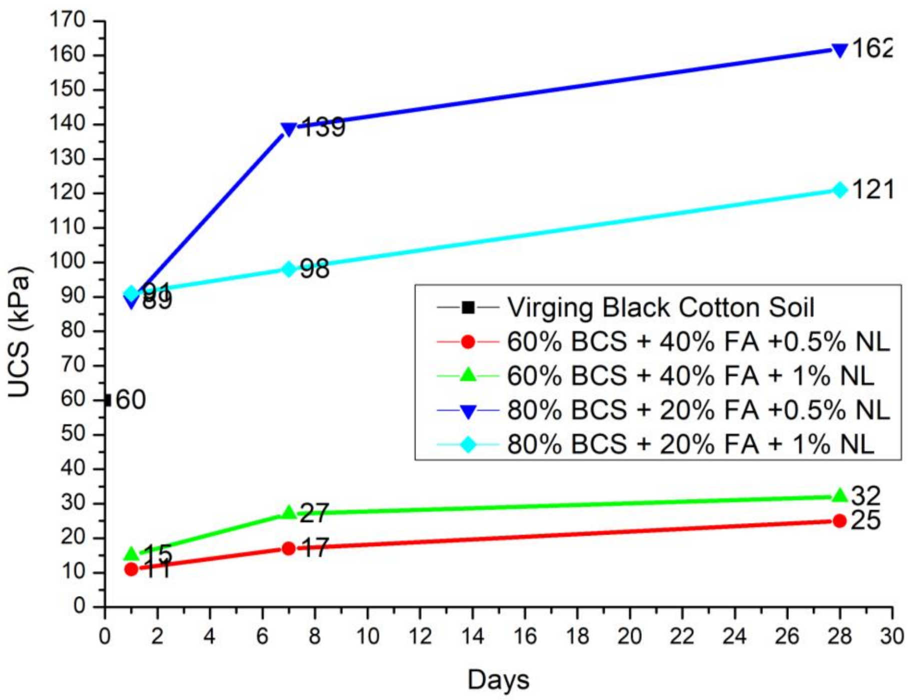


Fig. 3. UCS Test results of Virgin and Modified Rajkot Soil

4 Conclusions

The lime is significantly used for expansive soil treatment since many decades. The lime is required in huge quantity for soil treatment. The fly ash is a waste material and problem associated with it is to provide dumping space to dispose it. To overcome this problem, the use of nanolime and fly ash mixture has been proposed, which can be added to modify expansive soil properties. Following are the major conclusions that can be drawn from the findings of this research study:

1. The laboratory test results suggest that the nanolime-fly ash mixture helps in considerable improvement of strength over the traditional lime treatment methods. Soil replaced with 20% fly ash and added 0.5% and 1% of nanolime shows improvement in strength.
2. Curing period of lime has great effect on stabilizing the soil, as the curing time increases, the UCS of the soil sample increases. The highest strength improvement was 162 kN/m^2 and 121 kN/m^2 for 80% BCS 20% FA mixed with 0.5% and 1% nanolime observed at 28 days of curing period.
3. Besides enhancing the strength properties, the nanolime-fly ash treatment helped in significantly reducing the liquid limit, slight decrement in plastic limit and plasticity index, and soil designation shifting from CH type of soil to MH type of soil.
4. The prime reason for this stabilizing effect is agglomerate small clayey size soil particles and it convert it to the silt size soil particles.

Future prospect of the research includes a detailed study of the morphological and mineralogical characteristics of the modified sample so that a comprehensive soil treatment methodology using this novel admixture can be suggested for practicing engineers. Further studies are also required to reduce and optimize the proportion of admixture necessary for improving the engineering properties of a problematic soil.

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