Experimental Studies On The Influence Of Chemicals On Geotechnical Properties Of Black Cotton Soil In Puducherry Region

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Abstract. Generally, black cotton soils are shrinking and swelling due to changes in wa- ter content. In India, this soil is named expansive soil. The swell-shrink behavior of ex- pansive soils causes extensive problems to the substructure and distress in the infrastruc- tures such as buildings, pavements of breast walls, etc. Understanding the performance of black cotton soil and adopting suitable control measures have been significant work for geotechnical engineers. The present study examines the effectiveness of chemicals used to improve the engineering characteristics of black cotton soil (LL=103%, SL=1.82%) collected from a location in Puducherry, India. An experimental program has evaluated the effects of Alccofine-1203 (3, 6, 9, and 12 %) and Magnesium Chloride ($MgCl_2$) (0.25, 0.5, 0.75, and 1%) contents on the Index, Strength properties**,** pH, EC and cation exchange capacity (CEC) characteristics of black cotton soil. Both admixtures were added individually and mixed with the combination of these two admixtures to the untreated soil. The results showed that the combined action of 9% alccofine - 1203 + 0.75% $MgCl_2$ increased the dry density and unconfined compressive strength of soil while decreasing the liquid limit, plasticity index, and swelling properties. However, fur- ther increasing the addition of alccofine and $MgCl_2$ results in a decrease in the unconfined compressive strength. Thus, it proves that by adding the admixture, the problematic soil has turned into the best one, with the addition of 9% alccofine and 0.75 percent magne- sium chloride, which exhibited a significant stabilizer on a high swell, high shrink, and low bearing capacity soil.

Keywords: Expansive soil, Magnesium Chloride, Alccofine-1203, UCS.

1.0 Introduction

Black cotton soil is a highly plastic, low-quality soil that frequently absorbs the expected impact to produce undesirable engineering behavior, such as low load-bearing capacity, high shrink, swell potential, and high moisture susceptibility [1-3]. Montmorillonite and other active clay minerals are found in black cotton soil. It is a well-known issue that has raised concerns among scientists about how structural and transportation systems are designed, protected, and maintained. These soils can be found all over the world, but it is most prevalent in six Indian states: Gujarat, Madhya Pradesh, Maharashtra, Tamil Nadu, Andhra Pradesh, and Karnataka. It has been estimated as a probable natural hazard, if not treated well can cause serious harm to a building, or in humid climates, even a small amount of black cotton soil with a high plasticity index (PI) can endanger both human life and structures. Numerous variables can affect how black cotton soil behaves, but the main ones are whether the moisture is present and what kind of clay-sized particles are present in the soil. It is stated that when the water content of black cotton soil changes, the volume will also vary and can cause the soil to either swell or shrink in nature. [4-8]. Different solutions are used to improve the engineering features of soft soils, such as densification, chemical stabilization, reinforcing, and pore water pressure reduction. In most approaches to soil stabilization, chemical stabilization has developed appeal as it lowers setting and cure time. However, it is more costly than other techniques of stabilizing.

The issue created by the expansive soils has been addressed by various innovative techniques such as special foundations that include belled piers, drilled piers, friction piles, and moisture barriers. [9]. Apart from this techniques stabilization of expansive soils with various additives including fly ash, lime, cement, and calcium chloride, has also met with considerable success [10-12]. Recently several experiments indicate the increased behavior of poor soil when stabilized with alccofine 1203 and some other admixtures [13]. A combination of marble dust and alccofine 1108 can increase the CBR and other strength attributes of soil. The introduction of these admixtures reveals that the strength value is boosted from 98.5 kN/m^2 to 798 kN/m^2 at 28 days' strength [14]. The optimal dose of 3% alccofine successfully stabilized the weak lateritic soil displaying a strength improvement of 52.71% after a curing time of 3 days and forming appropriate CAH (Calcium Aluminate Hydrates) CSH (Calcium Silicate Hydrate) compounds, which enhances the strength of the soil. It is primarily related to its ultra-fine particle size, which supports filling the gaps and consequently interacting with the ions in soil to create CAH and CSH compounds [15]. It was discovered that industrial wastes like silica fume and alccofine can impact the engineering features of expansive red soil [16]. The function of fly ash as a stabilizing agent because its pozzolanic activities in the presence of admixture like alccofine applied in a proportion improve the strength and engineering features of expansive soil [17]. The use of waste material, i.e., ground granulated blast furnace slag (GGBS) as a replacement to lime or cement, was proved to be successful and economical in various building projects and taking bigger loads from the foundation structures [18,19]. Hence, it has been proposed that lime-treated GGBS be applied effectively as a cushion material for different civil engineering buildings created on expansive soil [20]. The rising fraction of chemicals $MgCl_2$ and $AlCl_3$ at 1% and fly ash at 10% remain stable after hitting a given concentration. Thus, the selected chemical and fly ash combination are exceptionally successful in minimizing the swell pressure and swell potential of the expansive soil [21]. Furthermore, the selected chemicals NH_4Cl, $MgCl_2$, and $AlCl_3$ had a big impact in decreasing the [24] swelling qualities and enhancing the strength characteristics of soil at 1% of chemical content and out of which aluminium chloride was judged to be more effective [22]. Hence, it can be proved that the presence of salt NaCl, $MgCl_2$, and $CaCl_2$ has a major influence on the liquid limit, plastic limit, and free swell of clays [23]. The various ratios of $CaCl_2$ and RHA combinations were utilized in a study by [25] to support clay soil as cushions (CNS) beneath footings, pavement slabs, and behind canal lining. The expansive soil contains montmorillonite mineral, which is responsible for the shrink and swelling characteristic of the soils. It generates differential settling in the structure, and collapse happens. So, it is desirable to stabilize the soils for construction reasons. The traditional way to stabilized these soils is cement, lime, gypsum, and other additives. Further, the fast-growing infrastructure developed in many nations has led to the development of numerous forms of industrial by-products resulting in environmental difficulties. By using hygroscopic material magnesium chloride ($MgCl_2$), is effective as a de-icing agent because of its exothermic interactions with water. It is also ideally suited for stabilizing expansive soils because it absorbs water from the atmosphere and prevents shrinkage cracks from developing in expansive soils during the summer [25]. Alccofine is a commercially available material from Alccofine 1101 and is high in calcium silicate, whereas the latter one Alccofine-1203 is low in calcium silicate [26,27]. It is commonly accepted that alccofine is a fantastic stabilizer employed in increasing the characteristics of the soil owing to its good impacts on its sustainable enhancement and the environment. When employed as a stabilizing agent, the combination of the two elements can be more advantageous than utilizing each one alone. Too far, no research has been published on the dual activation of alccofine and $MgCl_2$ as stabilizing agents for low-load-carrying soils. In this study, an attempt has been made to stabilize expansive soil chemically using an alccofine and $MgCl_2$ mixture. When assessing the effectiveness of high swell and shrink soil, consideration has been given to the effects of these chemicals on the FSI, plasticity, compaction, strength, and Cation Exchange Capacity (CEC) features of expansive soil.

2.0 Materials and Methodology:

2.1 Black Cotton Soil:

The soil from Location 1, in the Puducherry region, India, was used for this investigation because of its high swell, shrink, and low load-carrying capacity. The soil has collected at a depth of 1.5 m below the ground level. It is dried and sieved through a sieve of 4.75mm size to remove gravel fraction if any. And it is conserved in the test center. The soil is classified as 'CH' as per IS Classification (IS 1498: 1970) which has inorganic clay of High Plasticity [28]. Table 1 shows the index and engineering properties of high swell and shrinks soil.

2.2 Alccofine:

Alccofine 1203 is a fine cementitious Ground Granulated Blast Furnace Slag (GGBS) material that performs superior to all other mineral admixtures used and obtained from Counto Micro-Fine Product Private Limited, Goa, India. The majority of Ultra-fine slag products are used for high-performance soil stabilization purposes. Table 2 displays the physical and chemical characteristics of micro-fine slag.

Table 1. Physical properties of soil

Properties of soil	Results
Specific gravity, (G_S)	2.27
Color of soil	Blackish Grey
Grain size distribution	
Clay (%)	67.9
Silt (%)	28.49
Sand (%)	03.61
Atterberg Limits	
Liquid Limit, (W_L) (%)	103
Plastic Limit, (W_P) (%)	37.78
Shrinkage Limit (W_S) (%)	01.82
Plasticity Index, (PI) (%)	65.22
Free swell index (FSI) (%)	125
Free swell ratio (FSR)	02.25
Water absorption (W_A) (%)	93.73
Cation exchange capacity (CEC) meq/100g	26.27
Specific surface area (SSA) m^2/g	01.021
Unified soil classification	CH

Compaction characteristics	
Optimum Moisture Content (OMC) (%)	36
Maximum Dry Density (MDD) (KN/m^3)	13.8
Unconfined compressive strength (UCS) (kPa)	46.44
pH	02.78
Conductivity (mS/cm)	05.71

Table 2. Physical and chemical properties of ultra-fine slag

Properties	Results
Physical properties	
Particle size distribution (mm)	
D10	1.5
D50	5.0
D90	9.0
D95	11.5
Specific gravity	2.9
Bulk density (kg/m^3)	680
Chemical properties	
SiO_2	35.41 (%)
CaO	32.9 (%)
Al_2O_3	21.6 (%)
Fe_2O_3	1.9 (%)
MgO	7.98 (%)
SO_3	0.21 (%)

2.3 Magnesium chloride:

Magnesium Chloride is an inorganic salt with the chemical formula is $MgCl_2$. As a result, some hydrates, mainly hexahydrate $MgCl_2$ *$6H_2O$, consume a molecular weight of 203.301 g/mol. It is a colorless crystalline compound. The salt is very hygroscopic. Magnesium chloride is effective as a de-icing agent due to the exothermic nature of its relations with water. It is available in three distinct forms: flakes, powder, and liquid. Magnesium chloride hexahydrate, with a chemical formula of ($MgCl_2.6H_2O$), was the salt used in this study. Its purity ranged from 98 to 100 percent. And it is obtained from Sri Rajendra Scientific and Surgical Private Limited. Puducherry, India. Table 3 shows the chemical properties of $MgCl_2$.

Table 3. Chemical properties of Magnesium Chloride ($MgCl_2$)

Properties of $MgCl_2$	Results
Molecular weight (g/mol)	203.31 (hexahydrate)
Density (g/cm3)	1.569
Melting point	117° C, 390 K, 243° F
Boiling point	1412° C, 1685 K, 2574° F
Water solubility	235g/100ml water @20° C
Appearance	White (or) colorless crystalline solid

2.4 Testing methodology:

The index and engineering qualities of stabilized soils can be evaluated using a variety of tests. The current study is focused on analyzing the physical characteristics, compaction, strength, and swell/shrink behavior. Experiments have been done on expansive soil using varying concentrations of magnesium chloride (0.25, 0.50, 0.75, and 1.0%) and alccofine -1203 (3, 6, 9, and 12%). According to Indian Standards, the clay soil sample's specific gravity, Atterberg limits, compaction, unconfined compressive strength (UCS), consolidation, and swelling characteristics of soil were all determined.

The water absorption (W_A) of soil mixed with the admixtures $MgCl_2$ and alccofine-1203 was added independently and blended into the expansive soil. A water absorption (W_A) equation is developed and recommended by [29].
Water absorption equation is

$$W_A = 0.91\ W_L,$$

where, W_L is liquid limit.
A Specific Surface Area is established and recommended by [30] to determine the Specific Surface Area (SSA) of the soil-binders mixture. The cation exchange capacity (CEC) of the blended soil-admixture samples was determined. The Cation Exchange Capacity (CEC) was created and is advised [31].

3. Result and discussion

The effect of Alccofine and Magnesium Chloride ($MgCl_2$) on different properties of expansive soil was determined as per Indian standards and discussed in the following sections Atterberg limit, free swell index, compaction parameters, unconfined compressive strength, and free swell ratio.

3.1 Atterberg limits (LL, PL, PI):

The various percentage of Alccofine and $MgCl_2$ blended with problematic clay soil in the selected location is shown in Table 4. Results show that the liquid limit decreased from 103% to 42% at 12% Alccofine and 47% at 1% $MgCl_2$, and the plastic limit also decreased; hence the difference between liquid limit and plastic limit is termed as the plasticity index. The plasticity index is reduced from 65.22% to 10.82% and 18% when the soil is blended individually with 12% Alccofine and 1% $MgCl_2$. The sample mixed with both admixtures likewise showed a significant reduction in the liquid limit, and the shrinkage limit was increased by around 73% with the addition of 9% alccofine + 0.75% $MgCl_2$.

3.2 Free swell test:

The swelling behavior of soil is blended independently with different percentages of Alccofine and Magnesium Chloride present in Table 4, and the combination of these two admixtures is in Table 5. The presence of montmorillonite minerals greatly influences the swelling properties of soil. The addition of these two substances individually demonstrates that the soil's swell index steadily dropped from 125% to 4.5% at 12% Alccofine-1203 and 16.67% at 1% $MgCl_2$, respectively. The result proves that both chemicals reduced the swell potential of soil from high swelling to low. Similarly, the swelling property of clay soil is decreased from high swell to zero swell due to the accumulation of 9% Alccofine + 0.75% $MgCl_2$ as per IS 1498-1970 [29].

3.3 Cation Exchange Capacity:

The displacement of exchangeable cations Ca, Mg, Na, and K from soil colloids by NH_4 allowed for the identification of these cations. This work is done by Asian Enviro Labs Pvt. Ltd. of Pallavaram, Chennai.

3.4 Compaction parameters:

The compaction characteristics of untreated and treated soils are shown in Tables 4 and 5. The results show that the MDD increased from 13.8 kN/m^3 to 16.95 kN/m^3, and optimum moisture content is reduced from 36% to 14.3% with the inclusion of 9% alccofine and 0.75% $MgCl_2$; that is, for a sample which proves the maximum strength.

Table 4: Effects on Index & Engineering properties of soil blended with individual admixture

Admix-tures (%)	W_L (%)	W_P (%)	W_S (%)	PI (%)	G_S	CLAY (%)	SILT (%)	FSI (%)	FSR	MDD (kN/m^3)	OMC (%)	UCS (kPa)	W_A (%)
0	103	37.78	1.82	65.22	2.27	67.9	28.49	125	2.25	13.8	36	46.4	93.73
A 3	77.8	29.17	7.05	48.63	2.44	64.5	35.5	81.25	1.81	13.8	31.6	89.5	70.79
A 6	68	28.78	5.4	39.22	2.46	64	36	25	1.25	14.6	25	118	61.88
A 9	60.5	20.44	11.32	40.06	2.42	63.5	36.5	13.63	1.13	15.3	18.7	150	55.06
A 12	42	31.18	7.95	10.82	2.64	62.5	37.5	4.5	1.05	16.2	17.5	172	38.22
M 0.25	80	31.04	6.47	48.96	2.37	66	34	82.35	1.82	14.3	28	48	72.8
M 0.50	63.8	24.71	4.53	39.09	2.43	61	29	66.67	1.67	15.2	22	93	58.06
M 0.75	56.2	22.01	9.81	34.19	2.47	58	42	44.44	1.44	15.6	18.5	104	51.14
M 1	47	29	11.14	18	2.62	54.5	45.5	16.67	1.17	17	12	126	42.77

Note: A = Alccofine 1203; M = Magnesium chloride; W_L = Liquid limit; W_P = Plastic limit; W_S = Shrinkage limit; PI = Plasticity index; G_S = Specific gravity; FSI = Free swell index; FSR = Free swell ratio; MDD = Maximum dry density; OMC = Optimum moisture content; UCS = Unconfined compressive strength; W_A = Water absorption.

Table 5: Effects on Index and Engineering properties of soil blended with both admixtures

Admix-tures (%)	W_L (%)	W_P (%)	W_S (%)	PI (%)	G_S	CLAY (%)	SILT (%)	FSI (%)	FSR	MDD (kN/m^3)	OMC (%)	UCS (kPa)	W_A (%)
0	103	37.78	1.82	65.22	2.27	67.9	28.49	125	2.25	13.8	36	46.4	93.73
A 3 + M 0.25	66.5	28.71	10.29	37.79	2.52	65.7	32.3	70.58	1.71	17.3	13.3	137	60.52
A 6 + M 0.5	57	32.37	11.92	24.63	2.57	64.2	35.8	66.67	1.67	16.6	16.6	197	51.87
A 9 + M 0.75	41.4	24.58	18.32	16.82	2.65	61	39	0	0	16.95	14.3	274	37.67
A 12 + M 1	47.5	23.55	19.82	23.95	2.72	58.5	41.5	10.5	1.10	17.3	11.5	239	43.23

3.5 Unconfined compressive strength (UCS):

Alccofine and magnesium chloride are two chemicals that were separately added to the untreated soil and then mixed for the UCS test. It was performed [32] on both natural and chemically treated soil. The UCS value for intrinsic clay soil is 46.4 kPa. The percentage of alccofine (3, 6, 9and 12%) and $MgCl_2$ (0.25, 0.5, 0.75, and 1.0%) were added by dry weight of the soil. The UCS values are shown in Tables 4 and 5, and the optimum strength is obtained at 12% alccofine and 1% $MgCl_2$ individually. The UCS strength was increased from 46.4 kPa to 274 kPa with the combined effect of 9% alccofine + 0.75% $MgCl_2$. Beyond 9% alccofine with 1% $MgCl_2$ resulted in a slight decrease in UCS values.

3.5 Free swell ratio (FSR):

The free swell ratio method is very competitive, conducting a very simple procedure, for the prediction of the swell potential of a soil. It is, defined as the ratio of equilibrium sediment volume of 10 g oven-dried soil passing a 425 µm sieve in distilled water to that in kerosene [35].

$$FSR = V_d/V_k$$

The results show that the FSR value is reduced from 2.25 to 0, which indicates the swell of soil is changed from high swelling to non-swelling with the accumulation of 9% alccofine + 0.75% $MgCl_2$ respectively. And also, the dominating clay mineral is changed from montmorillonite to a mixture of kaolinite and montmorillonite. The following Table 6 illustrates it.

Table 6: FSR value of soil admixed with alccofine-1203 + magnesium chloride ($MgCl_2$)

Admixture (%)	Free swell ratio (FSR)	Clay type	Soil expansivity	Dominant clay mineral type
0	2.25	Swelling	High	Montmorillonite
A 3 + M 0.25	1.71	Swelling	Moderate	Montmorillonite
A 6 + M 0.5	1.67	Swelling	Moderate	Montmorillonite
A 9 + M 0.75	0	Swelling	Negligible	Kaolinite
A 12 + M 1	1.10	Mixture of swelling and non-swelling	Low	Mixture of Kaolinite and Montmorillonite

Table 7: Properties Obtained for Optimum Soil + alccofine + $MgCl_2$

Properties	Natural soil	90.25% soil + 0.75% $MgCl_2$ + 9% Alccofine – 1203
Specific gravity, (G_S)	2.27	2.65
Grain size distribution		
Clay (%)	67.9	61
Silt (%)	28.49	39
Atterberg Limits		
Liquid Limit, (W_L) (%)	103	41.4
Plastic Limit, (W_P) (%)	37.78	24.58
Shrinkage Limit (W_S) (%)	01.82	18.32
Plasticity Index, (PI) (%)	65.22	16.82
Free swell index (FSI) (%)	125	0
Free swell ratio (FSR)	02.25	0
Water absorption (W_A) (%)	93.73	37.67
Cation exchange capacity (CEC) meq/100g	26.27	34.87
Unified soil classification	CH	CI
Compaction characteristics		
Optimum Moisture Content (OMC) (%)	36	14.3
Maximum Dry Density (MDD) (kN/m^3)	13.8	16.95
Unconfined compressive strength (UCS) (kPa)	46.44	274

Conclusion:

In this investigation, several tests were carried out based on the laboratory investigation to investigate the impact of alccofine-1203 and MgCl2 on swelling characteristics and strength behavior of soil. The findings drawn from the data in this research are as follows:

When the soil is blended individually, the plasticity index decreases from 65.22% to 10.82% and 18%, and also the liquid limit value decreases from 103% to 42% at 12% Alccofine and from 103% to 47% at 1% $MgCl_2$. According to IS classification, the soil has barely placed under the CI classification from CH [33], despite the fact that increasing the shrinkage limit and decreasing the liquid limit demonstrates the combined action of adding 9% alccofine-1203 + 0.75% $MgCl_2$ to the soil.

The maximum dry density (MDD) increased from 13.8 kN/m^3 to 16.95 kN/m^3 with increasing chemical concentration 9% alccofine-1203 + 0.75% $MgCl_2$, whereas the optimum moisture content (OMC) decreased greatly from 36% to 14.3% [34].

Alccofine and $MgCl_2$ were separately added to the soil samples and blended before being used in the unconfined compressive strength (UCS) testing. Intrinsic soil has a UCS value of 46.44 kPa. The maximum improvement was observed at 9% alccofine and 0.75% $MgCl_2$. The UCS strength was raised from 46.44 kPa to 274 kPa. Beyond 9% alccofine with 0.75% $MgCl_2$ resulted in a slight decreased in UCS values.
The swell behavior of soil; swell index reduced from 125% to 0% and which means the swell of soil is changed from high swelling to non-swelling with the accumulation of 9% alccofine + 0.75% $MgCl_2$ respectively.
The results demonstrated that the type and quantity of additives play a critical role in the stabilizing process. The chemical characteristics of the additive are the most important among a number of considerations that must be taken into account when selecting an additive. Lightweight constructions frequently rest on top of cohesive non-swelling soils (CNS) as a cushion. It should be emphasized that because expanding soil lacks a CNS layer, there is a chance of differential heave and a reduction in shear strength at the foundation limits. An alternate cushion material is recommended to be made on-site utilizing the intrinsic soil (expansive soil) by admixing with it 9% Alccofine-1203 and 0.75% $MgCl_2$ by dry weight of the soil due to the extreme scarcity of suitable cohesive non-swelling soils (CNS) at numerous project sites. Based on the positive outcomes of the expansive soil containing alccofine and $MgCl_2$, a useful cohesive non-swelling soil (CNS) for roads, sidewalks, and floorings. Hence the result concluded that the addition of 9% alccofine and 0.75% magnesium chloride exhibited an essential stabilizer on a high swell and shrinks soil and poor bearing capacity soil, thereby it was discovered that by addition of the admixture problematic soil converted to best soil.

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