IMPROVEMENT OF PERFORMANCE OF FLEXIBLE PAVEMENT RESTING ON EXPANSIVE SOIL SUBGRADES USING FLY ASH AND INDUSTRIAL CHEMICALS

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ABSTRACT: ***Rapid industrialization and urbanization in a highly limited land area leads to serious waste disposal problems. Scarcity of land causes the disposal of waste in landfills to be extremely environmentally hazardous. An attractive alternative to waste disposal is conversion of waste into new resources. Past studies indicated that the conservation ofwaste into construction material is a potential option for the management of voluminous wastes resulting in two folded advantage of solution to waste disposal and its utilization as a promising alternative. In the proposed research work, an attempt was made to devise ways and economical means to use chemicals and waste materials obtained from various sources to examine their feasibility in modifying the engineering properties of expansive soil. The materials used are flyash and different chemicals viz. Ammonium Chloride (NH4Cl), Magnesium Chloride (MgCl2), Aluminum Chloride (AlCl3). The viability of these materials was studied through a methodical process involving laboratory experimentation to check their effect on different geotechnical properties of soil and to arrive at an optimum quantity of different additives. Analysis of expansive soil treated with Ferric Chloride which was considered to be feasible alternative drawn from various researchers was also documented. Laboratory studies were followed by field test track studies after laying different stretches of untreated and treated alternatives. The cyclic load responses of different stretches of the test track were investigated by conducting cyclic plate load test during dry and wet seasons. Scanning Electron Microscope (SEM) analysis of untreated and chemically treated samples was carried out to study the morphological, topographical and compositional information. Economic analysis wasalso taken up and the following rankings were observed.***

study on the use of fly ash and fly ash-based geopolymers for the stabilization of expansive soils (high and low plastic) as soil stabilizers and partial replacement of moorum (non-plastic soil). In the last decades, several traditional stabilizers such as cement and lime have been used, that cause adverse effects on environment. The carbon footprint and high energy consumption are associated with the manufacturing of these stabilizers form environmental limitations. For bulk soil stabilization of expansive soil, the consumption of these traditional binders is relatively high. Hence, the industry immensely needs new alternative binders that feature low environmental footprint without compromising soil stabilization capabilities. Fly ash-based geopolymers through alkali activation of fly ash forms a cementitious material that act as binders, as they involve useful recycling/diversion of discarded aluminosilicate industrial by-product materials. The fly ash-based geopolymer stabilized expansive soil shows significant increase in strength performance (UCS, CBR, and MR), and reduction in swelling and shrinkage behavior of soil. Based on the microstructural studies, microstructural changes of stabilized soil were observed that reflect the formation of geopolymeric gel. The optimized stabilizer dosage to achieve the maximum UCS (1606.14 kPa) was defined in terms of FAR and CD i.e., 1.5 and 22.75 (approx. 23) days. While maximum CBR performance was 40.03%, for FAR-2 and CD-27.98 (approx. 28) days. The application of fly ash-based geopolymer stabilized soil was demonstrated in terms of the design of flexible pavement for low and high-volume roads. In addition, to gain practical and economical confidence, cost analysis was carried out for stabilized soil (fly ash-based geopolymer) and comparison has been made with conventional materials. The stabilized soil for flexible pavement gives significant reduction in pavement thickness (51.68%) and the overall cost of pavement construction (10.50%).

Key Words: Flexible pavement, Expansive soils, fly ash, industrial chemicals.

I. INTRODUCTION

Flexible Pavements constructed on expansive soils always show signs of distress during their service period and this has been a challenging task for the geotechnical engineers and other organizations working on them (Selvakumar and Soundara 2019; Chittoori et al., 2018; Generally these expansive soils containing clay minerals exhibit peculiar chemical makeup which expand when they absorb water and shrink when it dries out (Bhuvaneswari et al., 2018; Biswajit and Nirmali 2015; Muthukumar and Phanikumar 2014; Ramana Murthy and Hari Krishna 2006; Kumar 2000). Volume changes are due to the existence of montmorillonite mineral which imparts high swell-shrink potential to the soil during wet and dry seasons respectively, leading to failure of pavements in the form of settlement, cracking, undulations, unevenness etc. (Magdi and Emam 2018; Qin et al., 2018). The research on expansive soil has been progressed nationally and internationally by various scientists, field engineers and other organizations. Different techniques like moisture control (Evans and Mc. Manus 1999; Nelson and Miller 1992), placement of required surcharge load (Lopez et al., 2017; Saad et al., 2014), heat treatment (Charles et al., 2017; Wang et al., 2008) etc. are available for solving the problem, but they are limited to a certain extent. Several researchers (Qin et al., 2018; Vandana et al., 2018; Mohanty et al., 2018; Mahmoud et al., 2018) carried out their work under controlled conditions of laboratory in which simulation of all field conditions were not presented. The problems still persist in spite of relentless efforts put forth by various researchers (Magdi 2018; James et al., 2017; Hanifi et al., 2015; Choudhary et al., 2009) worked on these aspects. Flyash has been used in bulk quantities for various geo- engineering activities like road embankments (Rajak et al., 2019; Bhuvaneswari et al., 2005; Bin Shafique et al., 2004; Snethen 1979), subgrade stabilization (Tija 2016; Kumar Pal and Ambarish Ghosh 2014; Seehra 2008; Edil et al., 2006), fill material (Muhardi 2010;Horiuchi et al., 2000) etc. Apart from this it is also used for making various construction materials like flyash bricks, concrete blocks, floor and ceiling tiles etc. (Saurabh et al., 2014; Freeda and Tensingb 2011). Utilization of flyash in huge volumes is possible only in the process of stabilization and it had been a technique since time immemorial (Memgmemg et al., 2018; Mir and Sridharan 2013; Nalbantoglu 2004). Field test tracks constructed either in off lane or on-lane (Manchikanti and Prasada Raju 2011; Schroeder 1994) evaluated the performance of test track under simulated conditions. But the field test track study gives a picture of pavement attitude and actions during the course of time after construction. The study of off-lane test tracks conducted by various experts may be of considerable help in evolving new feasible techniques to a limited extent.Research conducted with simple laboratory testing (Narendra Goudet al., 2018; Mahmoud et al., 2018; Sadam 2017), model study andfield investigation (Udayshankar and Purnik 2012; Seehra 2008), provided the information about different chemical stabilization methods for alleviating problems posed by expansive soil subgrades. Most of the studies on expansive soil have been limited to laboratory studies (Srirama Rao 1984). However the durability of the accepted methods will be proved only when it is exposed to timetrusted technologies under real life situation considering the increased demand of traffic volume.Test track studies are the sources through which one can accomplish this aspect in an effective manner. Various test track studies (Kumar and Raju 2009; Yang et al., 2009; Bhuvaneswari et al., 2005; Schroeder 1994; Reddy et al., 1981) were dwelt at full length only on pavement material characterization. In view of the above deliberations with regards to problems posed by expansive soils, flyash and other chemical additives along with the solutions attempted for improved pavement performance, there appears to be a dire need to arrive at a feasible solution eitherwith the materials along with their combinations used or the methodologies adopted. Efforts are on to arrive at amicable solutions so as to endorse a technique that addresses the concerns. Moreover, arrived techniques have to be authenticated with experimentation under field simulated conditions keeping economic aspects into consideration. ence an orderly procedure to learn the behavior of stabilized expansive soil with suitable chemical additives along with suitable techniques has to be resorted to with appropriate economic analysis and hence the present study has been taken up with the following objectives.

OBJECTIVES OF THE PRESENT STUDY

The present study is taken up with the following aims.

1. To iden tify strategic techniques to alleviate the problems posed by expansive subgrade soils with a view to adopt suitable methodology after thorough critical review of literature.

2. To perform model laboratory testing with a view to find the relative performance of different treatments.

3. To construct a field test track with different subgrade stretches to examine the relative performance of different stretches.

4. To analyze the impact of treatment on economic aspects.

II. MATERIALS USED

In this experimental program, the primary stage includes the preliminary research on selecting the raw materials.

EXPANSIVE SOIL

The expansive soil used in this research study was brought out from Komaragiripatnam village, Amalapuram mandal in the state of Andhra Pradesh, India. Soil is taken out from a depth of 1.5 m below ground level. Soil is dark black in color and is fine grained. The swelling nature of soil when tested was found very high.

CHEMICALS

The Chloride based chemicals used in this study are listed as follows.

Ammonium Chloride (NH_4Cl)

It is a white crystalline salt. It is highly soluble in water. Solutions of ammonium chloride are mildly acidic. It is commercial grade with 90% purity and it contains cations to ensure neutrality.

Magnesium Chloride ($MgCl_2$)

These salts are typical ionic halides and are highly soluble in water. It is commercial grade 89% purity consisting of two valance electrons responsible to accomplish ion exchange.

Aluminum Chloride ($AlCl_3$)

It is a main compound of aluminum and chlorine. It is white in colour, but samples are often contaminated with iron trichloride, giving it a yellow color. It is Commercial grade with 91% purity comprising three valance electrons resulting in improved relative performance.

FLYASH

The flyash used in this study was collected from Vijayawada Thermal Power Station (VTPS) of Andhra Pradesh, India. Flyash refers to the ash produced during combustion of coal. This product is freely available in bulk quantity. Flyash appears white in color.

MURRUM

In the present study murrum was collected form Dwarapudi, Andhra Pradesh, India. It was used as a subbase material for preparingthe model flexible pavements in laboratory and also in field experimentation for laying subbase of off lane test tracks. This materialis meeting the prescribed grading and physical requirements of theClause 401 of MORT & H specifications.

AGGREGATES

Coarse aggregate for WBM was obtained from Yeleswaram quarryin the state of Andhra Pradesh, India. Material is crushable stone metal grade of hard granite. Their size ranges confirm to WBM grading III ofIRC 19-1977. The percentage of material passing 53mm, 45mm, 22.4mm, 11.2mm designated sieves are of the order 95-100%, 65-90%, 0-10%, 0-5% respectively.

LABORATORY EXPERIMENTATION

Laboratory experimentation was carried out to investigate the effect of flyash and different chloride compound chemicals in modifying the geotechnical properties of expansive soil.

Different chemical contents used are Ammonium chloride (NH4Cl), Magnesium chloride (MgCl2), Aluminum chloride (AlCl3). Flyash and Chemicals were added to the expansive soil in varying percentages ranging from 0% to 15% and 0% to 2.0% of dry weight of soil respectively. Testing was done as per Indian Standard code of practice. During this course of study the following tests were conducted.

i. **Grading:** Percentage of fine sand, silt and clay contents in the soil using IS 2720 (Part 4)-1985.

ii. **Index Properties**: Liquid Limit, Plastic Limit and Shrinkage
Limits using IS 2720 (Part 5) -1985 & IS 2720 (Part VI) - 1972.
iii. **Swelling Properties**: Differential Free Swell, Swell Potential and

Swell Pressure using IS 2720 (Part XL &
iv. **Compaction Characteristics:**
Max Dry Density and Optimum Moisture Content carried out by using IS 2720 (Part 8) -1983.
v. **Strength Properties**: Shear strength parameters, Unconfined
vi. Compressive Strength and CaliforniaBearing Ratio were conducted by using IS 2720 (Part 11) -1993, (Part 10) -1991, (Part -16) -1987.

III. EXPERIMENTAL PROGRAM

The impact of flyash and different chemical contents on geotechnical properties of expansive soil has been studied through laboratory experimentation. To check the validity of results of laboratory testing field test track studies were carried out. A field test track was constructed in the JNTUK premises, close to the GeotechnicalEngineering Laboratory. Procedure for constructing field test track includes subgrade, subbase and base courses along with cyclic plate load testing were presented in this chapter.

CONSTRUCTION OF FIELD TEST TRACK

In the construction of field test track include Different stages clearing the site, excavation of trenches, laying of subgrade in the untreated and treated stretches, laying of subbase and base courses. These stretches were provided with untreated and different treated subgrades as listed in Table.The size of each stretch is 2 m X 1.5 m. As there are four stretches the length of the field test track is 8 meters and width 1.5 m. The relative performance of different stretches was determined by observingthe heave of field test track stretches and their responses to cyclic loading, during both dry and wet seasons.

Table 4.1 Field Test Track with different Subgrade condition

Sl. No.	Test Stretch	Subgrade	Subbase	Base Course
1	Untreated	Expansive soil	Murrum	WBM III
2	Treated	Expansive soil + 10% FA + 1% NH_4Cl	Murrum	WBM III
3	Treated	Expansive soil + 10% FA + 1% $MgCl_2$	Murrum	WBM III
4	Treated	Expansive soil + 10% FA + 1% $AlCl_3$	Murrum	WBM III

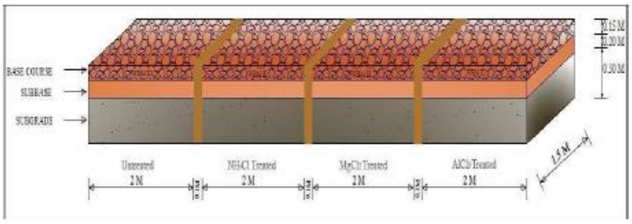


Plate 4.1 Field Test Track over Expansive Soil Subgrade

EXCAVATION FOR FIELD TEST TRACK

After clearing the site, trench was excavated with dimensions of 8 m long, 1.5 m wide and 0.85 m depth. As it is required to provide different subgrades along the length of the track, the total length was divided into four stretches each of 2 m long and 1.5 m wide, separated by a four inch sand wall. The open excavation made for laying the field test track was shown in Plate 4.2.

Plate 4.2 Open cut for Field Test Track

Plate 4.3 Flyash mixing with Expansive Soil

Plate 4.4 Untreated and Treated Subgrade

Plate 4.5 Subbase compaction with Earth Rammer

Plate 4.6 Subbase compaction with Hand Held Roller

Plate 4.8 Process of laying the Base Course

IV. RESULTS AND DISCUSSION

The results obtained in this research work were presented here.

Effect of additives on Liquid Limit

The summary of results on effect of flyash and chemicals onliquid limit of soil is shown in Table .1.

Table .1 Summary of results on Liquid Limit of soil

Flyash (%)	Chemical (%)	Liquid Limit (%)		
		NH_4Cl	$MgCl_2$	$AlCl_3$
0	0	85.2	85.2	85.2
5	0	82.0	82.0	82.0
10	0	74.6	74.6	74.6
15	0	71.8	71.8	71.8
0	0.5	80.0	77.9	73.3
5	0.5	77.5	75.5	71.2
10	0.5	71.2	68.5	67.1
15	0.5	68.4	66.6	65.7
0	1	69.3	65.1	61.6
5	1	65.1	63.2	60.3
10	1	62.3	57.9	53.8
15	1	60.2	56.5	52.7
0	1.5	67.4	63.8	59.8
5	1.5	63.2	61.2	57.7
10	1.5	60.5	56.5	53.1
15	1.5	58.5	55.4	51.6
0	2	65.1	61.8	58.2
5	2	61.2	60.2	57.1
10	2	59.1	55.6	52.1
15	2	57.5	54.3	50.1

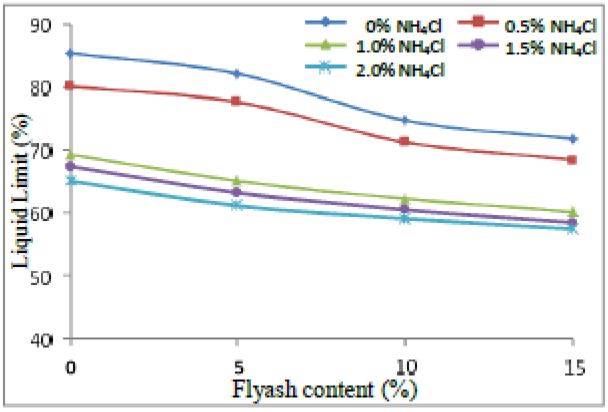


Fig. 1 Liquid Limit vs. Flyash at different percentages of Ammonium Chloride

Effect of additives on Plastic Limit

Summary of results on the effect of flyash and chemicals on plastic limit of soil is shown in Table 5. 3. Plastic limit of soil hasincreased slightly with increase in flyash and chemical contents. The increase in plastic limit is almost negligible after crossing 10% flyash content which is indicated by flattened portion of curves as shown in Figs.

Table 2. Summary of results on Plastic Limit of soil

Flyash (%)	Chemical (%)	Plastic Limit (%)		
		NH_4Cl	$MgCl_2$	$AlCl_3$
0	0	29.2	29.2	29.2
5	0	30.2	30.2	30.2
10	0	31.0	31.0	31.0
15	0	31.3	31.3	31.3
0	0.5	29.4	29.5	29.7
5	0.5	30.4	30.5	30.7
10	0.5	31.2	31.4	31.5
15	0.5	31.5	31.6	31.7
0	1	29.6	29.8	30.2
5	1	30.6	30.9	31.2
10	1	31.6	31.9	32.2
15	1	31.7	32.0	32.5
0	1.5	29.8	30.0	30.4
5	1.5	30.8	31.0	31.4
10	1.5	31.8	32.0	32.5
15	1.5	31.8	32.2	32.7
0	2	30	30.2	30.6
5	2	30.9	31.1	31.7
10	2	31.9	32.2	32.6
15	2	32.0	32.4	32.9

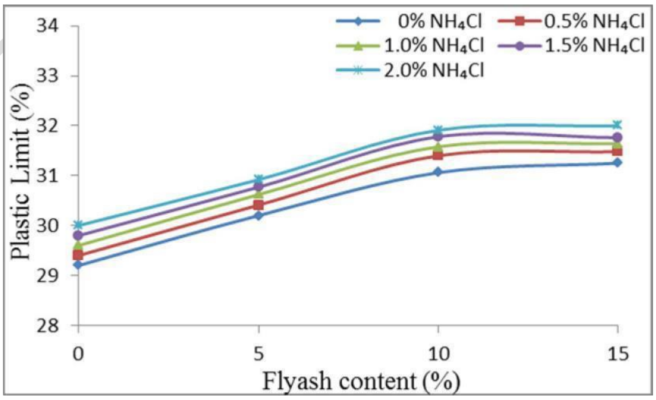


Fig. 2. Plastic Limit vs. Flyash at different percentages of Ammonium Chloride

Effect of additives on Shrinkage Limit

Summary of results on the effect of flyash and chemicals on shrinkage limit of soil is shown in Table. The variation of shrinkage limit with flyash and different chemical contents is shown in Figs.

Table 3. Summary of results on Shrinkage Limit of soil

Flyash (%)	Chemical (%)	Shrinkage Limit (%)		
		NH_4Cl	$MgCl_2$	$AlCl_3$
0	0	12.1	12.1	12.1
5	0	13.0	13.0	13.0
10	0	14.7	14.7	14.7
15	0	16.0	16.0	16.0
0	0.5	12.6	12.7	12.9
5	0.5	13.5	13.8	14.5
10	0.5	15.1	15.5	16.5
15	0.5	16.6	16.7	17.2
0	1	13.9	14.2	14.4
5	1	14.6	14.9	15.0
10	1	15.9	16.9	17.8
15	1	17.2	18.5	19.2
0	1.5	14.5	14.6	15.1
5	1.5	14.9	15.1	15.5
10	1.5	16.4	17.1	18.1
15	1.5	17.6	18.8	19.4
0	2	15.1	15.2	15.4
5	2	15.4	15.5	15.9
10	2	16.8	17.2	18.3
15	2	18.4	19.2	20.0

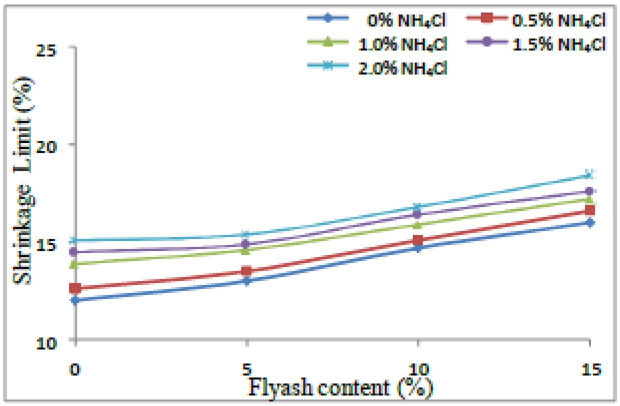


Fig. 3. Shrinkage Limit vs. Flyash at different percentages of Ammonium Chloride

Impact on Swell Pressure of Expansive Soil

The summary of results is shown in Table . The variation of swell pressure with flyash and different chemicals viz. NH4Cl, MgCl2 and AlCl3 are presented in Figs. The swell pressure of natural expansive soil was found to be 295 kPa. Swelling property of expansive soil has got reduced with the addition of flyash and chemical contents. Addition of 5% , 10% and 15% of flyash contents, the percentage reduction in swell pressure is 13.6% , 30.2% and 37.6% respectively. Reduction in swell pressure is gradually increasing with increase in flyash percentage. This could be due to the replacement of clay particles with equal flyash content having no swelling, pozzolanic and cementatious property.

Table 4. Summary of results on Swell Pressure of soil

Flyash (%)	Chemical (%)	Swell Pressure (kPa)		
		NH_4Cl	$MgCl_2$	$AlCl_3$
0	0	295	295	295
5	0	255	255	255
10	0	206	206	206
15	0	184	184	184
0	0.5	255	246	200
5	0.5	215	193	160
10	0.5	176	159	115
15	0.5	161	138	91
0	1	203	165	126
5	1	181	136	94
10	1	144	102	66
15	1	137	87	57
0	1.5	191	152	117
5	1.5	176	131	84
10	1.5	135	91	55
15	1.5	128	75	52
0	2	172	141	106
5	2	158	115	74
10	2	121	86	45
15	2	114	65	41

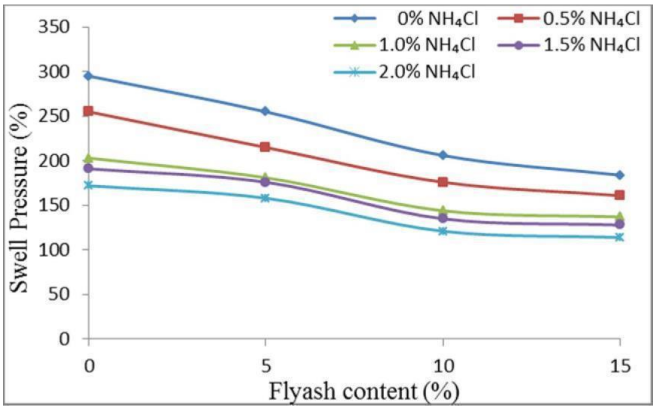


Fig. 4. Swell Pressure vs. Flyash at different percentages of Ammonium Chloride

INFLUENCE OF ADDITIVES ON CALIFORNIA BEARING RATIO

Summary of results on effect of flyash and different chemical contents on the California Bearing Ratio (CBR) of the expansive soil are presented in Table. Figs. depicts the variation of California Bearing Ratio (CBR) with flyash and different chemical combinations.

Table 5. Summary of results on CBR of soil

Flyash (%)	Chemical (%)	California Bearing Ratio (%)		
		NH_4Cl	$MgCl_2$	$AlCl_3$
0	0	2.1	2.1	2.1
5	0	4.2	4.2	4.2
10	0	6.1	6.1	6.1
15	0	6.7	6.7	6.7
0	0.5	2.6	2.7	3.0
5	0.5	5.0	5.2	6.0
10	0.5	7.0	7.7	8.1
15	0.5	7.4	8.3	8.5
0	1	3.1	3.3	4.0
5	1	5.6	6.0	6.8
10	1	7.6	8.7	9.7
15	1	8.1	9.1	9.9
0	1.5	3.4	3.7	4.2
5	1.5	5.9	6.3	7.1
10	1.5	7.8	8.8	9.9
15	1.5	8.4	9.2	10.1
0	2	3.7	3.9	4.4
5	2	6.1	6.5	7.5
10	2	8.0	9.0	10.1
15	2	8.6	9.3	10.5

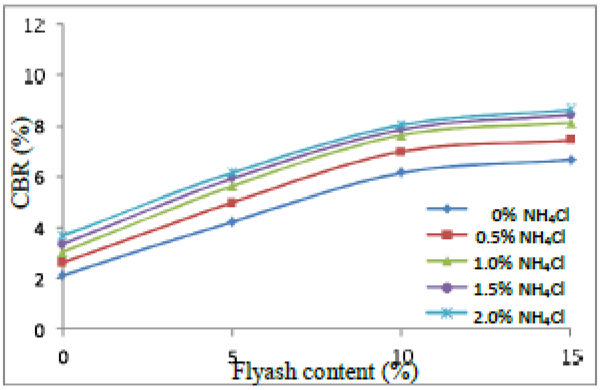


Fig.5 CBR vs. Flyash at different percentages of Ammonium Chloride

INFLUENCE OF ADDITIVES ON UNCONFINED COMPRESSIVE STRENGTH

Summary of results on the effect of flyash and different chemicals on Unconfined Compressive Strength (UCS) of expansive soil are presented in Table. The variation of UCS with flyash and NH4Cl, MgCl2, AlCl3 chemical contents is shown in Fig s

Table 6. Summary of results on Unconfined Compressive Strength of soil

Flyash (%)	Chemical (%)	UCS (kPa)		
		NH_4Cl	$MgCl_2$	$AlCl_3$
0	0	94	94	94
5	0	140	140	140
10	0	195	195	195
15	0	160	160	160
0	0.5	101	115	124
5	0.5	154	183	195
10	0.5	203	208	220
15	0.5	168	191	203
0	1	117	132	142
5	1	190	213	225
10	1	219	242	259
15	1	204	237	249
0	1.5	114	128	138
5	1.5	185	208	220
10	1.5	211	236	251
15	1.5	196	229	243
0	2	109	121	136
5	2	179	203	215
10	2	207	228	246
15	2	190	220	238

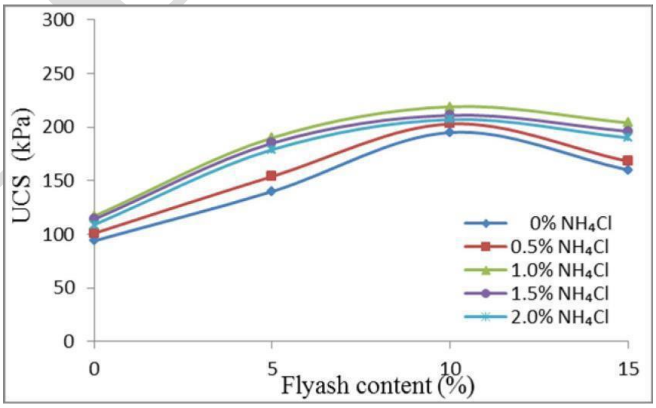
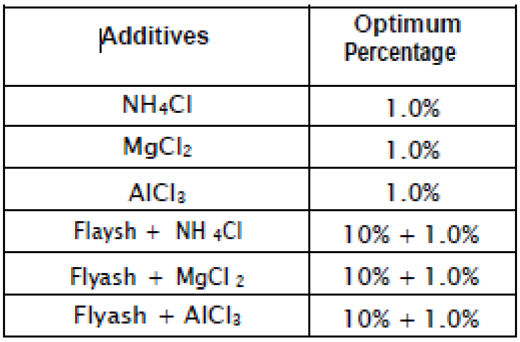


Fig.6. Variation of UCS with Flyash and Ammonium Chloride

OPTIMUM PERCENTAGE OF ADDITIVES

The Optimum percentages of different additives, perceived during the laboratory experimentation are summarized in the following Table.

Table 7 Optimum percentage of A dditives



Additives	Optimum Percentage
NH_4Cl	1.0%
$MgCl_2$	1.0%
$AlCl_3$	1.0%
Flaysh + NH_4Cl	10% + 1.0%
Flyash + $MgCl_2$	10% + 1.0%
Flyash + $AlCl_3$	10% + 1.0%

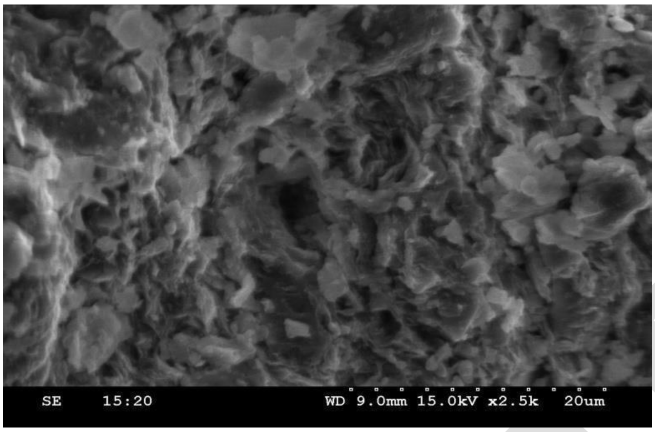


Fig 5. S canning Electron Micrograph of U ntreated soil sample

V. CONCLUSIONS

These following conclusions are given based on the above experimental results.

1. The collected soil for this study is highly expansive in nature having DFS of 140 and swell pressure of 295 kPa. It was classified as clay of high compressibility (CH).

The optimum contents of flyash, different chloride chemicals (NH4Cl, MgCl2 and AlCl3) were found to be 10% and 1% respectively.

2 The addition of flyash and different chloride compounds to expansive soil caused a reduction in liquid limit and plasticity indices whereas on the other hand there were increases in plastic limits and shrinkage limits.

3. Addition of optimum quantity of flyash (i.e.10%) the percentage reduction in plasticity index was 22%. Similarly addition of optimum dosage (1%) of different chloride chemicals (NH4Cl, MgCl2 and AlCl3) the plasticity index was reduced by 29%, 37% and 44% respectively.

4. Further the combined addition of flyash and chemicals played an active role in minimizing the plastic nature of expansive soil.

5. Addition of flyash and chemical contents of 10% and 1% to the soil, the percentage reduction in plasticity index was estimatedto be about 45%, 54% and 61% for FA+NH4Cl, FA+MgCl2 and FA+AlCl3 respectively.

6. The shrinkage limit increased to an order of 31%, 40% and 47% when treated with optimum amount of FA+NH4Cl, FA+MgCl2 and FA+AlCl3 respectively.

7. The reduction in Differential free swell of soil is more prominent when treated with chloride compounds than flyash.

8. On treating the natural soil with combination of optimum dosages of flyashand chloride compounds (FA+ NH4Cl, FA+MgCl2 and FA+AlCl3) the DFS decreased by 46%, 57% and 68% respectively.

9. Addition of optimum dosages of flaysh and different chloride chemicals (10% FA+1% NH4Cl, 10% FA+1% MgCl2, and 10% FA+1%AlCl3), the percentage reduction in swell pressure was found to be 51%, 65% and 78% respectively.

10. Blending of flyash to soil caused a considerable increase in CBR. With the addition of 10% flaysh CBR increased to 6.1% from its original value of 2.1%.

Similarly Addition of 1% chemical has shown increased CBR values of the order of 3.1%, 3.3% and 4.0% for NH4Cl, MgCl2 and AlCl3 respectively.

11. The combined influence has prominent effect on CBR value and increased to 8%, 9% and 10% for 10%FA+1%NH4Cl, 10%FA+1%MgCl2 and 10% FA+1% AlCl3 contents respectively.

12. Unconfined Compressive Strength (UCS) of original soil was found to be 94 kPa and addition of 10% flyash to soil UCS increased to 195 kPa. Similarly addition of 1% chemical has shown an increase to 117 kPa, 132 kPa and 142 kPa for NH4Cl, MgCl2 and AlCl3 chemicals respectively. The combined addition has increased to 219 kPa, 242 kPa and 259 kPa for 10%FA+1%NH4Cl, 10%FA+1%MgCl2, and 10%FA+1%AlCl3 contents respectively.

13. Curing period has considerable influence on UCS. Optimum curing period of 14 days was found to be effective and UCS increased to 509 kPa, 527 kPa and 539 kPa for 10%FA+1%NH4Cl, 10%FA+1%MgCl2, and 10%FA+1%AlCl3 contents respectively.

14. The flyash and chloride compound chemicals improved the geotechnical properties of expansive soil, however among the three chemicals used flyash and aluminum chloride chemical combination was found to be effective in reducing expansive nature of soil and for stabilizing expansive soil.

15. The model pavements provided with treated subgrade shows reduced heave during saturation. For an optimum content of flyash and chemicals heave of pavements reduced by 58%, 64%and 74% for FA+NH4Cl, FA+MgCl2, and FA+AlCl3 contents respectively.

16. Cyclic plate load testing shows a reduction in total and elastic deformation for the treated model pavements. For a

specific pressure of 1000 kPa, total deformation of untreated and treated pavements is 18.24mm, 5.78mm, 4.89mm and 3.68 mm

17. for FA+NH4Cl, FA+MgCl2, and FA+AlCl3 contents respectively. Similarly elastic deformation at a pressure 1000 kPa was 6.01mm, 3.41mm, 2.89mm and 2.34 mm for untreated, FA+NH4Cl, FA+MgCl2, and FA+AlCl3 contents respectively.

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