# Experimental Study on the Influence of Alccofine-1203 and Phosphogypsum on the Strength Characteristics of Expansive Soil

V. Jaladevi, V. Murugaiyan

*Abstract: Expansive soil is generally found in arid and semi-arid regions of the world. One of the main issues with these expansive soils is their tendency to swell when their natural water content increases. The various swell-shrink tendencies of expansive soils cause numerous issues with the substructure and distress in infrastructures such as buildings, pavements, and breast walls, among others. Geotechnical engineers have worked diligently to understand the behaviour of expanding soils and implement effective management strategies. The current study aims to elucidate the efficacy of alcofine-1203 and Phosphogypsum (PG) powder in achieving the geotechnical properties of soil and improving its high swell, high shrinkage, and low bearing capacity, which have benefits for civil engineering. The combination of the two materials can be more beneficial when used as a stabilising agent than when used individually. An experimental programme has calculated the effects of alcofine-1203 (3, 6, 9, and 12%) and Phosphogypsum (0.25, 0.5, 0.75, and 1.0%) on the Atterberg limits, optimum moisture content (OMC), unconfined compressive strength (UCS), maximum dry density (MDD), and other essential soil characteristics. Both admixtures were added independently and blended into the expansive soil. It was found that the liquid limit, plasticity index, optimum moisture content, and swelling behaviour of the expansive soil have been significantly reduced with the addition of specified admixtures. UCS gradually increases from 46.4 kPa to 948 kPa after 56 days due to the combined effect of 12% alccofine and 1.0% Phosphogypsum reacting with soil, which plays a critical role when compared to the remaining admixture combination. Hence, the results concluded that the addition of 12% alccofine and 1.0% PG exhibited an essential improvement for expansive soils, proving that adding the admixture is a potential stabiliser and also demonstrating that the problematic soil was transformed into the best soil. It also reduced the construction cost by making the best use of locally available materials.*

*Keywords: Alccofine-1203, Expansive soil, Phosphogypsum, Shrinking, Swelling, Unconfined Compressive Strength.*

## I. INTRODUCTION

Expansive soils are well known around the world for their volume change behaviour in response to moisture fluctuation. due to their intrinsic mineralogical behaviour. It typically consumes the expected impact to produce unwanted engineering behaviour, such as low load-bearing capacity, high shrinkage and swelling potential, and high moisture susceptibility (F. H. Chen, 1975 & 1988, [7,8]). These types of soils are primarily found in arid and semi-arid regions worldwide. They cover a significant portion of the world's geographical area, including Australia, Canada, China, India, South Africa, and the United States. India has an extensive track of expansive soils known as black cotton soil, which covers about 20% of the total land. Such soils are found extensively in Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Tamil Nadu, and Puducherry. One of the most difficult soils for civil engineering to work with is the expansive soil or black cotton soil, which expands and contracts because of changes in water flow (Azam et al., 2013, [4]). The foundations of structures built on expansive soil are seriously at risk. Due to its natural shrinking and swelling behaviour (Abdullah et al., 1999, [1]; Mishra et al., 2008, [20]) when it reacts with water, this type of soil can generate uplift forces that significantly damage lightly loaded buildings such as sidewalks, basements, etc. (Selvamsagayaradja et al., 2021, [28]; K.S. Subba Rao, 2000, [16]). As a result, the problematic soils are distinguished by their severe hardness when dry and by their great swelling potential during the wetting process, and the damages from expansive soils is very common where the yearly loss exceeds annual rainfall in arid and semi-arid areas (Suresh et al., 2018, 2019, [32,33]). It has been estimated that, if not treated adequately, it can cause catastrophic damage to the structure and destruction to human life. To achieve the desired strength, mechanical stabilization, such as compaction, and chemical admixture approach were utilized to strengthen the soil qualities, to regain the index properties of soil as well as its shrinking and swelling characteristics. Differential free swell has been performed on the soil, and a denti reduction in swelling potential and a change in the state of behaviour from plastic to brittle nature has been observed by (G. Ramakrishna et al., 2018, [12]). A study by (Suresh et.al., 2019, [33]) used the various proportions of alccofine and $CaCl_2$ admixtures to stabilize the clay soil as cohesive non swelling soils (CNS) cushions below the light weight structures and the optimum strength of expansive soil is obtained at 6% alccofine and 1% $CaCl_2$. On the other hand, $CaCl_2$ and $MgCl_2$, are hygroscopic materials and therefore ideally suited for stabilizing expansive soils because they absorb water from the environment and prevent shrinkage cracks from appearing in expansive soils during the

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summer season (Mishra et al., 2008, [20]).

Additionally, the stiffness and strength qualities of soft soils can be increased by mixing waste materials and fibres with chemical agents (Fatahi et al., 2013, [10]; Fatahi and Khabbaz, 2012, [9]). According to (Hayder Hasan et al., 2016[14]), stabilizing expansive soils using bagasse ash and hydrated lime not only increases strength but also makes it easier to address environmental issues by reducing waste from the sugar industry. To manage the consolidation features of the expansive soil, (A.T. Manikandan & M. Moganraj 2014, [17]) found that the addition of bagasse ash and hydrated lime together is more efficient than the addition of bagasse ash alone. Hence, 3% of lime and 0.75% of sisal fibre content (K.R. Manjunath et al., 2013, [19]) can be considered as optimum percentages for black cotton soil to increase the CBR value. Many researchers used the industrial by-product material such as alccofine (Rajesh Prasad Shukla et al., 2016, [24]; Rakesh Kumar Dutta et al., 2019, [26]), using pond ash and alccofine (Mohd Fahiem Tahir & Er. Tripti Goyal, 2019, [21]), cement kiln dust, alccofine-1101 (Amit Talgotra & Er. Neeraj Sharma, 2017, [3]), marble dust, alccofine-1108 (Manish Kumar Soni & Sandeep Singh, 2019, [18]), as additives are becoming more popular due to their relatively low cost, additionally, CO2 emissions can be reduced significantly by the increased use of such supplementary cementing materials currently wasted in lagoons and landfill sites. The most essential feature in the stabilisation of clay soils is the ability of the stabiliser to provide enough calcium. The goal of this study is to stabilize expansive soil by enhancing its geotechnical properties and increase the compressive strength of compacted expansive soil using a combination of alccofine and Phosphogypsum (PG) as a binder, while avoiding the harmful health and environmental issues that can be induced due to the disposal of this material. Therefore, the combination of the two materials can be more beneficial when used as a stabilising agent than when used individually. However, no research on the joint activation of Phosphogypsum (PG) and alccofine as stabilising agents for expansive soils has been published so far. The additives used have been selected with a focus on waste reduction, economic efficiency, and their eco-friendly nature.

## II. MATERIALS AND METHODOLOGY

### A. Materials

**Black Cotton Soil:** The soil from Location 1, in the Puducherry region, India, was used for this investigation because of its high swell, shrinkage, and low load-carrying capacity. The soil has been collected at a depth of 1.5 m below the ground level. It is dried and sieved through a 4.75mm sieve to remove any gravel fraction. And it is conserved in the test centre. The soil is classified as 'CH' as per IS Classification (IS 1498: 1970), which has inorganic clay of High Plasticity (Sridharan & Nagaraj, 2009, [31]). Table 1 shows the index and engineering properties of high-swelling and shrinking soil.

**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 |
| Swell potential (S) (%) | 57.74 |
| 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 |

**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. Most 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 2. Physical and Chemical Properties of Ultra-Fine Slag**

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

**Phosphogypsum (PG):** Phosphogypsum (PG) is the calcium sulphate hydrate formed as a by-product of the production of fertiliser from phosphate rock. It is mainly composed of gypsum ($CaSO_4 \cdot 2H_2O$). but also contains impurities of environmental concern, such as residual acids, fluoride, heavy metals, and naturally occurring radionuclides. Impurity composition within Phosphogypsum can vary greatly depending on the source of phosphate rock used in phosphoric acid production, and by treating phosphate ore (apatite) with sulfuric acid according to the following reaction:

$$Ca_5(PO_4)_3X + 5\ H_2SO_4 + 10\ H_2O \rightarrow 3\ H_3PO_4 + 5\ (CaSO_4 \cdot 2\ H_2O) + HX$$

where X may include OH, F, Cl, or Br

Approximately 4-6 tons of PG are generated per ton of phosphoric acid production.

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The continuous growth in the world population increases food production demand, which requires an increase in phosphate fertilizer production, increasing PG content (Alaa M. Rashad 2017, [2]). Only 15% of the world's PG production is recycled as building materials, including cement retarder, building gypsum powder, gypsum board, filler in papermaking, fibre plasterboard, mine filling agent, and roadbed material (Siqi Zhao et al., 2017, [29]; Holanda et al., 2017, [11]). Approximately 85% of this by-product is still discarded into the ocean or river, or stored in ponds or lakes without purification. This disposal causes severe contamination. The reduction in the disposal of this by-product offers both economic and environmental benefits. It is also recycled as agricultural fertilizers or soil stabilization amendments and as a set controller in the manufacture of Portland cement (Hanan Tayibi et al., 2009, [13]). Table 3 shows the oxide composition of Phosphogypsum.

**Table 3: Oxide Composition of Phosphogypsum**

| Major elements | Result |
|---|---|
| $SO_3$ | 44.7 |
| CaO | 32.04 |
| F | 0.79 |
| $Na_2O$ | 0.13 |
| Cl | 0.72 |
| $P_2O_5$ | 0.67 |
| $SiO_2$ | 0.43 |
| $Al_2O_3$ | 0.24 |
| MgO | 0.14 |
| $Fe_2O_3$ | 0.07 |
| LOI | 21.06 |

### B. Methodology

The index and engineering characteristics of stabilized soils can be evaluated using a variety of tests. The current study focuses on analysing the physical properties, compaction, strength, and swell/shrink behaviour. Experiments have been done on expansive soil using varying concentrations of Phosphogypsum (0.25, 0.50, 0.75, and 1.0%) and alccofine-1203 (3, 6, 9, and 12%). According to Indian Standards, the specific gravity, Atterberg limits, compaction, unconfined compressive strength (UCS), consolidation, and swelling characteristics of the expansive soil sample were all determined. The water absorption ($W_A$) of soil mixed with the admixtures Phosphogypsum and alccofine-1203 were added independently and blended into the combination of both admixtures with expansive soil. A water absorption ($W_A$) equation is developed and recommended by (Mokeagus J.A., 1978, [22]). The water absorption equation is WA = 0.91 WL, where WL is the liquid limit. The cation exchange capacity (CEC) of the blended soil-admixture samples was determined. The Cation Exchange Capacity (CEC) was created and is advised (Sridharan A & Nagaraj H.B, 2009, [31]).

## III. RESULT AND DISCUSSION

The effect of Alccofine-1203 and Phosphogypsum (PG) 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.

**A. Atterberg limits (LL, PL, PI):** The influence of alccofine and Phosphogypsum on Atterberg limits of expansive soil is shown in Fig 1. Results show that the liquid limit and plastic limit are decreased gradually, and the shrinkage limit increases; hence, the difference between the plastic limit and the shrinkage limit is termed the shrinkage index, and similarly, the difference between the liquid limit and the plastic limit is the plasticity index. Plasticity index is reduced by about 66% and Shrinkage index is increased by about 53% when the soil is blended with 12% alccofine + 1% Phosphogypsum due to the pozzolanic reaction and the capacity of cation exchange of the blend when compared to the soil mixed with admixture individually from Table 4. Based on IS (1498) – 1970 classification, the results proved that the index properties of natural soil are changed from high swell potential to medium swell potential due to the accumulation of 12% alccofine + 1% Phosphogypsum. (J. Mitchell, 1993, [15]) Suggested that plasticity is a good indicator of swell potential; that is, that a lower plasticity index reflects a lower swell potential. The addition of calcium chloride to soil increases the charge concentration (Ramanamurty, V & Praveen G.V, 2008, [27]).

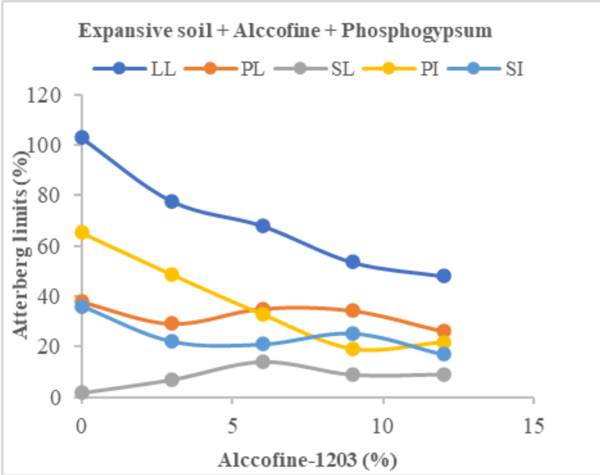


**Fig. 1. Effect of Alccofine and Phosphogypsum on Atterberg limits**

The compaction characteristics of treated and untreated soils are shown in Fig. 2 (a) and (b). The results of compaction show that the MDD is increased from 13.8 kN/m³ to 17.5 kN/m³, and the optimum moisture content is reduced from 36% to 15.6%, with an increase of 12% alccofine and 1% Phosphogypsum binder. This is for the sample that shows maximum strength. Similar behaviour of MDD and OMC was observed. Ground granulated blast furnace slag (GGBS) or industrial waste was used as stabilizing agents (Erdal Cokca, 2001, [6]; Phani Kumar & Sharma, 2004, [5]). An increase in dry density for a given compaction effect is desirable for use as construction materials, as it indicates soil improvement. An increase in MDD and a decrease in the OMC with increasing alcofine (Sivapullaiah, 2004, [30]; Rajesh Prasad Shukla et al., 2015, [25]).

**B. Free swell index (FSI):** A swelling behaviour of soil blended with different percentages of alccofine and Phosphogypsum is presented in Table 4. The presence of montmorillonite minerals greatly influences the swelling properties of soil.

Adding these chemicals individually to the soil, it is proven that the FSI is gradually reduced from 125% to 4.5% at 12% of alccofine


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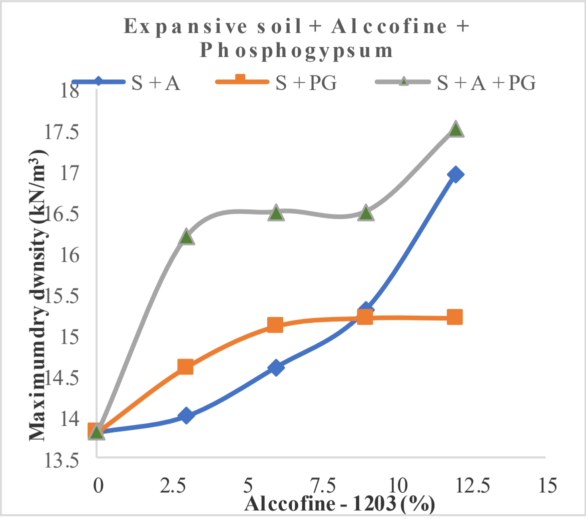
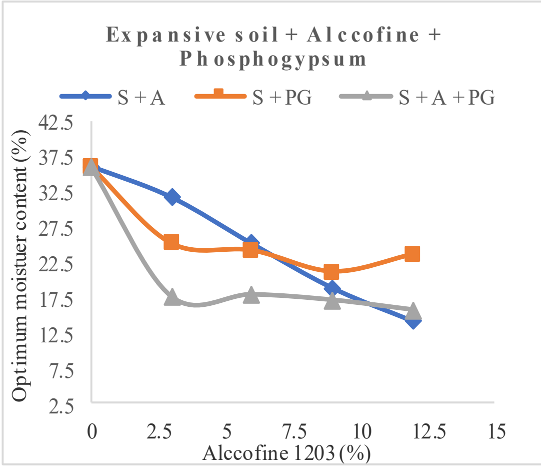
and 38.89% at 0.75% of Phosphogypsum. Hence, the result shows that both admixtures reduced the swell potential of soil from high swelling to low swelling and a similar result is obtained when the soil is blended with the combined action of 12% alccofine + 1% Phosphogypsum as per IS 1498-1970 (Sridharan & Nagarajan, 2009, [31]). **A similar** result is obtained by (Suresh & Murugaiyan, 2019, [33]) the swelling behavior is changed from high swelling to zero swelling at 6% alccofine and 1% $CaCl_2$ with intrinsic soil.




**(a) Maximum dry Density (MDD)**




**(a) Optimum Moisture Content**

**Fig. 2. Compaction Characteristics of Treated and Untreated Soil**

**C. Free swell ratio (FSR):** The free swell ratio method is very competitive, involving a straightforward procedure, for the prediction of the swell potential of a soil. It is defined as the ratio of the equilibrium sediment volume of 10 g oven-dried soil passing a 425 μm sieve in distilled water to that in kerosene.

$FSR = V_d/V_k$

The results show that the FSR value is reduced from 2.25 to 1.17, which means the swelling of soil is changed from high swelling to low swelling with the accumulation of 12% alccofine + 1% Phosphogypsum, respectively. And also, the dominating clay mineral is changed from montmorillonite to a mixture of kaolinite and montmorillonite (Prakash et al., 2009, [23]).

**D. Cation Exchange Capacity:** The exchangeable cations, such as Ca, Mg, Na, and K, were determined by displacing these from soil colloids with $NH_4$. This is done by Asian Enviro Labs Pvt. Ltd., Pallavaram, Chennai.

**Table 4: Effects on Index and Engineering Properties of Soil Blended with Admixtures**

| Admixtures (%) | $W_L$ (%) | $W_P$ (%) | $W_S$ (%) | PI (%) | SI (%) | $G_S$ | FSI (%) | FSR | UCS (kPa) | MDD (kN/m³) | OMC % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 103 | 37.78 | 1.82 | 65.22 | 35.96 | 2.27 | 125 | 2.25 | 46.4 | 13.8 | 36 |
| A 3 | 77.8 | 29.17 | 7.05 | 48.63 | 22.12 | 2.44 | 81.25 | 1.81 | 89.5 | 14 | 31.6 |
| A 6 | 68 | 28.78 | 5.4 | 39.22 | 23.38 | 2.46 | 25 | 1.25 | 118 | 14.6 | 25 |
| A 9 | 60.5 | 20.44 | 11.32 | 40.06 | 9.12 | 2.42 | 13.63 | 1.13 | 150 | 15.3 | 18.7 |
| A 12 | 42 | 31.18 | 17.95 | 10.82 | 13.23 | 2.64 | 4.5 | 1.05 | 172 | 16.95 | 14 |
| PG 0.25 | 68.2 | 26.41 | 5.85 | 41.79 | 20.56 | 2.45 | 70.59 | 1.71 | 94 | 14.6 | 25 |
| PG 0.50 | 60.5 | 32.18 | 0.97 | 28.32 | 31.21 | 2.53 | 66.67 | 1.67 | 110 | 15.1 | 24 |
| PG 0.75 | 42 | 22.82 | 8.77 | 19.18 | 14.05 | 2.95 | 38.89 | 1.39 | 128 | 15.2 | 21 |
| PG 1 | 66 | 29.09 | 5.93 | 36.91 | 23.16 | 2.88 | 44.4 | 1.44 | 83 | 15.2 | 23.5 |
| A 3 + PG 0.25 | 77.8 | 29.17 | 7.05 | 48.63 | 22.12 | 2.31 | 82.35 | 1.82 | 81 | 16.2 | 17.5 |
| A 6 + PG 0.50 | 68 | 35.09 | 14.14 | 32.91 | 20.95 | 2.79 | 66.67 | 1.67 | 120 | 16.5 | 17.8 |
| A 9 + PG 0.75 | 53.5 | 34.28 | 9.06 | 19.22 | 25.22 | 2.61 | 44.4 | 1.44 | 135 | 16.5 | 17 |
| A 12 + PG 1 | 48 | 26.14 | 9.16 | 21.86 | 16.98 | 2.68 | 16.67 | 1.17 | 155 | 17.5 | 15.6 |

**Note:** A = Alccofine; PG = Phosphogypsum; $W_L$ = Liquid limit; $W_P$ = Plastic limit; $W_S$ = Shrinkage limit; PI = Plasticity index; SI = Shrinkage index; $G_S$ = Specific gravity; FSI = Free swell index; FSR = Free swell ratio; UCS = Unconfined compressive strength; S = Swell potential; $W_A$ = Water absorption.

### 3.5 Unconfined Compressive Strength (UCS):

The prepared soil sample for the UCS test was conducted with alccofine and phosphogypsum added independently and blended into the expansive soil. It was performed on both natural soil and chemically treated soils.

The UCS value of natural soil is 46.4 kPa. The percentage of

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Alccofine-1203 (3, 6, 9, and 12%) and Phosphogypsum (0.25, 0.5, 0.75 and 1.0%). Were added by the dry weight of the soil. In addition, the effect of curing time on strength improvement was examined for a period of 0, 7, 14, 28, and 56 days. The optimum strength was noticed at 12% alccofine with 1% Phosphogypsum. The UCS strength is gradually increased from 46.4 kPa to 155 kPa, 229 kPa, 454 kPa, 706 kPa, and 948 kPa at 0, 7, 14, 28, and 56 days, with the accumulation of 12% alccofine and 1% Phosphogypsum. The result shows that the UCS strength increased from 46.4 kPa to 948 kPa after 56 days of curing. Therefore, based on the unconfined compressive strength behaviour with the addition of 12% alccofine and 1% Phosphogypsum binder, this is recommended as the optimum content for effectively stabilising this expansive soil.

**Table 5: Properties Obtained for Optimum Soil + Alccofine + Phosphogypsum**

| Properties | Natural soil | 87% S + 12% A + 1% PG |
|---|---|---|
| Specific gravity ($G_S$) | 2.27 | 2.68 |
| Atterberg Limits | | |
| Liquid Limit, ($W_L$) (%) | 103 | 48 |
| Plastic Limit, ($W_P$) (%) | 37.78 | 26.14 |
| Shrinkage Limit ($W_S$) (%) | 01.82 | 9.16 |
| Plasticity Index (PI) (%) | 65.22 | 21.86 |
| Shrinkage Index (SI) (%) | 35.96 | 16.98 |
| Free swell index (FSI) (%) | 125 | 16.67 |
| Free swell ratio (FSR) | 02.25 | 1.17 |
| Water absorption ($W_A$) (%) | 93.73 | 43.68 |
| Cation exchange capacity (CEC) meq/100g | 26.27 | 45.52 |
| Unified soil classification | CH | CI |
| Compaction characteristics | | |
| Optimum Moisture Content (OMC) (%) | 36 | 15.6 |
| Maximum Dry Density (MDD) (kN/m$^3$) | 13.8 | 17.5 |
| Unconfined compressive strength (UCS) (kPa) | 46.44 | 155 |

## IV. CONCLUSION

In this investigation, several laboratory tests were conducted to examine the impact of Alccofine-1203 and Phosphogypsum on the swelling characteristics and strength behaviour of the soil. The findings drawn from the data in this research are as follows:

1. The addition of alccofine-1203 and Phosphogypsum to the soil decreased the liquid limit and plasticity index while increasing the shrinkage limit. It is found that the addition of stabilizers causes flocculation of clay particles and increases the number of coarse particles which help in reducing the Atterberg limits.
2. The optimum moisture content (OMC) was found to decrease 36 36 36 36% to 15.6% while the maximum dry density (MDD) increases from 13.8 kN/m$^3$ to 17.5 kN/m$^3$ with a binding content.
3. Unconfined compressive strength (UCS) tests were conducted with alccofine-1203 and Phosphogypsum added independently and blended with the expansive soils. It was performed on both natural and chemically treated soil. The UCS value for natural soil is 46.4 kPa. The maximum UCS strength was an increase from 46.4 kPa to 948 kPa with 56 days of curing with soil + 12% alccofine + 1% Phosphogypsum.
4. The swell behaviour of soil; swell index is reduced from 125% to 16.67%, which means the swelling of soil is changed from high swelling to low swelling with the accumulation of 12% alccofine + 1% Phosphogypsum, respectively.

Based on the positive outcomes, it can be said that the expansive soil containing alccofine and Phosphogypsum is a proper cohesive non-swelling soil (CNS) for roads, sidewalks, and floorings. Hence the result concluded that the addition of 12% alccofine + 1% Phosphogypsum exhibited an essential stabilizer on a high swell, high shrink soil and poor bearing capacity soil thereby it was discovered that by addition of the admixture a problematic soil is converted to best soil.

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| Ethical Approval and Consent to Participate | We further confirm that any aspects of the work covered in this manuscript that have involved human patients have been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript. |
| Availability of Data and Material/ Data Access Statement | The data that support the findings of this study are available from the corresponding author upon reasonable request. |
| Authors Contributions | V. Jaladevi: Conceptualization, Methodology, Writing-original draft. V. Murugaiyan: Visualization, Supervision and editing. |

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