Effect of randomly inclusion of alccofine and Phosphogypsum on strength behavior of expansive soil

V. Jaladevi[1], B. Seralathan[2], V. Murugaiyan[2]
[1,2]Research Scholar, Department of Civil Engineering, Puducherry Technological University, Puducherry-605014.
[3]Professor, Department of Civil Engineering, Puducherry technological university, Puducherry-605014.

Abstract: Generally expansive soils are problematic to civil engineers by the increase and decrease its volume due to movement of water in and out, and the swell-shrink behavior of expansive soils causes extensive problems to the substructure and distress in the infrastructures 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=83.9%, SL=4.28%) collected from a location in Puducherry, India. An experimental program has evaluated the effects of Alccofine-1203 (3, 6, 9, and 12 %) and Phosphogypsum (PG) (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% Phosphogypsum (PG) increased the dry density and unconfined compressive strength of soil while decreasing the liquid limit, plasticity index, and swelling properties. However, further increasing the addition of alccofine and Phosphogypsum (PG) 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 Phosphogypsum (PG), which exhibited a significant stabilizer on a high swell, high shrink, and low bearing capacity soil thereby it was discovered that by addition of the admixture problematic soil converted to best soil and also reduce the construction cost by making best use of locally available materials.

Keywords: Expansive soil, Phosphogypsum (PG), Alccofine, Unconfined compressive strength, Shrinkage index.

I. Introduction

Generally, problematic soil is weak in strength and will undertake great volume change behavior due to moisture content changes from periodical fluctuations [5]. Soft soils or expansive soils exposure to large settlements when they are loaded, and certain naturally result in excessive settlement of the constructions built over them. In some frameworks, swell and shrinkage of expansive soil can cause remarkable damage to structures. Volumetric changes deteriorate the sub grade materials, in due course, leads to the expansion of cracks and permanent damage. The poor-quality soils typically consume the expected impact to produce unwanted engineering behaviour, such as low load bearing capacity, high shrink, swell potential, and high moisture susceptibility. This clay soil with low strength was found in various places of the world and in India, these soils are dominantly represented in six states namely, Gujarat, Madhya Pradesh, Maharashtra, Tamil Nadu, Andhra Pradesh, and Karnataka. It has been estimated as a probable natural hazard, if not treated adequately can cause catastrophic destruction to the structures and human life. Different solutions are utilised to improve the engineering features of expansive soils such as densification, chemical stabilisation, reinforcing, and pore water pressure reduction have been developed to mitigate the problem posed by the expansive soils [8]. Improvement on strength and stiffness properties of soils, and reduction of volume change behavior with addition of chemical [20] – [24] involvement, was carried out. Apart from these techniques, stabilization of expansive soil with various additives such as cement, fly ash, lime, ground granulated blast furnace slag, calcium and magnesium chloride, has also met with considerable success [3], [26], [28]. Still, many researchers have recognized that other stabilizing agents like gypsum are used in expansive soil. An extensive study examines the strength characteristics of Phosphogypsum and Bagasse Ash (BA) blended with marine clay is approved [17]. They also determined the plasticity index and strength parameters of soil shows the gradual development of strength occurs at 6% of Phosphogypsum and 20% of (BA) content of marine clay showing about 33.7% for UCS and 80.5% for soaked CBR. [15], [16] the inclusion of 2% Phosphogypsum to 5.5% lime led to the increased early strength of stabilized soil. [18] also showed the engineering property of bentonite stabilized with Lime and Phosphogypsum mixed from 0 to 10% of additive content. They concluded the optimum value obtained at 8% of both additions proves the strength and engineering properties such as Atterberg limits, CEC (Cation exchange capacity), free swell, and UCS test on natural and treated soil specimens experienced in compaction effort [31] to determine OMC and cured for seven days. The result found that the soil has efficiently stabilized with gypsum and had a lesser cost than lime and observed the increased UCS value of bentonite with gypsum percentages equal to or less than 5% for optimum results [32], [34]. The objective of this research is to determine how Phosphogypsum and alccofine addition affect expansive soil stability. The majority of this material is utilized in the high performance of concrete structures either as a cement replacement or as an additive to improve concrete properties in both fresh and hardened states and soil stabilization purpose, while it is mostly used to reduce swelling and raise the shear strength of expansive soil for stabilisation since it absorbs water from the atmosphere and prevents shrinkage cracks occurring in expansive soils during summer [19]. The combination of the two materials can be more beneficial when used as a stabilizing agent then using them individual. However, no research on the combined activation of Phosphogypsum and alccofine as stabilising agents for expansive soils has yet been reported. This study's primary goals were to stabilise expansive soil by improving its geotechnical qualities with the stabilisers alccofine and Phosphogypsum, to boost expansive soil strength properties, and to decrease building costs by making the greatest use of locally available resources.

II. Materials and methods

2.1 Expansive soil

The high swell, high shrink, and low carrying capacity soil employed for this experiment were taken from Location 1, which has located in the Puducherry region, India. The soil accumulated to a depth of 1.5m 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 preserved in the test centre. The soil is categorised as 'CH' as per IS Classification (IS 1498: 1970) that it consists inorganic clay with High Plasticity [10]. The following Table 1 provides the index and engineering characteristics of expansive 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 applied and it was obtained from County Micro-Fine Product Private Limited, Goa, India. The bulk of Ultra-fine slag products is employed for high-performance soil stabilising causes. The chemical components and physical features of micro-fine slag are reported in Table 2.

Table 1. Physical properties of soil

Properties of soil	Results
Specific gravity, (G_S)	2.38
Color of soil	Grey to black
Grain size distribution	
Clay (%)	69
Silt (%)	24
Sand (%)	07
Atterberg Limits	
Liquid Limit, (W_L) (%)	83.90
Plastic Limit, (W_P) (%)	33.47
Shrinkage Limit (W_S) (%)	04.28
Plasticity Index, (PI) (%)	50.43
Free swell index (FSI) (%)	66.67
Free swell ratio (FSR)	01.67
Unified soil classification	CH
Compaction characteristics	
Optimum Moisture Content (OMC) (%)	21
Maximum Dry Density (MDD) (kN/m^3)	14.2
Unconfined compressive strength (UCS) (kPa)	52.6

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 (%)

2.3 Phosphogypsum (PG)

Phosphogypsum (PG) is the calcium sulphate hydrate formed as a by-product of the production of fertilizer 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 tonnes of PG are generated per tonne of phosphoric acid production. The continuous growth in the world population increases food production demand which requires an increase in phosphate fertilizer production resulting in an increase in PG content [1]. Only 15% of world 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 [7], [28]. Approximately 85% of this by-product is still discarded into the ocean or river, or stored in ponds or leaps without purification. This disposal causes serious contamination. Reduction in the disposal of this by-product has economic and environmental benefits. It is also recycled as agricultural fertilizers or soil stabilization amendments and as set controller in the manufacture of Portland cement [9]. Table 3 shows the oxides 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

2.4 Testing methodology:

The index and engineering characteristics of stabilized soils can be evaluated using a variety of tests. The current study is focused on analysing the physical properties, compaction, strength, and swell/shrink behavior. 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 expansive 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 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 [30]. Water absorption equation is $W_A = 0.91\ W_L$, where, W_L is 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 [19].

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.

3.1 Atterberg limits (LL, PL, PI):

Fig. 1 illustrates how alccofine and Phosphogypsum affect the Atterberg limits of expansive soil. Results indicate that shrinkage limit increases while liquid limit and plastic limit continuously decrease. As a result, the plasticity index represents the difference between the two limits. Plasticity index is reduced by about 67% and Shrinkage index is increased by about 71% when the soil is blended with 9% alccofine + 0.75% Phosphogypsum due to the pozzolanic reaction and the capacity of cation exchange of the blend when compared to the soil is blended 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 low swell potential due to the accumulation of 9% alccofine + 0.75% Phosphogypsum (PG) binder. Alccofine and calcium chloride were utilised as stabilising agents of expansive soil, and similar behaviour of the plasticity index was observed [32]. [14] It was proposed that plasticity is an excellent predictor of swell potential, i.e., that a lower plasticity index represents a lower swell potential. The charge concentration is raised in soil by the addition of calcium chloride [35].

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/m^3 to 17 .6 kN/m^3 and optimum moisture content is reducing from 36% to 11.8% with an increase of 9% alccofine and 0.75% Phosphogypsum binder; that is, for the sample which shows maximum strength. Likewise, an industrial waste or ground-granulated blast furnace slag (GGBS) were utilised as stabilising agents and similar behaviour of MDD and OMC was observed [2]. In order to improve soil quality, it is preferable for construction materials to have a higher dry density for a given compaction impact. Increasing the alccofine was reported to increase MDD and decrease OMC [25], [29].

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)	S (%)	W_A (%)
0	83.9	33.47	04.28	50.43	29.19	2.38	66.67	1.67	52.6	30.83	76.35
S + A 3	66	43.90	08.77	22.1	35.13	2.47	66.67	1.66	78	4.12	60.06
S + A 6	47	31.72	16.82	15.28	14.9	2.59	29.41	1.29	143	1.67	42.77
S + A 9	51	24.45	09.53	26.55	14.92	2.53	36.84	1.36	113	6.44	46.41
S + A 12	63	26.79	06.64	36.21	20.15	2.49	61.11	1.61	88	13.74	57.33
S + PG 0.25	79.4	38.42	5.64	40.98	32.78	2.42	70.59	1.71	74	18.58	72.25
S + PG 0.50	61.2	32.18	6.42	29.02	25.76	2.53	66.67	1.67	98	8.01	55.69
S + PG 0.75	54	28.89	8.77	25.11	20.12	2.57	38.89	1.39	126	5.62	49.14
S + PG 1	51	21.62	11.82	29.38	9.8	2.59	44.4	1.44	139	8.25	46.41
S + A 3 + PG 0.25	62	25.60	11.47	36.4	14.13	2.44	66.67	1.67	81	13.92	56.42
S + A 6 + PG 0.50	49.5	31.67	18.63	17.83	13.04	2.79	16.67	1.17	155	2.4	45.05
S + A 9 + PG 0.75	46	29.39	20.84	16.61	8.55	2.87	4.5	1.05	179	2.05	41.86
S + A 12 + PG 1	53	28.57	15.53	24.43	13.04	2.68	44.4	1.44	123	5.26	48.23

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.

3.2 Free swell index (FSI):

A swelling behavior of soil is blended with different percentages of alccofine and Phosphogypsum is presented in Table 4. The presence of montmorillonite minerals greatly influences [27] the swelling properties of soil. By adding these chemicals individually to the soil proves that the FSI is gradually dropped from 66.67% to 29.41% at 6% of alccofine and 38.89% at 0.75% of Phosphogypsum. Hence, the result shows that both admixtures were reduced the swell potential of soil from high swelling to low swelling and, also similar result is obtained when the soil is blended with 9% alccofine + 0.75% Phosphogypsum as per IS 1498-1970 [30]. Similar result is obtained by [32] the swelling behavior is changed from high swelling to zero swelling at 6% alccofine and 1% $CaCl_2$ with intrinsic soil.

3.3 Free swell ratio (FSR):

The free swell ratio method is very competitive, involving 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.

$$FSR = V_d/V_k$$

The results show that the FSR value is reduced from 1.67 to 1.05 which means the swelling of soil is changed from high swelling to low swelling with the accumulation of 9% alccofine + 0.75% Phosphogypsum respectively. And also, the dominating clay mineral is changed from montmorillonite to mixture of kaolinite and montmorillonite [23]. [4] proposed a system, this fully automatic vehicle is equipped by micro controller, motor driving mechanism and battery. The power stored in the battery is used to drive the DC motor that causes the movement to AGV. The speed of rotation of DC motor i.e., velocity of AGV is controlled by the microprocessor controller.This is an era of automation where it is broadly defined as replacement of manual effort by mechanical power in all degrees of automation. The operation remains an essential part of the system although with changing demands on physical input as the degree of mechanization is increased. [6] proposed a principle in which another NN yield input control law was created for an under incited quad rotor UAV which uses the regular limitations of the under incited framework to create virtual control contributions to ensure the UAV tracks a craved direction. Utilizing the versatile back venturing method, every one of the six DOF are effectively followed utilizing just four control inputs while within the sight of undemonstrated flow and limited unsettling influences. Elements and speed vectors were thought to be inaccessible, along these lines a NN eyewitness was intended to recoup the limitless states. At that point, a novel NN virtual control structure which permitted the craved translational speeds to be controlled utilizing the pitch and the move of the UAV. At long last, a NN was used in the figuring of the real control inputs for the UAV dynamic framework. Utilizing Lyapunov systems, it was demonstrated that the estimation blunders of each NN, the spectator, Virtual controller, and the position, introduction, and speed following mistakes were all SGUUB while unwinding the partition Principle.

3.4 Cation Exchange Capacity:

The exchangeable cations such as Ca, Mg, Na, and K determined displacing these from soil colloids with NH_4. This is done by Asian Enviro Labs Pvt. Ltd. Pallavaram, Chennai.

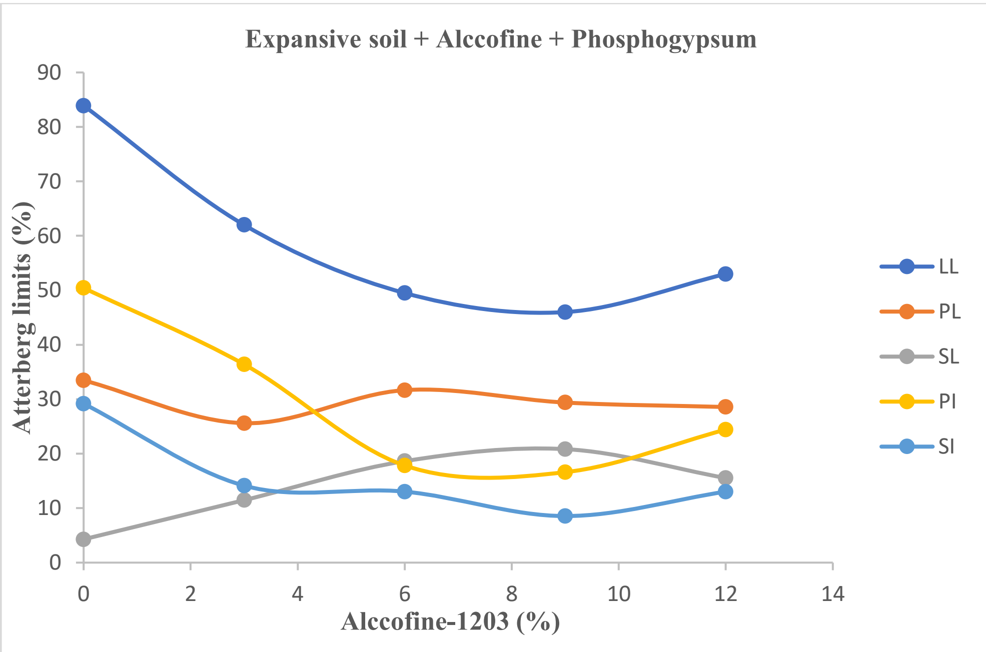
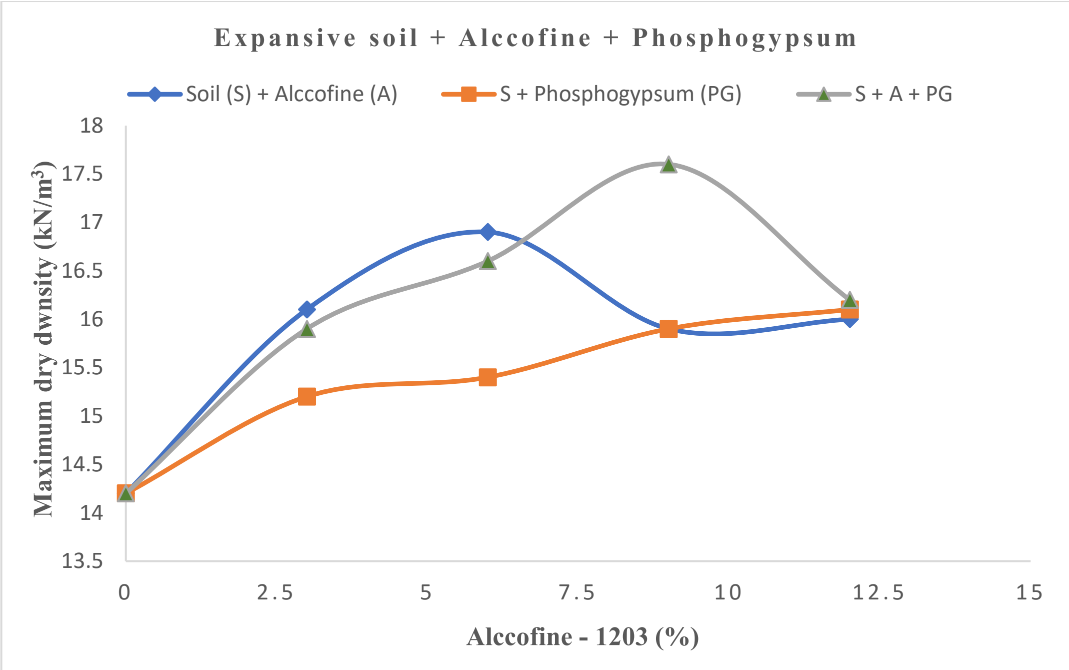
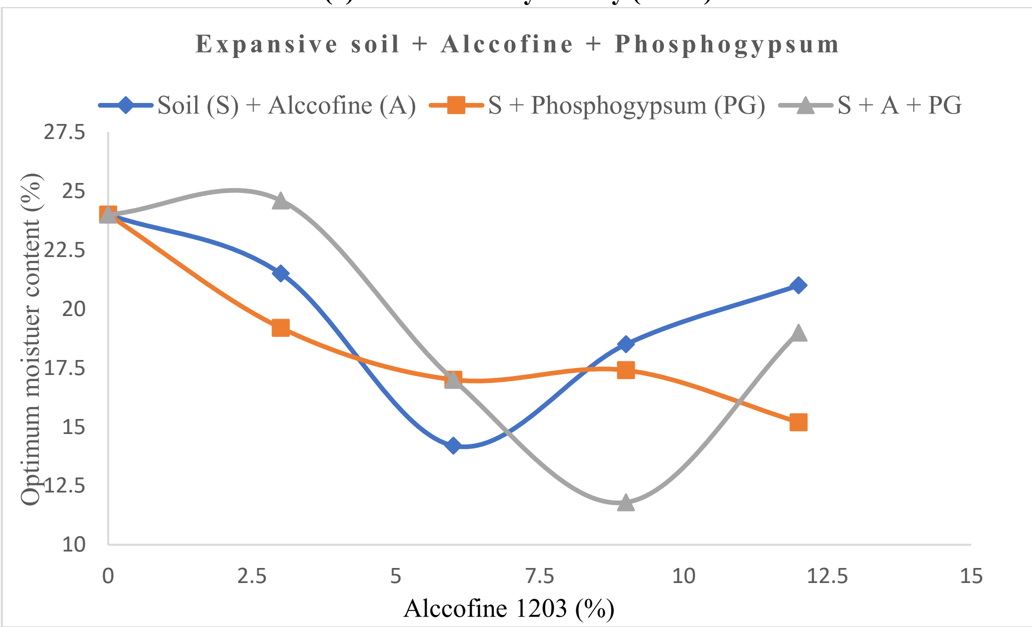


Fig. 1. Effect of alccofine and Phosphogypsum on Atterberg limits



(a) Maximum dry density (MDD)



(b) Optimum moisture content

Fig. 2. Compaction characteristics of treated and untreated soil

3.5 Unconfined compressive strength (UCS):

The prepared soil sample of UCS test were conducted with alccofine and Phosphogypsum were added independently and blended to the expansive soil. it was performed on both natural soil and chemically treated soils. The UCS value of natural soil is 52.6 kPa. The percentage of Alccofine-1203 (3, 6, 9, and 12%) and Phosphogypsum (0.25, 0.5, 0.75 and 1.0%) were added by dry weight of the soil. In addition, the effect of curing time on strength improvement was examined as per [11] for a period of 0, 7, 14, 28, and 56 days. The UCS values are shown in Fig. 3. The optimum strength was noticed at 9% alccofine with 0.75% Phosphogypsum. Beyond 9% of alccofine with 0.75% Phosphogypsum resulted in a slight decreased in UCS values. Fig 3 shows the UCS strength is gradually increased from 52.6 kPa to 179 kPa, 229 kPa, 354 kPa, 476 kPa and 592 kPa at 0, 7, 14, 28, and 56days with the accumulation of 9% alccofine with 0.75% Phosphogypsum. And the result proves that the UCS strength was increased from 52.6 kPa to 592 kPa with 56 days of curing. In contrast to past studies, the strength was decreased when more binder was added than 7%

alccofine. Once the stabiliser content exceeds a particular limit, there is a significant decrease in the compressive strength of soil [25]. As a result, adding 9% alccofine and 0.75 percent Phosphogypsum binder is suggested as the ideal content to effectively stabilise this expansive soil based on the behaviour of unconfined compressive strength. Similar findings were made by [33], demonstrated that the best strength was obtained using natural soil and an alccofine concentration of 8% and 1% CaCl2. Related research has been done [35]. Utilization of calcium chloride and rice husk ash (RHA) with a ratio of 8% RHA to 1% CaCl2 in soil made of black cotton.

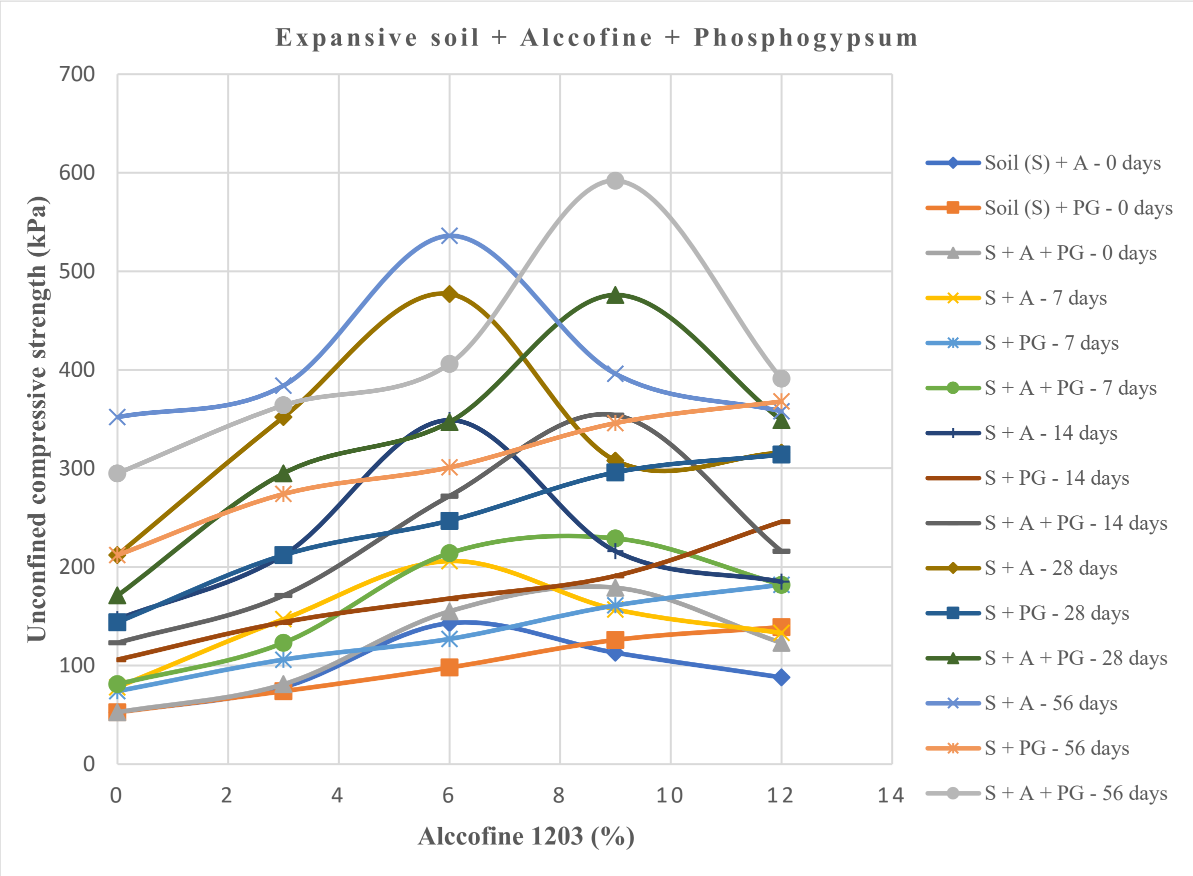


Fig. 3. Variation of UCS of soil with Alccofine – 1203 and Phosphogypsum

Table 5: Properties Obtained for Optimum Soil + Alccofine (A) + Phosphogypsum (PG)

Properties	Natural soil	Soil + 6% A	Soil + 1.0% PG	90.25% soil + 9% A + 0.75% PG
Specific gravity, (G_S)	2.38	2.59	2.59	2.87
Atterberg Limits				
Liquid Limit, (W_L) (%)	83.9	47	51	46
Plastic Limit, (W_P) (%)	33.47	31.72	21.62	29.39
Shrinkage Limit (W_S) (%)	04.28	16.82	11.82	20.84
Plasticity Index, (PI) (%)	50.43	15.28	29.38	16.61
Shrinkage Index (SI) (%)	29.19	14.9	9.8	8.55
Free swell index (FSI) (%)	66.67	29.41	44.4	4.5
Free swell ratio (FSR)	01.67	1.29	1.44	1.05
Water absorption (W_A) (%)	76.35	42.77	46.41	41.86
Swell potential (S) (%)	30.83	1.67	8.25	2.05
Unified soil classification	CH	CI	CI	CI
Compaction characteristics				
Optimum Moisture Content (OMC) (%)	24	14.2	15.2	11.8
Maximum Dry Density (MDD) (kN/m^3)	14.2	16.9	16.1	17.6
Unconfined compressive strength (UCS) (kPa)	52.6	143	139	179

IV. Conclusion

In this study, a number of tests were carried out based on the laboratory investigation to investigate the impact of Alccofine – 1203 and Phosphogypsum on the swelling characteristics and strength behavior of soils and the optimum values of tested soil samples are shown in Table 5. The findings drawn from the data in this research are as follows:

1. The liquid limit value is decreased from 83.9% to 47% at 6% alccofine and 83.9% to 51% at 1.0% Phosphogypsum and the plasticity index is reduced from 50.43% to 15.28% and 50.43% to 29.38% when the soil is blended individually with 6% alccofine and 1% Phosphogypsum. While raising the shrinkage limit and lowering the liquid limit, proves the combined action of 9% alccofine + 0.75% Phosphogypsum were added to the soil, as per IS classification, the soil is barely positioned under the CI classification from CH as per IS 2720-1985 [12].
2. The maximum dry density (MDD) increased from 14.2 kN/m^3 to 17.6 kN/m^3 with increasing chemical concentration 9% alccofine + 0.75% Phosphogypsum, whereas the optimum moisture content (OMC) decreased greatly from 24% to 11.8% as per IS 2720-1980 [13].
3. Alccofine and Phosphogypsum were separately added to the soil samples and blended before being used in the unconfined compressive strength (UCS) testing. Natural soil has a UCS value of 52.6 kPa. Soil with 9% alccofine + 0.75% Phosphogypsum, the maximum improvement was observed.
4. Hence the strength is gradually increased from 52.6 kPa to 179 kPa, 229 kPa, 354 kPa, 476 kPa and 592 kPa at 0, 7, 14, 28, and 56days with the combined effect of 9% alccofine + 0.75% Phosphogypsum reacted with soil is played a vital role when compared to the other combination of admixtures. Beyond 9% alccofine + 0.75% Phosphogypsum resulted in a slight decreased in UCS values.
5. The swell behavior of soil; swell index is reduced from 66.67% to 4.5% and which means the swelling of soil is changed from high swelling to low swelling with the accumulation of 9% alccofine + 0.75% Phosphogypsum respectively.

Based on the positive outcomes, it can be said that the expansive soil containing alccofine + Phosphogypsum is a useful cohesive non-swelling soil (CNS) for roads, sidewalks, and floorings. Hence the result concluded that the addition of 9% alccofine + 0.75% 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 problematic soil converted to best soil also reduce the construction cost by making best use of locally available materials.

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