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Research Article

Evaluation of Efficacy of Chemical Stabilizers on Expansive Soil

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Abstract

Expansive soils are mostly found in the arid and semi-arid regions and occupy major area of the world. About 22% of the land mass in India mostly entire Deccan plateau. These kinds of highly swelling soil are usually termed as Black Cotton Soils. The delta region in Andhra Pradesh formed between 60 and 68 million years ago at the end of the Cretaceous period. In this region the main classes of soil are black, brown soil. The volcanic, clay-like soil of the region owes its black colour to the high iron content of the basalt from which it formed. As the Delta region is mainly dominated by Black Cotton Soil, it is one of the types of expansive soil, which has a high prospective for shrinkage and swelling under varying moisture environment. These deposits, due to their dominating physical and chemical constituents, are subject to change in volume with seasonal variations. Because of the inherent property of swelling, these soils are a latent peril to the natural balance and it results in incomparable disfigurement world-wide every year. Usage of expansive soils in sub grades in its natural form is not viable and chemical stabilization is one of the many alternative tried. One of the many a established methods is stabilizing with chemicals like KCl, $CaCl_2$, $FeCl_3$. Expansive soils untreated and treated with chemicals have been tested for various Engineering properties and also analyzed in Scanning Electron Microscope to understand the mineralogical changes manifested at different resolutions.

Keywords: *Expansive Soils, mineralogical changes, chemical stabilization, Crystalline and Amorphous structures.*

1. Introduction

Black cotton soils occupy upto about 72 million hectares in India between 80 45' to 260 N latitude and 680 to 830 45' to E longitude. This soil is approximately spread over 257 million hectares of earth's surface and is having major share. Venkatarathnam (1987) Expansive soils are predominantly clayey soils or very fine silts showing marked tendency to volumetric changes i.e., swelling and shrinking cycles on variation in moisture conditions. This precarious property of swell and shrink has created numerous problems due to highly unpredictable upward movement of structures founded on them, resulting in severe cracking either in the buildings or pavements. This is a universal phenomenon. This crucial trend affects the serviceability performance of the pavements or the structures founded on these kinds of soils. The doming (Centre heave) and dishing (edge heave) curvatures in foundations would result, due to soil movement. Doming is due to long term progressive swelling under the centre of slab and dishing is due to cyclic heave beneath perimeter of the foundation (Masia *et al.*, 2004; Day, 2006).

Expansive soils are a universal problem prevalent in the semi-arid regions of the tropical and temperate climate zones across five continents (Chen, 1988). Major problem associated with these kinds of highly expansive soils is that the deformations are very much higher than elastic deformations and conventional elastic or plastic theory are no suffice to forecast the performance. Extensive damage is caused to the structures or pavements founded on them since the movement of soils doesn't follow a defined pattern and its magnitude cannot be assessed. (Nelson and Miller, 1992). Highly unpredictable swell / shrink behaviour of expansive soils due to variation in moisture content is more detrimental to the structures built on them. The black cotton soils are predominantly argillaceous type and hold clay fraction varying between 50-70%. This high percentage of clay content coupled with principal Montmorillonite mineral is responsible for the volumetric change behaviour due to alternate wetting and drying. Since this swell-shrink behavior of expansive soil has serious consequences on

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the construction industry. It is quiet essential to modify the structure of the expansive clay for its effective usage in pavements. The efficacy of chemical stabilisers on the Engineering properties of the soils and its structural changes are of paramount importance in its usage as good pavement material.

2. Literature Review

Clay is the expression used to denote both particle size and representation of a family of minerals (Velde, 1995). When representing particle size, it specifies the soil particles those have their size less than 0.002 mm. Minerals are characterized by a) small particle size, b) a net electrical negative charge and c) plasticity when mixed with water. Clay minerals in general are principally hydrous aluminum silicates, having usually platy shape or in some cases needle shaped or tubular (Mitchell and Soga, 2005). Murray (1999) stated the significance of clay minerals in various industries. According to him, clay minerals like kaolin, smectites and palygorskite-sepiolite are some of the world's most important and useful industrial minerals. Lightly loaded structures and pavement founded on these soils are more susceptible for damages due to degree of variation caused by the expansive soil. They play an important role in various geological studies such as stratigraphic correlations, environment of deposition and study of temperature at the time of generation of hydrocarbons (Murray, 1999).

Soils generally include a range of non-clay, crystalline clay and minerals, no crystalline matter and precipitated salts (Mitchell and Soga, 2005). Most of the soils are comprised of crystalline minerals, which are basically non – clay. Therefore the percentage of crystalline clay minerals in a given soil is comparatively low. However, these clay minerals have more influence on the properties of the soil than their presence in volume. Size, shape, physical and chemical properties are influenced by the mineralogy of soil.
Working or handling expansive clays as foundation soils is difficult proposition due to innate property of alternate swell-shrink behavior. Experience over years proved that expansive soils are global geological hazard.(Sabine Chabrillat *et al*.,2002) Jones and Holtz, 1973; Eduardo Rojas *et al*., 2006; Thomas *et al*., 2006; Robert 1992; stated that the root cause for the damages to the structures on expansive soils is excess irrigation or poor drainage, unless they are properly addressed.

3. Materials

3.1 Expansive Soils

Soil used in the experiments has been collected from a two different rural areas i.e., from Kottapeta and Moolapalem villages in East Godavari District in Andhrapradesh. Engineering properties of these untreated soils have been analyzed in the laboratory and the results are presents in table.1

Table 1 Properties of untreated expansive soils

S.No	Property	Kottapeta Soil	Moolapalem Soil
1	**Grain size distribution**		
	Sand (%)	4	2
	Silt (%)	16	9
	Clay (%)	80	89
2	**Atterberg limits**		
	Liquid limit (%)	80	88
	Plastic limit (%)	38	40
	Plasticity index (%)	42	48
	Shrinkage limit (%)	14	13
3	**Compaction properties**		
	O.M.C. (%)	26.3	31.2
	M.D.D (g/cc)	1.46	1.38
4	Specific Gravity (G)	2.70	2.70
5	IS Classification	CH	CH
6	Soaked C.B.R (%)	2	1.20
7	DFS (%)	125	190
9	**Shear Strength Parameters**		
	Cohesion (C) (Kg/cm^2)	0.52	0.36
	Angle of internal friction (ø)	0^0	0^0

3.2 Stabilizing agents – Chemicals used

a) Potassium Chloride (KCl)
b) Calcium Chloride ($CaCl_2$)
c) Ferric Chloride ($FeCl_3$)

The above additives are mixed at 0.50%, 1.0% and 1.50% of dry weight of soil

4. Methodology adopted

Untreated & treated expansive soils have been tested in the laboratory for the following engineering properties. Expansive soils untreated and treated with chemicals have been tested for various Engineering properties and also analyzed in Scanning Electron Microscope to understand the mineralogical changes manifested at different resolutions. **Table 2** shows the tests conducted and relevant IS Codes followed.

Table 2 IS codes followed for laboratory testing

S.No	Name of the test	IS code
1	Grain size distribution	IS 2720,Part 4,1965
2	IS Heavy Compaction	IS 2720,Part 8,1983
3	Index Properties	IS 2720,Part 5,1985
4	Free Swell Index	IS 2720,Part 40,1977
5	California Bearing Ratio	IS 2720,Part 16,1997
6	Shear strength parameters	IS 2720,Part 10,1993

5. Results and Discussion

5.1 Grain size Distribution

Based on particle size distribution and indices properties of both the expansive soils, both of them resulted in a clay fraction of 80% - 89% and classified as CH soil group.

5.2 Compaction test

Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for the untreated are found out using IS Heavy Compaction test. The OMC is as high as 26.30% to 31.20% and MDD is varying from 1.46 gm/cc to 1.38 gm/cc.

5.3 Index properties

Atterberg Limits are found out for both untreated & treated soils. There is considerable reduction of Plasticity Index (PI) in case of treated soils, which is an important property stipulated for a soil to be utilised as subgrade. The reduction in the PI values is attributed to adsorption of positive ions onto the clay particle surface which ultimately reduces repulsion between successive diffused double layer and enhances edge to face contacts between successive clay sheets. Accordingly the clay particles flocculate into large clusters. Variation of Atterberg limits of both treated and untreated expansive soils from both the sources are presented Fig.5.1 to 5.8

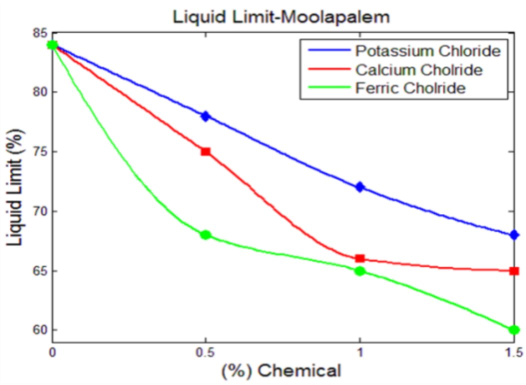


Fig 5.1 Liquid limit – Moolapalem

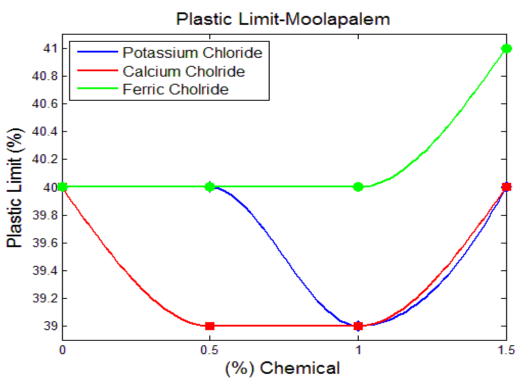


Fig 5.2 Plastic limit – Moolapalem

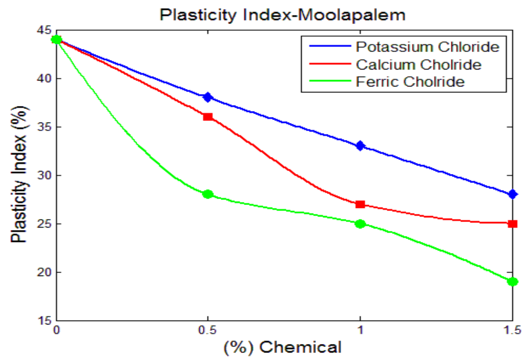


Fig 5.3 Plasticity Index – Moolapalem

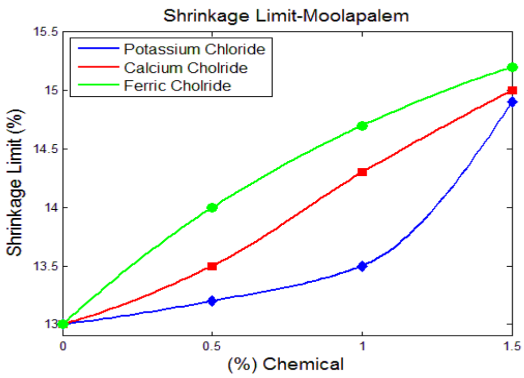


Fig 5.4 Shrinkage Limit –Moolapalem

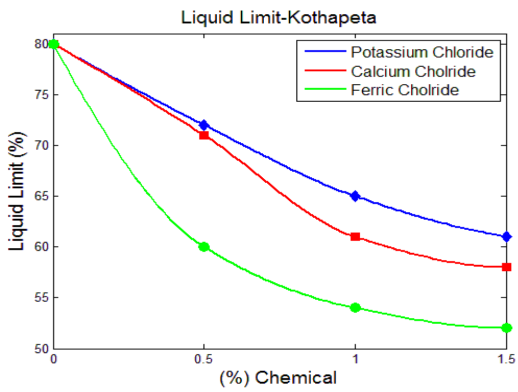


Fig 5.5 Liquid limit – Kottapeta

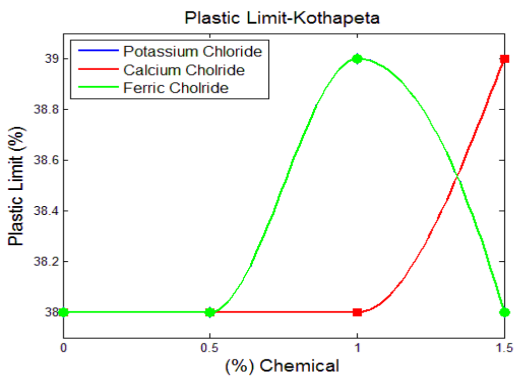


Fig 5.6 Plastic limit – Kottapeta

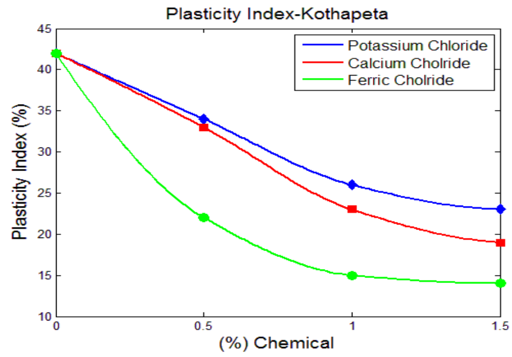


Fig 5.7 Plasticity Index – Kottapeta

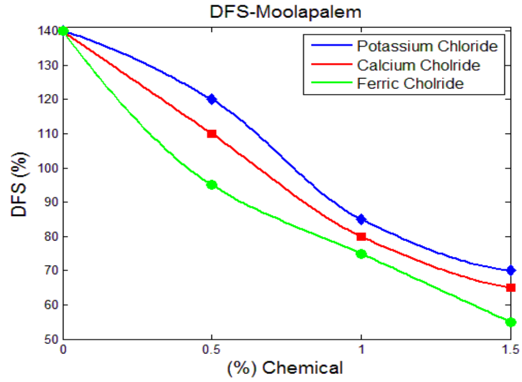


Fig 5.10 Differential free swell Index – Moolapalem

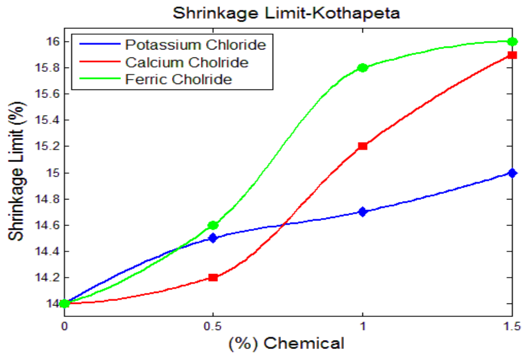


Fig 5.8 Shrinkage Limit – Kottapeta

5.4 Free Swell Index (FSI)

Treated soils have shown considerable reduction in the differential free swell in the order of 39% to 46% at 1% optimum chemical content. The reduction in free swell is attributed to the formation of crystalline structure and decrease in double layer thickness. Fig.5.9 & 5.10 present the reduction of the differential free swell between treated and untreated soils from both the sources.

Decrease in Plasticity Index, FSI and increase in Shear strength and friction angle due to cation exchange capacity are in conformity with reported work by W.S. Abdullah a,, A.M. Al-Abadi (2009) in soils treated with KCl and $CaCl_2$.

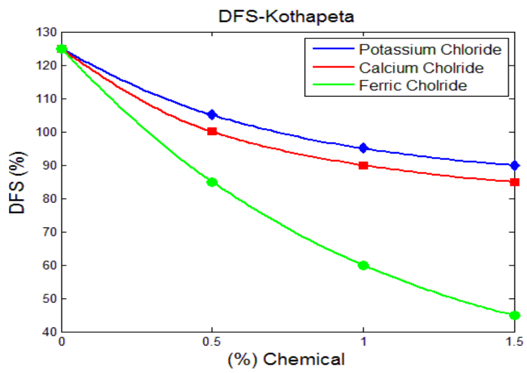


Fig 5.9 Differential free swell Index – Kottapeta

5.5 California Bearing Ratio (CBR)

Expansive soils upon treatment with chemicals have shown increase in the order of 105% to 333% making them more suitable as pavement material. The increase is more predominant up to 1% of the Chemical and thereafter, no significant increase is observed for both type of soils. The increase in the CBR is attributed to formation of harder lattice on chemical reactions. Fig.5.11 and 5.12 present the variation of CBR with increase in Chemicals for both type of soils.

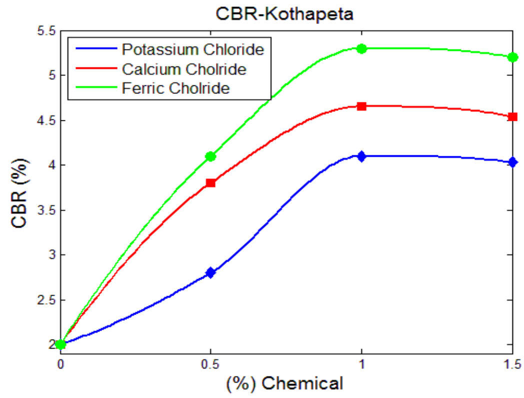


Fig 5.11 Differential free swell Index – Kottapeta

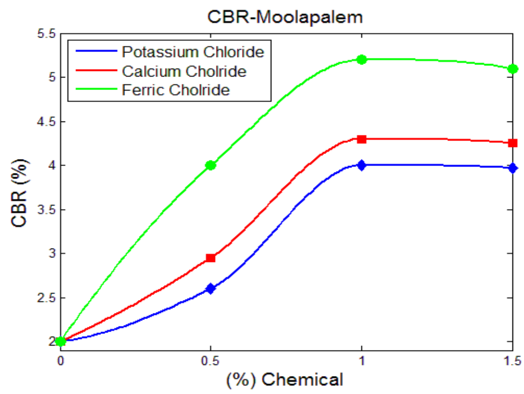
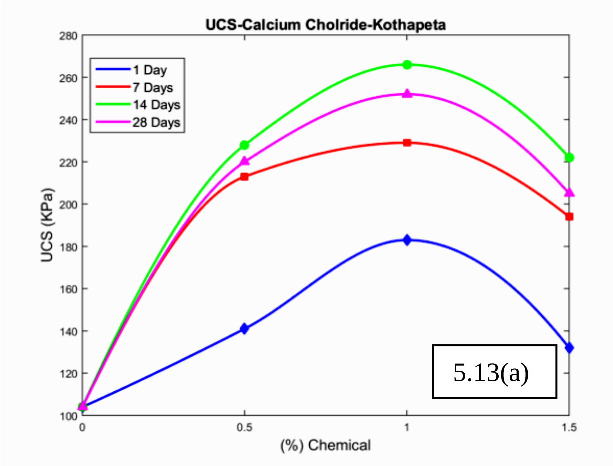
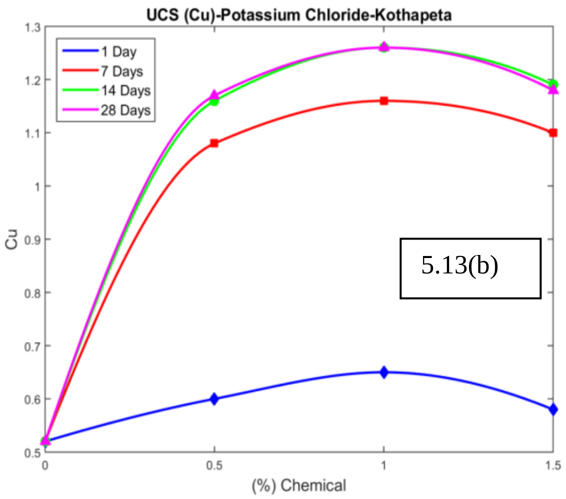


Fig 5.12 Differential free swell Index – Moolapalem

5.6 Shear strength parameters (c, Θ)





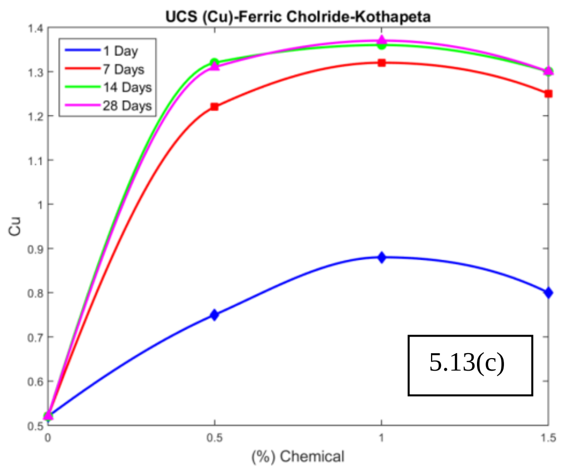
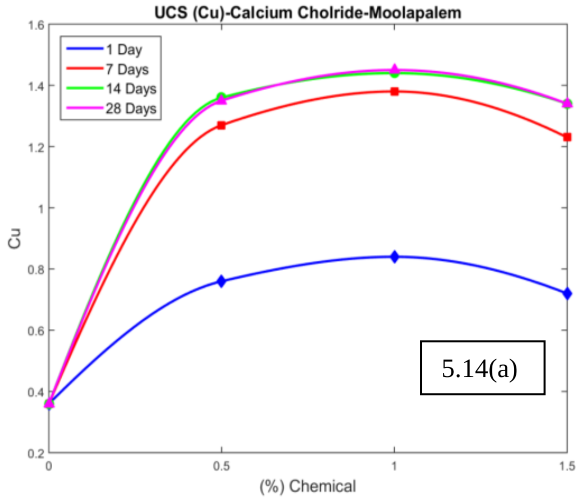
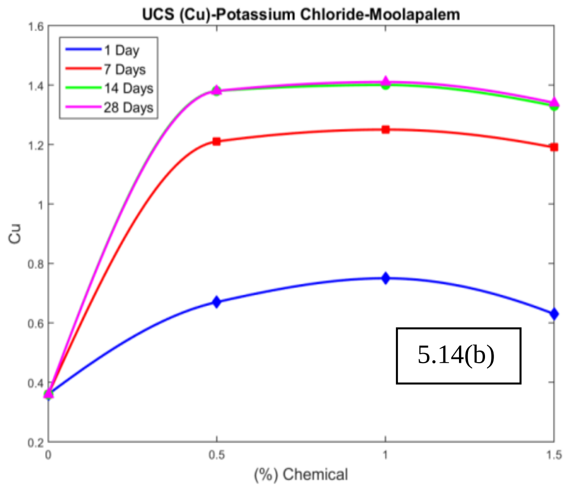


Fig 5.13(a,b,c) Unconfined shear strength with different % of chemicals at different ages of curing – Kottapeta soils





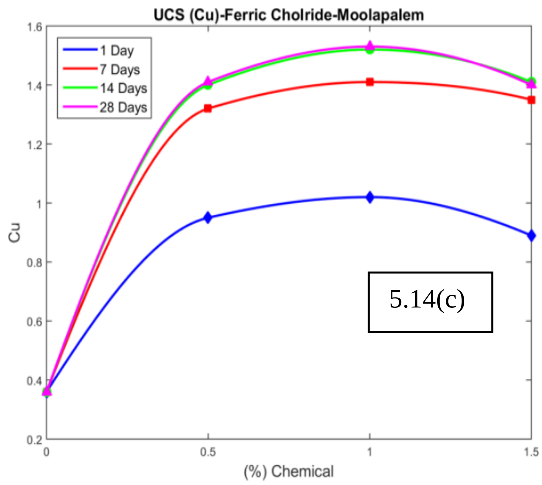


Fig 5.14 (a, b, c) Unconfined shear strength with different % of chemicals at different ages of curing – Moolapalem soils

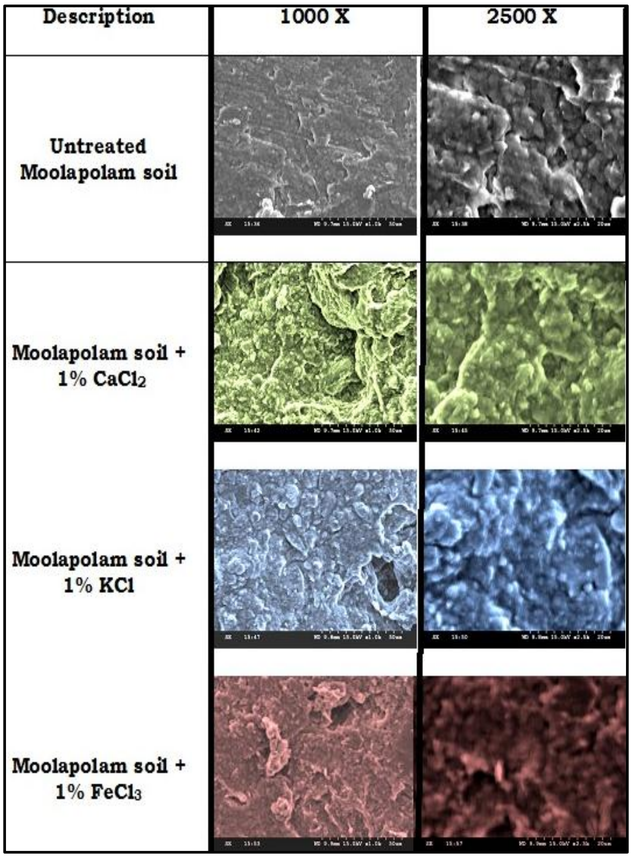


Fig.6.1 SEM images of Moolapalem treated & untreated soils

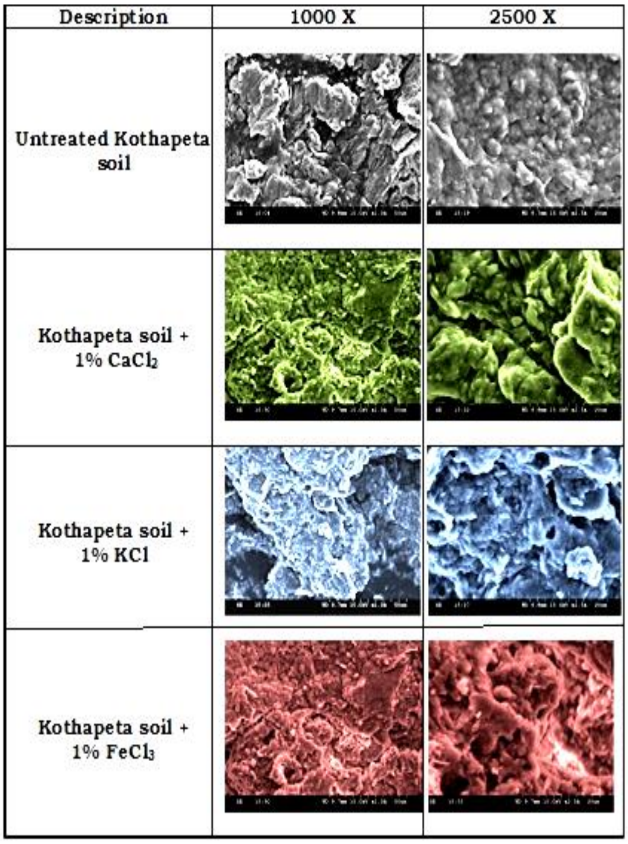


Fig.6.2 SEM images of Kothapeta treated & untreated soils

6. Scanning Electron microscope examination

Both untreated and untreated and also cured samples with three electrolytes were scanned in Scanning electron microscope to understand the changes developed in the soil microstructure due to addition of electrolytes. These samples prepared with optimum percentage of electrolyte at 1% were scanned at two levels of resolution and presented in the above shown Fig.6.1 & 6.2. Most of the clay minerals are crystalline possessing sheet or layered structure and some are either fibrous structure or elongated.

SEM images of soils treated with electrolytes indicate perfect gel formation and randomly oriented plates resulting lesser space for water to intrude which is prime agent causing swelling. Thus the shear strength of the treated soils shows an increment along with other properties.

From the above comparative images of both types of soils a conclusion is drawn that soils treated with 1% of $FeCl_3$ have shown better improvements than the other electrolytes. An abstract of results comparing the performance of different percentages of chemicals on both type of soils is tabulated (Table 3 & 4) for better of appreciation of the improvements manifested in expansive soils. Upward arrow ↑ indicate improvement and downward arrow ↓ indicate reduction in values, when compared with the values of untreated soils.

Table 3 Performance of chemicals on Moolapalem soils

Property		Untreated soil	Treated soil with		
			KCl	$CaCl_2$	$FeCl_3$
Liquid Limit	**WL**	88	72	66	65
	% reduction		18(%) ↓	25(%) ↓	26(%) ↓
Plasticity index	**PI**	48	33	27	25
	% reduction		31(%) ↓	44(%) ↓	48(%) ↓
D.F.S	**DFS**	190	85	80	75
	% reduction		46(%) ↓	56(%) ↓	61(%) ↓
C B R	**C B R**	1.2	4	4.3	5.2
	% improvement		233% ↑	258% ↑	333% ↑
UCS	**UCS**	72	209	255	312
	% improvement		190% ↑	254% ↑	333 % ↑

Table 6.2 Performance of chemicals on Kottapeta soils

Property		Untreated soil	Treated Soil With		
			KCl	$CaCl_2$	$FeCl_3$
Liquid Limit	**WL**	80	65	61	54
	% reduction		19(%) ↓	24(%) ↓	33(%) ↓
Plasticity index	**PI**	42	26	23	15
	% reduction		38(%) ↓	45(%) ↓	64(%) ↓
D.F.S	**DFS**	125	95	90	60
	% reduction		24(%) ↓	28(%) ↓	52(%) ↓
C B R	**C B R**	2	4.1	4.65	5.3
	% improvement		105% ↑	133% ↑	165% ↑
UCS	**UCS**	104	213	266	324
	% improvement		108% ↑	156% ↑	212 % ↑

Conclusions

The efficacy of the chemical stabilisers is well established as observed from the tables 6.1 & 6.2. All the chemicals have shown similar trend in improvements of various properties on both type of expansive soils. Reduction in plasticity Index and improvement in California Bearing Ratio is a welcoming feature. Out of three chemicals used, 1% of $FeCl_3$ has phenomenal improvement in either case and the reduction in differential free swell in the range of 52% to 61% and increase in California Bearing Ratio in the order of 165% to 333% thus making the soils more amenable for their usage as subgrade material in road construction. Both the samples have shown a similar trend in increase of UCS up to 14 days period of curing with different percentage of chemicals used. There after there is a small decrease in the trend which is insignificant and the optimum chemical content can be taken as 1% of chemicals used. The rise is phenomenal i.e., from 108% to 333% for both type of soils with three varieties of chemicals.

At 1% of $FeCl_3$ the amorphous nature of virgin soils have shown improvement and resulted in flocculated structure with less space for water intrusion. Due to this phenomenon the soils have become less expensive and more suitable.

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