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ROLE OF PHOSPHOGYPSUM AND CERAMIC DUST IN AMENDING THE EARLY STRENGTH DEVELOPMENT OF A LIME STABILIZED EXPANSIVE SOIL

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Abstract

This investigation delves into the potential of two solid wastes viz. Phosphogypsum (PG) and Ceramic Dust (CD) in enhancing the development of the early strength of an expansive soil. The minimum lime content required for modification of the soil called as Lime Modification Optimum (LMO) was determined using pH test. The expansive soil was then stabilized using one lime content chosen below LMO and another lime content chosen above LMO. These two lime contents were amended with varying doses of the two solid wastes. The unconfined compressive strength of the stabilized soil combinations with and without additives was determined after curing for three different periods of 2 hours, 3 days and 7 days. The results of the strength tests were analyzed and compared for the two solid wastes adopted as additives. The results showed that PG enabled a quicker development of strength of the lime stabilized soil whereas CD did not have much of an influence on the early strength of the stabilized soil.

Keywords: *Expansive soil, lime stabilization, phosphogypsum, ceramic dust, early strength, unconfined compression.*

1.0 Introduction

Poor and problematic soils are found all over the world posing different levels of challenge to a geotechnical engineer. One such problematic soil type is expansive soil. Expansive soils are soils that have the tendency to undergo volume change behavior with variation in moisture content [1]. The tendency for such soils to swell and shrink is due to the predominance of montmorillonite group of minerals in the soil mineralogy. Such soils need to be stabilized to ensure a favorable engineering performance. Soil stabilization is a widely-adopted group of methodologies or techniques for favorably modifying the physico-mechanical properties of any soil, making them suitable for engineering applications. The technique has been widely adopted for improving the performance of poor soils. Expansive soils result in severe damage to constructed facilities in or on them, posing a major challenge to Civil Engineers dealing with such soils [2]. Several reports from countries like Australia, China, India, Israel, South Africa, the United Kingdom and the United States of America document the damages caused by expansive soils to lightly loaded structures [3]. Lime and cement stabilization have been effectively used for improving the properties of problematic soils. However, among the various chemical stabilization techniques adopted for expansive soils, lime stabilization is most widely adopted for controlling the swell shrink properties of expansive soils [4]. Lime stabilization has been extensively practiced as a standalone stabilizer or with additives called as pozzolans. A pozzolan is defined as a finely divided siliceous or aluminous material which in the presence of water and calcium in the form of oxide or hydroxide will form a cemented product [5]. Recently, generation of industrial solid wastes from various streams of manufacturing and production in immense quantities has resulted in the reuse of solid wastes in soil stabilization as standalone stabilizers [6] or additives to lime and cement as pozzolans for improved performance [7]. A lot of solid wastes have been studied along with lime and cement as additives including fly ash, rice husk ash, ceramic wastes, phosphogypsum, red mud, steel slag, blast furnace slag, copper slag, paper sludge, lime sludge, carbide residue, bagasse ash, bottom ash, incineration. A lot of these researches have concentrated on the various index and engineering properties of the soil like Atterberg limits, compressive strength, compaction characteristics, swell characteristics, compressibility, permeability, California Bearing Ratio (CBR) to name a few. The researchers who have worked on the strength of stabilized soils have concentrated on the development of strength with curing period with periods of curing reaching 360 days and beyond. But the work on the development of early strength of the stabilized soil has been sparse [8], [9] and needs to be focused upon especially when stabilization works are adopted for road projects where long periods of curing will delay opening up of roads for traffic. Hence, in this work, an attempt has been made to compare the early strength performance of lime stabilized expansive soil admixed with two industrial solid waste materials viz. Phosphogypsum (PG) and Ceramic Dust (CD).

2.0 Materials

The materials adopted in this study include the natural soil whose properties need to be improved, lime adopted for stabilization and PG and CD, the solid wastes used as additives to lime in stabilizing the soil.

2.1 Natural Soil

The natural soil used in the study was collected from a village in Ponneri Taluk, Thiruvallur district of Tamil Nadu, India. The soil was extracted using an excavator from shallow depth of around 1m below the ground. The soil was tested for its properties in the laboratory in accordance with Bureau of Indian Standards (BIS) and was found to be clay of high plasticity (CH) [10]. The properties of the soil have been tabulated in Table 1. The chemical composition of the soil adopted in the study is given in Table 2.

Table 1: Properties of Soil

Property	Value
Liquid Limit [11]	68%
Plastic Limit [11]	27%
Plasticity Index	41%
Shrinkage Limit [12]	10%
Specific Gravity [13]	2.76
%Gravel [14]	0
%Sand [14]	2.5
%Silt [14]	60.5
%Clay [14]	37
Maximum Dry Density [15]	15.3 kN/m3
Optimum Moisture Content [15]	25%
UCC Strength [16]	115.8 kPa
pH [17]	6.53

2.2 Lime

The lime adopted for the stabilization was laboratory grade hydrated lime of 95% purity manufactured by Nice Chemical India Pvt. Ltd., Cochin, India. Quicklime and hydrated lime are widely used forms of lime in stabilization of soils [1]. Carbonate lime, another form of lime is rarely used as it is stable and remains inert in the presence of water. However, there have been attempts to use carbonate lime from natural sources in soil stabilization [18], [19]. The chemical composition of lime adopted in the study is given in Table 2.

2.3 Phosphogypsum

Phosphogypsum (PG) is the industrial by-product of phosphoric acid production, needed for manufacture of fertilizer, from phosphate ore [20], [21]. The worldwide production of PG is estimated to be in the order of 100-280 million tonnes per year [22], [23]. The production of this waste material in India is 11 million tonnes per annum [24]. Set controller in the manufacture of Portland cement, raw material for clinker, secondary binder with lime and cement, production of artificial aggregates and in road stabilization are some the applications of PG [21] in the field of construction and materials. However, recently, the effectiveness of PG in soil stabilization has been recognized as well with lot of work involving PG in soil modification [20], [21], [25]–[29] The PG adopted in the study was sourced from the fertilizer plant of Coromandel International Limited, Ennore, Chennai. The PG was sieved through 75-micron BIS sieve and the particle size distribution was studied using hydrometer analysis in accordance with BIS [14]. It was found that the PG adopted in the study had 88% silt and 12% clay size fractions. The specific gravity of PG done in accordance with BIS [13] was found to be 2.48 and the pH determined in accordance with BIS [17] was found to be 3.08. The chemical composition of PG determined by x-ray fluorescence (XRF) technique is given in Table 2.

2.4 Ceramic Dust

Ceramic Dust (CD) is a construction and demolition waste particularly classified as a demolition waste by Centre for Science and Environment [30]. The amount of construction and demolition waste generated in India is estimated to be 530 million tonnes in 2013 [30]. Ceramic materials represent around 45 % of construction and demolition waste, and originate not only from the building process, but also as rejected bricks and tiles from industry [31]. The global production of ceramic tiles is around 8500 million square meters [32]. The annual ceramics production in India is around 100 million tons worth ₹ 18,000 crores with an approximate production of 600 million square metres [33], [34]. Ceramic wastes are known pozzolans. White paste ceramics and red paste ceramics are two major categories of ceramic wastes [35]. The CD used in the study is not a readily available form of the waste. White paste ceramic tiles were collected from a demolition site and carefully segregated to choose the tiles alone and pulverized using abrasion testing machine and sieved through 75-micron BIS sieve for use in stabilization. Grain size distribution was performed on the fine fractions and was found to have 97% silt and 3% clay size fractions. The specific gravity of CD was found to be 2.55 which was lower than the value reported by Sabat [36] but higher than the value reported by Veera Reddy [37]. The chemical composition of CD obtained from XRF is tabulated in Table 2. Scanning Electron Microscopy was used to study the structure of particles of the materials adopted. Figure 1 shows the Scanning electron micrographs of all materials adopted in the study. Figure 2 shows the X-ray diffractograms of the materials adopted in the study.

Table 2: Chemical Composition of Materials

(%) of	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	SO_3
Soil	18.82	2.297	7.484	2.288	1.737	0.035	1.415	0.043	63.62	0.876	0.207
Lime	0.053	72.77	0.037	0.003	14.60	0.004	0.047	0.005	0.245	0.003	0.048
PG	0.649	35.73	4.88	0.042	0.661	0.001	0.106	10.70	16.96	0.015	4.598
CD	25.24	1.879	6.527	3.888	1.114	0.021	1.808	0.111	57.14	0.679	0.006

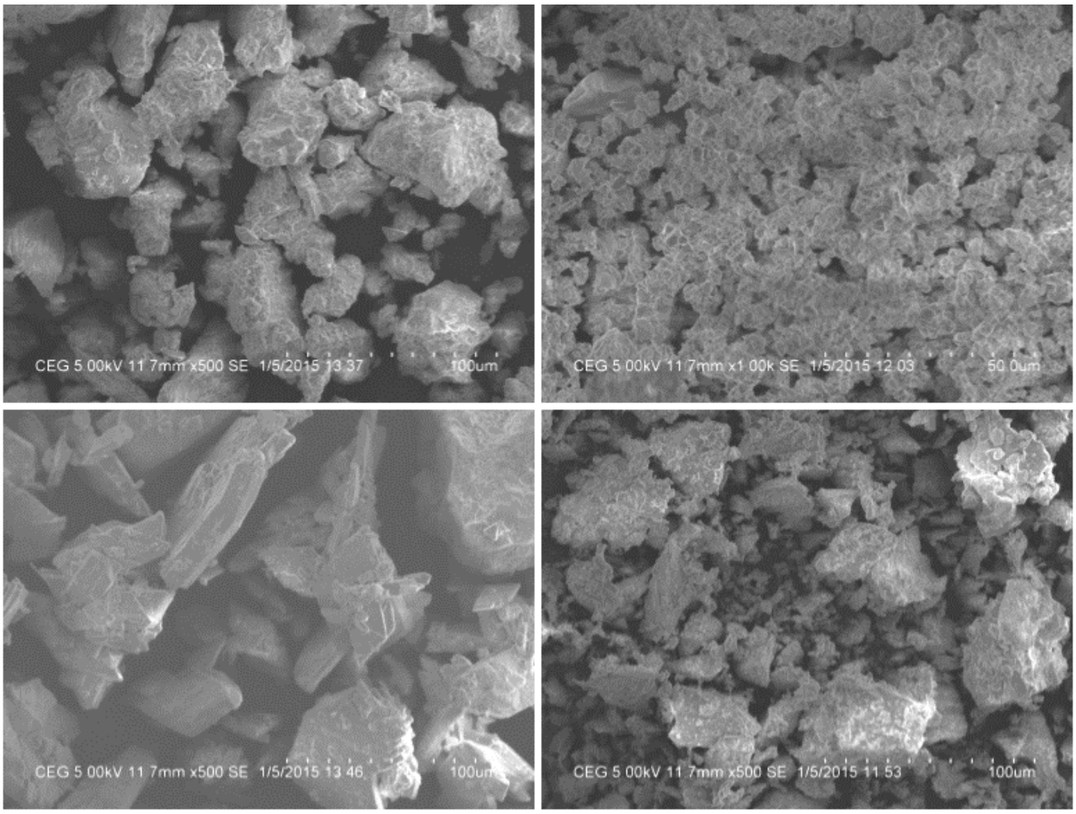

Figure 1: Scanning Electron micrographs of (Clockwise) Soil, Lime, CD and PG

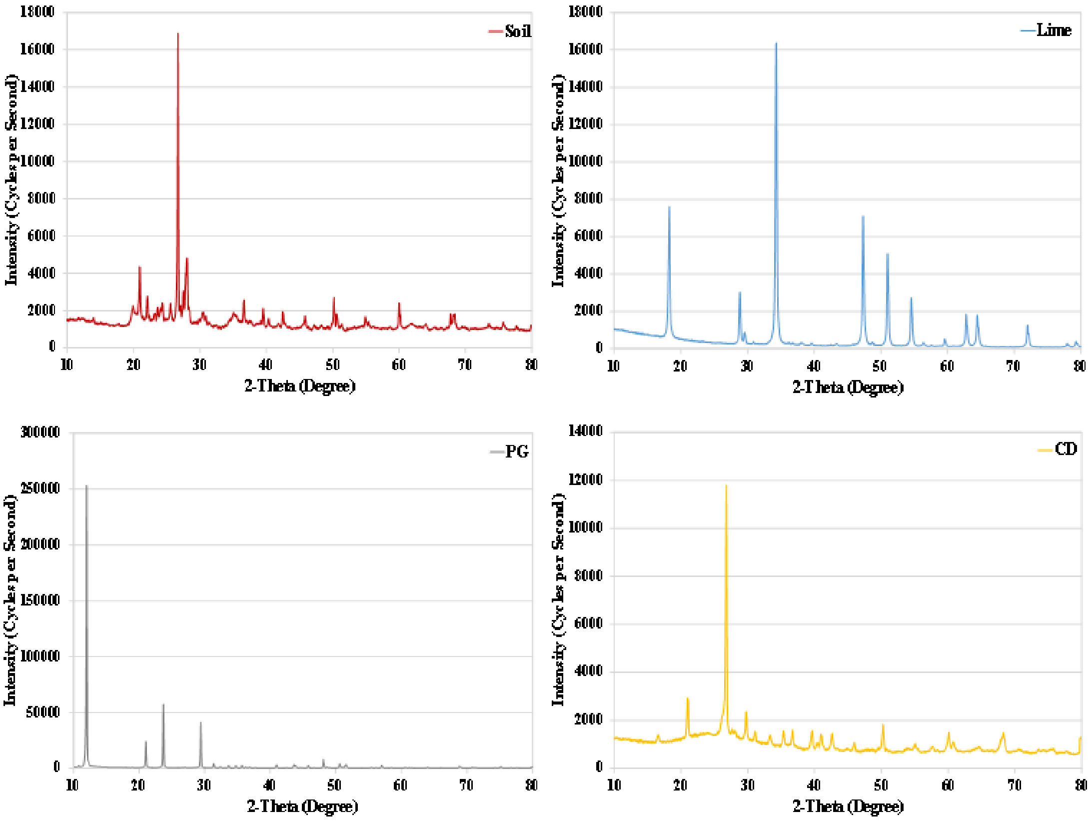

Figure 2: X-ray Diffractograms of (Clockwise) Soil, Lime, CD and PG

The analysis of the x-ray diffractograms of the various materials was carried out to determine the mineralogy of the materials. The virgin expansive soil revealed the presence of montmorillonite and quartz. Calcium hydroxide was detected in the scatter pattern of lime. PG revealed the presence of gypsum whereas CD revealed the presence of quartz and calcite.

3.0 Methodology

The soil collected from the site was cleaned, crushed and pulverized in order to prepare it for various tests in accordance with BIS [38]. The various materials adopted in the investigation were subjected to chemical, mineral and microstructural characterization. The soil sample was also characterized for its geotechnical properties in the laboratory. It is well documented in literature that the minimum amount of lime required for modification of soil properties is called as the Initial Consumption of Lime or Lime Modification Optimum (LMO). The LMO was determined using Eades and Grim pH test [39] in accordance with ASTM [40]. After the determination of LMO, two lime contents one below LMO and the other above LMO was chosen for the study as according to Nazrizar et al. [41] LMO and Lime Stabilization Optimum (LSO), also called as Optimum Lime Content, divide the relationship between strength and lime content of a stabilized soil into three phases. The lime content below LMO was randomly selected. The LSO was determined by performing unconfined compression strength (UCS) test on stabilized soil specimens at varying lime contents for determining the lime content which produced the maximum strength of the stabilized soil in accordance with the procedure adopted by earlier researchers [28], [42]–[44]. The UCS was determined in a split mould of dimensions 38mm diameter and 76mm height and cured for period of 2 days. After fixing the two lime contents for stabilization, the soil sample was stabilized with the lime contents amended with four randomly fixed additive contents of 0.25%, 0.5%, 1% and 2% and UCS samples were prepared at a density of 14.72 kN/m^3 and 25% moisture content. The prepared samples were cured for periods of 2 hours, 3 and 7 days in sealed polythene covers for studying the development of early strength. The results of the UCS tests of lime stabilized soil admixed with PG and CD were compared to determine the performance of the additives. Table 3 shows the stabilizer-additive combinations adopted in the study.

Table 3: Stabilizer-Additive Combinations

Designation	Lime (%)	PG (%)	Designation	Lime (%)	CD (%)
3L	3	0	3L0.25CD	3	0.25
3L0.25PG	3	0.25	3L0.5CD	3	0.5
3L0.5PG	3	0.5	3L1CD	3	1
3L1PG	3	1	3L2CD	3	2
3L2PG	3	2	7L0.25CD	7	0.25
7L0.25PG	7	0.25	7L0.5CD	7	0.5
7L0.5PG	7	0.5	7L1CD	7	1
7L1PG	7	1	7L2CD	7	2
7L2PG	7	2	7L	7	0

4.0 Results and Discussions

The Eades and Grim pH tests revealed that the LMO of the soil used in the study was 5.5%. The LSO determined from UCS tests was 7%. Three percent lime content was randomly selected as the lime content below LMO for the study. Three percent lime and seven percent lime stabilized soil were admixed with small quantities of PG and CD for stabilizing the soil. The results of the UCS tests are discussed in the subsequent sections.

4.1 Effect of PG on the Early Strength of Lime Stabilized Soil

The effect of PG on the development of early strength of lime stabilized soil is shown in Figure 3. It can be seen that the addition of PG to lime stabilized soil increases the strength of the soil. For 3% lime stabilized soil, 0.25% PG was found to produce enhanced strength of the stabilized soil. However, at a higher lime content of 7%, a higher PG content of 1% was found to develop enhanced strength of the stabilized soil. Comparing the periods of strength development, at lower lime content of 3%, a significant gain in strength was visible only at seven days of curing whereas at 7% lime content, a clear demarcation can be seen at two hours of curing and a significant change at 3 days of curing.

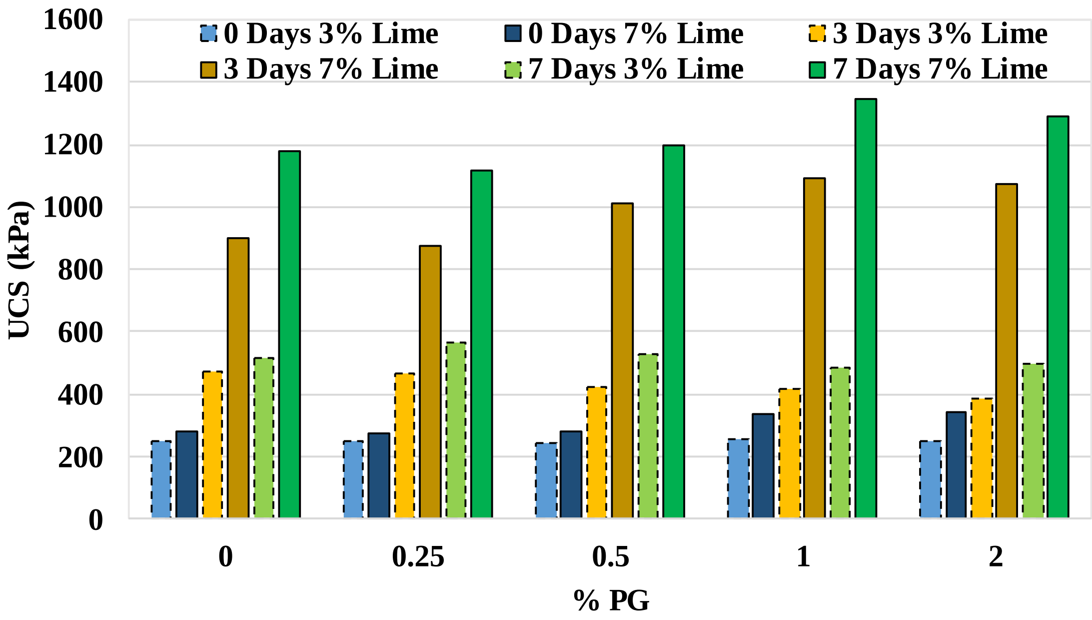

Figure 3: Strength of Lime Stabilized Soil with PG

In order to better understand the development of strength of the stabilized soil, the effect of curing period was analyzed in detail. Figure 4 shows the development of strength of PG-lime stabilized soil with curing period. From the figure, it can be seen that the development of strength is better in 7% lime stabilization when compared to 3% lime because it is less than the minimum required lime of 5.5% for soil modification as determined from the Eades and Grim pH test. On observing the strength curves of 3% lime stabilization in Figure 4, it can be seen that the curve corresponding to 3% lime with 0.25% PG lies on top of all the curves with the exception of 3% lime at 3 days of curing. A detailed analysis of percentage strength gain of all combinations for 3% lime stabilized soil indicated that only 0.25% and 0.5% PG addition resulted in a positive gain at the end of 7 days. 0.25% PG gained 9% additional strength whereas 0.5% could manage only 2%. All higher PG dosages resulted in strength loss. For 7% lime stabilization, with the exception of 0.25%, all other PG doses resulted in positive strength gain. 1% PG addition resulted in the highest gain of 14%. It was 1.6% and 9% gain respectively for 0.5% and 2% PG addition. The early strength gain in PG admixed lime stabilized soil in this work is similar to the results obtained by earlier works done by Ghosh [45] who investigated PG admixed lime stabilization of pond ash and Krishnan et al. [46] who studied PG admixed fly ash stabilization of an expansive soil.

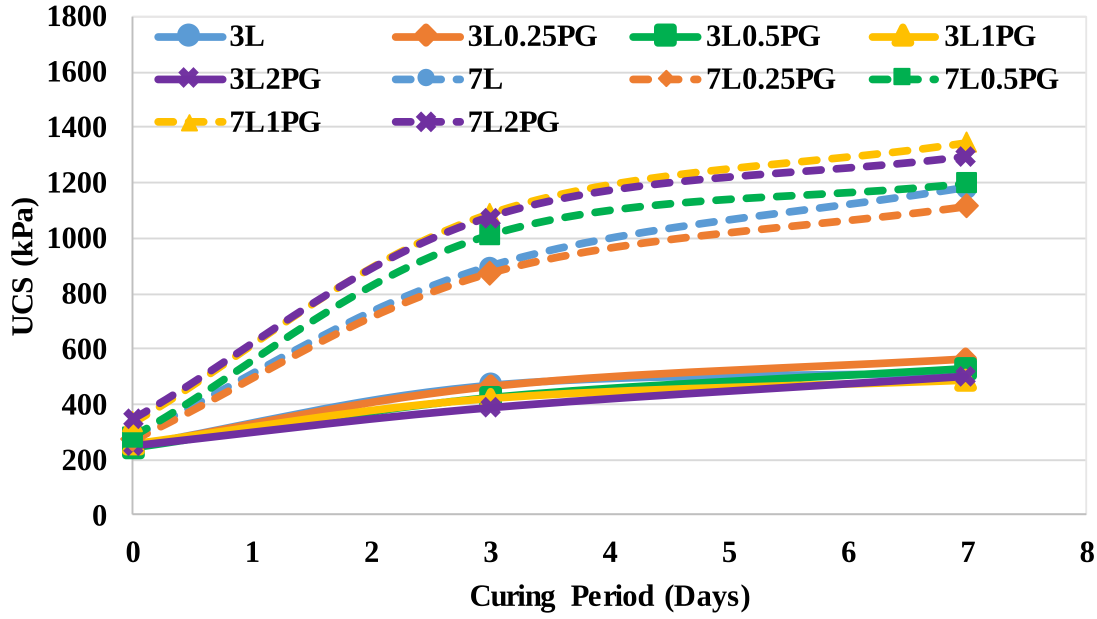

Figure 4: Strength Development of Lime Stabilized Soil with PG

4.2 Effect of CD on the Early Strength of Lime Stabilized Soil

The effect of CD on the early strength of lime stabilized soil is shown in Figure 5. From the figure, it can be seen that the strength of lime stabilized soil admixed with CD gave contrasting results for the two lime contents studied.

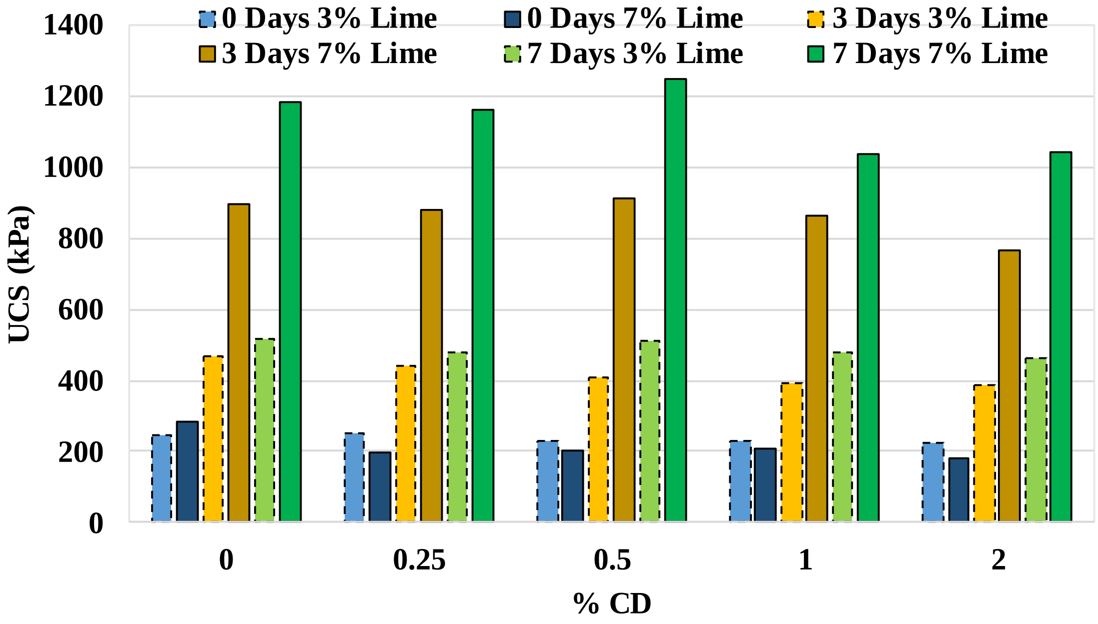

Figure 5: Strength of Lime Stabilized Soil with CD

At 3% lime stabilization, the addition of CD did not result in any significant development of strength at early ages. At 7% lime stabilization, addition of CD to lime resulted positive strength gain only for 0.5% addition of CD. A clear trend could not be seen across curing periods for all combinations. However, on isolation, a general trend of reduced strength on increasing addition of CD could be seen for both 3% and 7% lime stabilization for curing periods of 3 and 7 days with the exception of 0.5% CD dosage wherein there was a slight increase in strength compared to other combinations.

Figure 6 shows the development of strength of CD admixed lime stabilized soil. At 3% lime stabilization, it can be seen that the strength curve for 3% lime stabilization lies on top of all the curves clearly indicating that the addition of CD has resulted in a reduction in strength of the lime stabilized soil. In 7% lime stabilization, only 0.5% CD addition resulted in strength gain which is evident from the position of the curve. Percentage strength gain analysis yielded completely negative trends for 3% lime stabilization at 7 days of curing whereas 7% lime stabilized soil gained a meagre 6% strength on addition of 0.5% CD at the same age of curing. Reduced early strength with lime and CD in the present study is in agreement with the work done by Moropoulou et al. [47] who studied CD admixed lime mortars. Bakolas et al. [48] also reported that calcium hydroxide in lime-CD mortars was not fully consumed even after 270 days of curing.

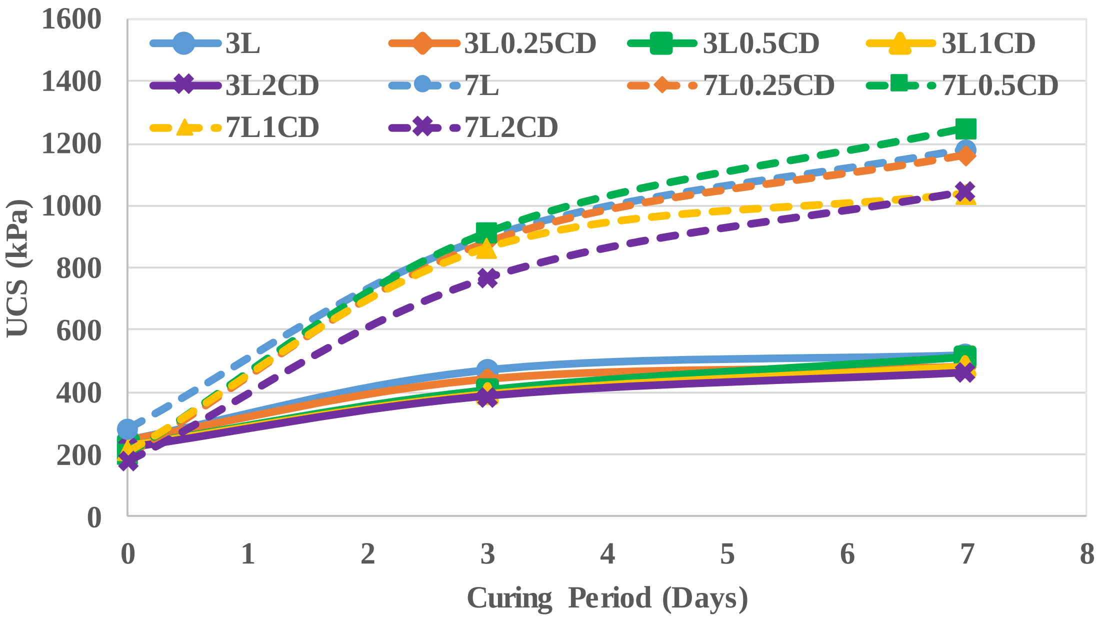

Figure 6: Strength Development of Lime Stabilized Soil with CD

4.3 Comparison of Strength Development of PG and CD admixed Lime Stabilized Soil

Figure 7 shows the comparison of the strength development curves of pure lime stabilized soil, lime stabilized soil admixed with CD and PG at optimal dosages of the additives. From the curves, it can be seen that PG admixed lime stabilized soil develops significant early strength across the three curing periods studied whereas CD admixed lime stabilized soil performed marginally with strength gain only at higher lime content but still lesser than PG admixed lime stabilized soil. The possible mechanism behind enhanced development of strength due to addition of PG may be augmentation in the supply of calcium ions since PG is predominantly composed of calcium sulphate. Moreover some researchers have attributed the formation of a mineral called ettringite as one reason for the increased gain in early strength [49]–[52]. Moreover, PG has been reported to accelerate pozzolanic reactions [49]–[51]. In the case of CD, the delayed in the development of early strength may be due to the reduced reactivity of the CD particles. It may be noted that 97% of the CD particles used in the study were silt size fractions. Hence, due to larger particles sizes, the dissolution of silica and alumina in CD particles would have taken a longer duration in the highly alkaline environment, thereby resulting in a delay in development of strength.

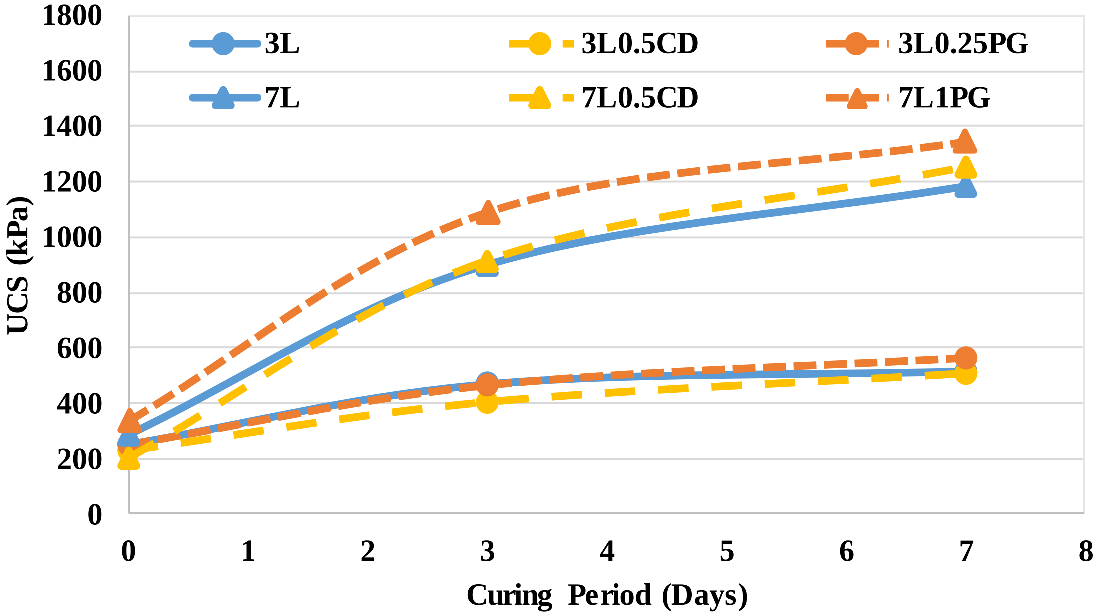

Figure 7: Comparison of Strength Development of Lime stabilized Soil with and without Additives

5.0 Conclusions

This work aimed at studying the early strength development of lime stabilized soil admixed with two different industrial wastes and compare their performances. From the results of the study, the following may be concluded:

i. Addition of PG to lime stabilized soil increased its early strength despite the lime content used for stabilizing the soil whereas addition of CD to lime stabilized soil produced only marginal results with positive strength gain only at one particular dosage of CD at higher lime content.

ii. At higher lime content, better strength gain was achieved at higher PG content whereas in the case of CD, performance was consistent at one particular dosage of 0.5% CD for both lime contents.

iii. PG admixed lime stabilized soil developed higher early strength when compared to CD admixed lime stabilized soil.

iv. Development of early strength in PG can be attributed to augmented supply of calcium ions by PG, thereby accelerating pozzolanic reactions whereas the delayed strength development due to CD addition can be attributed to the difficulty in dissolution of larger CD particles to release silica and alumina for pozzolanic reactions.

v. PG can be recommended as an additive for achieving higher early strength of lime stabilized soil, however after due testing, depending upon the soil under consideration for stabilization.

vi. Thus, it can be concluded that both PG and CD do play a role in amending the development of early strength of lime stabilized soil but with contrasting results; the former enhancing it, while the latter, marginally reducing it.

The late strength development of CD admixed lime stabilized soil can be further studied and successful results can lead to CD being used as an additive for lime soil stabilization were early strength development is not a significant requirement.

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References

[1] S. Bhuvaneshwari, R. G. Robinson, and S. R. Gandhi, "Behaviour of Lime Treated Cured Expansive Soil Composites," Indian Geotech. J., vol. 44, no. 3, pp. 278–293, 2013.
[2] M. Al-Mukhtar, S. Khattab, and J. Alcover, "Microstructure and geotechnical properties of lime-treated expansive clayey soil," Eng. Geol., vol. 139, pp. 17–27, 2012.
[3] J. Li, D. A. Cameron, and G. Ren, "Case study and back analysis of a residential building damaged by expansive soils," Comput. Geotech., vol. 56, pp. 89–99, 2014.
[4] T. Thyagaraj, S. M. Rao, P. Sai Suresh, and U. Salini, "Laboratory Studies on Stabilization of an Expansive Soil by Lime Precipitation Technique," J. Mater. Civ. Eng., vol. 24, no. 8, pp. 1067–1075, 2012.
[5] D. N. Little, "Handbook for Stabilization of Pavement Subgrades and Base Courses with Lime," Austin, Texas, 1995.
[6] J. James and P. K. Pandian, "Soil Stabilization as an Avenue for Reuse of Solid Wastes : A Review," Acta Tech. Napocensis Civ. Eng. Arch., vol. 58, no. 1, pp. 50–76, 2015.
[7] J. James and P. K. Pandian, "Industrial Wastes as Auxiliary Additives to Cement / Lime Stabilization of Soils," Adv. Civ. Eng., vol. 2016, no. Article ID 1267391, pp. 1–17, 2016.
[8] J. James and P. K. Pandian, "A Study on the Early UCC Strength of Stabilized Soil Admixed with Industrial Waste Materials," Int. J. Earth Sci. Eng., vol. 7, no. 3, pp. 1055–1063, 2014.
[9] J. James and P. K. Pandian, "Development of Early Strength of Lime Stabilized Expansive Soil: Effect of Red Mud and Egg Shell Ash," Acta Tech. Corviniensis - Bull. Eng., vol. 9, no. 1, pp. 93–100, 2016.
[10] BIS, IS 1498 Classification and Identification of Soils for General Engineering Purposes. India, 1970, pp. 4–24.
[11] BIS, IS 2720 Methods of Test for Soils:Part 5 Determination of Liquid and Plastic Limit. India, 1985, pp. 1–16.
[12] BIS, IS 2720 Methods of Test for Soils:Part 6 Determination of Shrinkage Factors. India, 1972, pp. 1–12.
[13] BIS, IS 2720 Methods of Test for Soils Part 3:Determination of Specific Gravity/Section 1 Fine Grained Soils. India, 1980, pp. 1–8.
[14] BIS, IS 2720 Methods of Test for Soils:Part 4 Grain Size Analysis. India, 1985, pp. 1–38.
[15] BIS, IS 2720 Methods of Test for Soils:Part 7 Determination of Water Content-Dry Density Relation Using Light Compaction. India, 1980, pp. 1–9.
[16] BIS, IS 2720 Methods of Test for Soils:Part 10 - Determination of Unconfined Compressive Strength. India, 1991, pp. 1–4.
[17] BIS, IS 2720 Methods of Test for Soils:Part 26 Determination of pH. India, 1987, pp. 1–10.
[18] O. O. Amu, A. B. Fajobi, and B. O. Oke, "Effect of Eggshell Powder on the Stabilizing Potential of Lime on an Expansive Soil," J. Appl. Sci., vol. 5, no. 8, pp. 1474–1478, 2005.
[19] J. James and P. K. Pandian, "Performance Study on Soil Stabilisation using Natural Materials," Int. J. Earth Sci. Eng., vol. 6, no. 1, pp. 194–203, 2013.
[20] N. Degirmenci, A. Okucu, and A. Turabi, "Application of phosphogypsum in soil stabilization,"

Build. Environ., vol. 42, no. 9, pp. 3393–3398, 2007.

[21] N. Degirmenci, "The using of waste phosphogypsum and natural gypsum in adobe stabilization," Constr. Build. Mater., vol. 22, no. 6, pp. 1220–1224, 2008.

[22] L. Ã. Reijnders, "Cleaner phosphogypsum , coal combustion ashes and waste incineration ashes for application in building materials : A review," Build. Environ., vol. 42, no. 2, pp. 1036–1042, 2007.

[23] H. Tayibi, M. Choura, F. A. Lopez, F. J. Alguacil, and A. Lopez-Delgado, "Environmental impact and management of phosphogypsum," J. Environ. Manage., vol. 90, no. 8, pp. 2377–2386, 2009.

[24] Central Pollution Control Board, "Guidelines for Management and Handling of Phosphogypsum Generated from Phosphoric Acid Plants (Final Draft)," New Delhi, India, 2012.

[25] J. James, S. V. Lakshmi, and P. K. Pandian, "Strength and Index Properties of Phosphogypsum Stabilized Expansive Soil," Int. J. Appl. Environ. Sci., vol. 9, no. 5, pp. 2721–2731, 2014.

[26] S. M. Al-zaidyeen and A. N. S. Al-qadi, "Effect of Phosphogypsum As a Waste Material in Soil Stabilization of Pavement Layers," Jordan J. Civ. Eng., vol. 9, no. 1, pp. 1–7, 2015.

[27] S. Kumar, R. K. Dutta, and B. Mohanty, "Engineering Properties of Bentonite Stabilized With Lime and Phosphogypsum," Slovak J. Civ. Eng., vol. 22, no. 4, pp. 35–44, 2014.

[28] J. James and P. K. Pandian, "Effect of Phosphogypsum on the Strength of Lime Stabilized Expansive Soil," Gradevinar, vol. 66, no. 12, pp. 1109–1116, 2014.

[29] J. James and P. K. Pandian, "Plasticity, Swell-Shrink and Microstructure of Phosphogypsum Admixed Lime Stabilized Expansive Soil," Adv. Civ. Eng., vol. 2016, no. Article ID 9798456, pp. 1–10, 2016.

[30] Centre for Science and Environment, "Construction and Demolition Waste," New Delhi, India, 2014.

[31] L. Reig, M. M. Tashima, L. Soriano, M. V Borrachero, J. Monzo, and J. Paya, "Alkaline Activation of Ceramic Waste Materials," Waste and Biomass Valorization, vol. 4, no. 4, pp. 729–736, 2013.

[32] D. Tavakoli, A. Heidari, and M. Karimian, "Properties of Concrete Produced with Waste Ceramic Tile Aggregate," Asian J. Civ. Eng., vol. 14, no. 3, pp. 369–382, 2013.

[33] A. D. Raval, D. I. N. Patel, and P. J. Pitroda, "Ceramic Waste : Effective Replacement Of Cement For Establishing Sustainable Concrete," Int. J. Eng. Trends Technol., vol. 4, no. 6, pp. 2324–2329, 2013.

[34] A. Anwar, S. Ahmad, S. Mohd, A. Husain, and S. A. Ahmad, "Replacement Of Cement By Marble Dust And Ceramic Waste In Concrete For Sustainable Development," Int. J. Innov. Sci. Eng. Technol., vol. 2, no. 6, pp. 496–503, 2015.

[35] F. Pacheco-Torgal and S. Jalali, "Compressive strength and durability properties of ceramic wastes based concrete," Mater. Struct., vol. 44, no. 1, pp. 155–167, Apr. 2010.

[36] A. K. Sabat, "Stabilization of Expansive Soil Using Waste Ceramic Dust," Electron. J. Geotech. Eng., vol. 17, no. Bund. Z, pp. 3915–3926, 2012.

[37] M. Veera Reddy, "Investigations on stone dust and ceramic scrap as aggregate," Int. J. Civ. Struct. Eng., vol. 1, no. 3, pp. 661–666, 2010.

[38] BIS, IS 2720 Methods of Test For Soils:Part 1 - Preparation of Dry Soil Sample for Various Tests. India, 1983, pp. 1–10.

[39] J. L. Eades and R. E. Grim, "A Quick Test to Determine Lime Requirements for Lime Stabilization," Highw. Res. Rec., vol. 139, pp. 61–72, 1966.

[40] ASTM, D6276 Standard Test Method for Using pH to Estimate the Soil-Lime Proportion Requirement, vol. 14. United States, 1999, pp. 1–4.

[41] A. A. Nasrizar, K. Ilamparuthi, and M. Muttharam, "Quantitative Models for Strength of Lime Treated Expansive Soil," in GeoCongress 2012, March 25-29, 2012, pp. 978–987.

[42] M. R. Thompson, "Factors influencing the plasticity and strength of lime soil mixtures," Univ. Illunois Bull., vol. 64, no. 100, pp. 1–20, 1967.

[43] P. V Sivapullaiah, B. Katageri, and R. N. Herkal, "Enhancement of Strength of Soft Soils with Fly Ash and Lime," in Procs. of First Sri Lankan Geotechnical Society International Conference on Soil and Rock Engineering, 6-11 August, 2007, pp. 1–6.

[44] D. Ciancio, C. T. S. Beckett, and J. A. H. Carraro, "Optimum lime content identification for lime-

stabilised rammed earth," Constr. Build. Mater., vol. 53, pp. 59–65, 2014.

[45] A. Ghosh, "Compaction Characteristics and Bearing Ratio of Pond Ash Stabilized with Lime and Phosphogypsum," J. Mater. Civ. Eng., vol. 22, no. 4, pp. 343–351, 2010.

[46] D. Krishnan, V. Janani, P. T. Ravichandran, R. Annadurai, and M. Gunturi, "Effect of Fly Ash and PhosphoGypsum on Properties of Expansive Soils," Int. J. Sci. Eng. Technol., vol. 3, no. 5, pp. 592–596, 2014.

[47] A. Moropoulou, A. Bakolas, P. Moundoulas, E. Aggelakopoulou, and S. Anagnostopoulou, "Strength development and lime reaction in mortars for repairing historic masonries," Cem. Concr. Compos., vol. 27, no. 2, pp. 289–294, 2005.

[48] A. Bakolas, E. Aggelakopoulou, A. Moropoulou, and S. Anagnostopoulou, "Evaluation of Pozzolanic Activity and Physico- Mechanical Characteristics in Metakaolin-Lime Pastes," J. Therm. Anal. Calorim., vol. 84, no. 1, pp. 157–163, 2006.

[49] W. Shen, M. Zhou, and Q. Zhao, "Study on lime–fly ash–phosphogypsum binder," Constr. Build. Mater., vol. 21, no. 7, pp. 1480–1485, 2007.

[50] W. Shen, M. Zhou, W. Ma, J. Hu, and Z. Cai, "Investigation on the application of steel slag-fly ash-phosphogypsum solidified material as road base material.," J. Hazard. Mater., vol. 164, no. 1, pp. 99–104, 2009.

[51] Y. Min, Q. Jueshi, and P. Ying, "Activation of fly ash–lime systems using calcined phosphogypsum," Constr. Build. Mater., vol. 22, no. 5, pp. 1004–1008, 2008.

[52] Y. Huang and Z. Lin, "Investigation on phosphogypsum–steel slag–granulated blast-furnace slag–limestone cement," Constr. Build. Mater., vol. 24, no. 7, pp. 1296–1301, 2010.