Application of lime and GGBS to improve the strength of clayey sand

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Abstract. Lot of industrial waste by-products such as fly ash, GGBS, silica fume, paper pulp etc. are generated all over the world leading to environmental degradation and pollution. Utilization of the industrial waste by-products in construction industry will at least reduce the quantity of these wastes that are being dumped in landfills leading to wastage of useful land area. But utilization of these industrial wastes as a construction material or as partial replacement in concrete or soil should not have a negative effect on their properties. Thus a thorough experimental investigation should be carried out before these industrial wastes are utilized in the construction industry. In the present experimental work, an attempt has been made to utilize GGBS along with quick lime to study their effect on the strength characteristics of locally available soil. GGBS was mixed with locally available Clayey Sand (SC soil) along with quick lime to investigate their effect on the UCC strength and soaked CBR strength of the soil. Quick lime was varied in percentages of 2%, 4%, 6% and 8% whereas GGBS was varied in percentages of 20%, 25%, 30%, 35% and 40% to determine the ideal percentage of lime and GGBS that should be added to SC soil for which maximum UCC strength and soaked CBR strength was attained. From the experimental results, it was found that for soil mixed with lime and GGBS increase in UCC strength and soaked CBR strength of 2.11 times and 7.44 times that of untreated soil was observed respectively.

1. Introduction

Advancement in technology and industrialization has led to generation of lot of waste by-products all over the world. The different varieties of waste may be classified as industrial waste, agricultural waste, construction and demolition waste, municipal solid waste etc. The different industrial waste by-products that are generated may be listed as fly ash, cenosphere, silica fume, rice husk ash, ground granulated blast furnace slag (GGBS), paper pulp etc. Utilization of industrial wastes in construction industry will reduce the volume of these wastes that are being dumped in landfills thus reducing environmental pollution. Also utilization of such wastes as construction materials will reduce the requirement of conventional materials like coarse aggregates, stones, sand, cement, lime, backfill material etc. thus preserving them for future generations. As per [27], soil stabilisation with by-product materials has proved to be a useful cost effective option. In the current project, an attempt has been made to utilize GGBS along with quick lime to improve the strength characteristics of locally available soil. GGBS is a waste by-product of iron and steel manufacturing industries. GGBS is highly cementitious and high in calcium silicate hydrates (CSH) which is a strength enhancing compound. Generally, GGBS is used in concrete but in recent times GGBS is also being used for stabilizing weak
and problematic soil and for improving the strength characteristics of different soil. Utilizing GGBS in the construction industry will thus lead to economical and sustainable construction. The soil used in the experimental work was classified as Clayey Sand (SC soil) as per Indian Standard Soil Classification System (ISCS). SC soil is not a weak soil but still if we can further improve the strength of SC soil by utilizing GGBS and lime we can reduce the quantity of GGBS that is being dumped as waste and can also reduce the requirement of conventional construction materials thus leading to cost-effective construction. SC soil was first mixed with varying lime content to determine the ideal percentage of lime that needs to be added to SC soil for which maximum UCC strength and soaked CBR strength was attained after 3 days curing. SC soil with optimum lime content was then mixed with varying percentages of GGBS to determine the ideal percentage of GGBS that needs to be added to SC soil for which maximum UCC strength and soaked CBR strength was attained after 3 days curing. The experimental results were then compared with that of untreated soil or control specimen (CS) to evaluate the maximum UCC strength and soaked CBR strength gain attained.

Many studies have been conducted to study about the effect of lime on the geotechnical properties of different types of soil. As per [5], compared to hydrated lime, quick lime stabilized soil showed improved performance and was considered to be superior for soil treatment. As per [1], amount of lime required to effectively treat a soil depends on the type of clay mineral present, like for Kaolinite 4 to 6 % lime was required and for illite and montmorillonite about 8 % lime was required for maximum strength gain. As per [19], treatment of Ikpayongo laterite with 4 % lime efficiently modified it for economic stabilization. Reference [8, 13, 17], applied lime treatment to improve and stabilize expansive clays, black cotton soil and observed improvement in their plasticity and swelling characteristics. Reference [2, 4, 6, 8, 11], observed that adding lime and water to soil quickly increased the pH of soil thus causing pozzolanic reaction between free Calcium cations and the dissolved silica and alumina found in soil. This lead to the formation of calcium-silicate-hydrates (CSH) and calcium-aluminate-hydrates (CAH) which are cementitious products similar to that formed in Portland cement, thus contributing to the strength of lime-stabilized soil. As per [10, 12, 14, 16, 18], lime-clay-water interaction happens due to four main processes which causes modification in soil properties. They are hydration of lime, cation exchange between pore fluids and clay minerals, flocculation of clay to form larger clusters and aggregation of the soil matrix by cementitious precipitates.

Few researchers have worked on the application of GGBS along with some additives like lime, cement, carbide slag, reactive magnesia (MgO) etc. for improving the characteristics of different soil types. As per [23], GGBS was widely used to stabilize soils due to its environmental and economic merits. Reference [21] used a binder developed by mixing fly ash and GGBS to stabilise expansive soils and the binder was found to be effective and economic to stabilise expansive soils with lesser amount of lime. As per [22], carbide slag-GGBS was a better binder than cement for the treatment of gypseous soil. Reference [31, 32], utilized reactive magnesia-activated GGBS for soil stabilisation. As per [30], optimum reactive magnesia-GGBS and carbide slag-GGBS were superior to Portland cement. As per [33], soil stabilization using a mixture of soda residue and GGBS increased shear strength as GGBS content and curing time increased. As per [34], GGBS activated with olivine (Mg$_2$SiO$_4$) and sodium hydroxide (NaOH) was used to stabilise a clayey soil and the significant strength increase was attributed to the higher reaction degree provided by the NaOH. As per [29], lower temperature curing environment (<5°C) significantly retards the hydration and pozzolanic reactions, thereby inhibiting the strength development. Reference [25, 26], studied the effectiveness of GGBS for providing better stabilization of sulfate bearing soils. As per [15, 35], stabilisation/solidification has emerged as an efficient and cost-effective technology for the treatment of contaminated soils with a blend of hydrated lime and GGBS as the binder.

2. Experimental work and result discussion

In the present work, disturbed soil collected from Vembakkam in Thiruvannamalai district of Tamil Nadu was used. The disturbed soil was collected from a depth of 0.5 m below the ground surface after clearing the surface of vegetation. Basic index property tests such as specific gravity test, liquid limit and plastic limit test, wet sieve analysis and Standard Proctor Compaction (SPC) test were conducted on the disturbed soil as per the Indian Standard [36, 37, 38, 40], results of which are tabulated below.
in Table 1. The soil was then classified as per ISCS [39] and based on the maximum dry density (MDD) and optimum moisture content (OMC), the soil specimen for Unconfined Compression (UCC) test and soaked CBR test were prepared at 97% relative compaction.

### Table 1. Basic Index Properties of Soil.

| Soil Test                  | Result                      |
|----------------------------|-----------------------------|
| Specific Gravity           | 2.6                         |
| Liquid Limit               | 25 %                        |
| Plastic Limit              | 13.8 %                      |
| Plasticity Index           | 11.2 %                      |
| Wet Sieve Analysis         | Gravel = 0 %                |
|                            | Sand = 62.6 %               |
|                            | Silt and Clay = 37.4 %      |
| SPC Test                   | MDD = 2.01 gm/cc            |
|                            | OMC = 11.04 %               |
| Soil Classification as per ISCS | SC (Clayey Sand)           |

It was observed that soil specimen used in the experimental work had a specific gravity of 2.6 and based on the results of wet sieve analysis and consistency limit tests, the soil has been classified as Clayey Sand (SC).

2.1. **SC Soil mixed with varying percentage of lime**

SC soil was mixed with quick lime in the percentages of 2%, 4%, 6% and 8% and allowed to cure for a period of 3 days. After 3 days curing, UCC test and soaked CBR test were conducted on the soil with varying lime content to determine the ideal percentage of lime to be added to SC soil based on the shear strength and soaked CBR strength gain observed from the test results. Generally, for soaked CBR test the prepared soil specimen is soaked in water for a period of 96 hours or 4 days but in the current experimental work the prepared soil specimen was soaked in water for a period of 3 days for the purpose of comparison of results.

2.1.1. **UCC test conducted on SC soil with varying lime content**

UCC test was conducted as per IS:2720 (Part 10) – 1991 [41] on SC soil or Control specimen (CS) by preparing the soil specimen at 97% relative compaction based on the MDD and OMC values obtained from SPC test. SC soil was then mixed with varying percentage of quick lime (2%, 4%, 6% and 8%) and the soil lime mixture was allowed to cure for 3 days. Soil and quick lime was first mixed in dry condition and then water equal to OMC was added slowly and mixed with soil and quick lime to form a homogeneous mixture. This soil lime mixture was then kept covered with polythene sheet to prevent air drying of the mixture and allowed to cure for a period of 3 days. After 3 days curing, soil specimen for UCC test was prepared at 97% relative compaction by compacting in a UCC mould. UCC test on CS was carried out immediately without curing as the specimen prepared for UCC test after 3 days curing became very brittle due to loss of moisture. Table 2 shows the UCC strength of SC soil mixed with varying percentage of lime after 3 days curing which is represented graphically in Figure 1.

### Table 2. UCC strength of SC soil with varying lime content.

| Soil Sample | CS (Soil + 0% lime) | Soil + 2% lime | Soil + 4% lime | Soil + 6% lime | Soil + 8% lime |
|-------------|----------------------|----------------|----------------|----------------|----------------|
| UCC Strength | 39.43                | 54.98          | 82.38          | 60.04          | 55.09          |
From the results, it can be observed that addition of quick lime to SC soil increased the UCC strength of the soil after 3 days curing. As the percentage of lime increased, UCC strength of SC soil also increased up to 4% lime beyond which the UCC strength decreased. For soil mixed with 4% lime, maximum UCC strength was found to be 82.38 kPa and the increase in UCC strength of 2.09 times the UCC strength of CS was observed. Thus optimum percentage of lime to be added to SC soil is 4% based on the UCC strength attained. Decrease in UCC strength for the soil mixed with lime more than the optimum percentage may be attributed to the fact that, there were no more silica or/and alumina minerals available within the soil to react with the calcium found in excess lime thus resulting in decreased UCC strength of the soil beyond the optimum percentage of 4% lime. According to [7], peak soil strength was attained at an optimum lime content which for many soils lies within the range of 3% to 9%.

2.1.2. Soaked CBR test conducted on SC soil with varying lime content

Soaked CBR test was conducted as per IS:2720 (Part 16) – 1987 [42] on CS and on SC soil with varying lime content (2%, 4%, 6% and 8%) after 3 days soaking in water. To prepare the soil specimen for soaked CBR test, soil and quick lime was first mixed in dry condition and then water equal to OMC was added slowly and mixed with soil and lime to form a homogeneous mixture. This soil lime mixture was compacted in CBR mould at 97% relative compaction by means of dynamic compaction and then soaked in water for a period of 3 days. After 3 days curing period, soaked CBR test was conducted on CS and on soil with varying lime content to determine the ideal percentage of lime to be added to SC soil based on the improvement observed in soaked CBR strength of soil. Table 3 shows the soaked CBR strength of SC soil mixed with varying percentage of lime after 3 days curing which is represented graphically in Figure 2.

**Table 3.** Soaked CBR value of SC soil with varying percentage of lime.

| Soil Sample | CS (Soil + 0% lime) | Soil + 2% lime | Soil + 4% lime | Soil + 6% lime | Soil + 8% lime |
|-------------|----------------------|----------------|----------------|----------------|----------------|
| Soaked CBR (%) | 2.98                 | 2.13           | 2.56           | 2.13           | 2.13           |
Based on the results of soaked CBR test, it can be observed that CBR value of SC reduced on addition of varying lime content after 3 days curing. This reduction in CBR strength after 3 days curing may be due to the fact that more time is required for the pozzolanic reaction to complete between the silica and/or alumina minerals found in soil and calcium found in lime, leading to the formation of cementitious products like CSH and CAH which are responsible for the strength gain within soil. As per [7, 9], CBR strength of soil increased drastically with increasing curing period. For SC soil mixed with 4% lime, CBR strength of 2.56% was attained and the decrease in CBR value of 0.85 times that of CS was observed.

2.2. SC Soil mixed with 4% lime and varying percentage of GGBS
SC soil with optimum percentage of quick lime (4%) was mixed with varying percentage of GGBS (20%, 25%, 30%, 35% and 40%) and allowed to cure for a period of 3 days. After 3 days curing, UCC test and soaked CBR test were conducted on SC soil with 4% lime and varying GGBS content to determine the ideal percentage of GGBS to be added to SC soil containing 4% lime based on the UCC strength gain and soaked CBR strength gain observed in the experimental work.

2.2.1. UCC test conducted on SC soil with 4% lime and varying GGBS content
Soil specimen for UCC test was prepared by first mixing SC soil, 4% quick lime and varying percentages of GGBS in dry state and then water equal to OMC was added slowly to this dry mixture of soil-lime-GGBS to form a homogenous mixture. Soil-lime-GGBS mixture was then allowed to cure for a period of 3 days by covering it with polythene sheets to avoid air drying of the specimen. After 3 days curing, the soil specimen for UCC test was prepared at 97% relative compaction and the UCC test was conducted as per IS:2720 (Part 10) – 1991 [41]. The results of the UCC test was then compared with that of CS and with soil containing 4% lime. Figure 3 shows the stress strain deformation curve obtained from UCC test for SC soil mixed with 4% lime and varying percentage of GGBS after 3 days curing. Table 4 shows the UCC strength of SC soil mixed with 4% lime and varying percentage of GGBS after 3 days curing which has been represented graphically in Figure 4.
Figure 3. Stress - Strain curve of UCC test conducted on SC soil with 4% lime and varying percentage of GGBS.

Table 4. UCC Strength of SC soil with 4% lime and varying percentage of GGBS.

| Soil Specimen                  | UCC Strength (kPa) | Increase/Decrease in UCC strength w.r.t. CS | Increase/Decrease in UCC strength w.r.t. soil with 4% lime |
|--------------------------------|--------------------|--------------------------------------------|----------------------------------------------------------|
| CS                             | 39.43              | -                                          | -                                                        |
| Soil + 4% lime                 | 82.378             | 2.09 times UCC strength of CS              | 0.47 times UCC strength of soil with 4% lime             |
| Soil + 4% lime + 20% GGBS      | 38.79              | 0.98 times UCC strength of CS              | 0.53 times UCC strength of soil with 4% lime             |
| Soil + 4% lime + 25% GGBS      | 44.029             | 1.12 times UCC strength of CS              | 1.01 times UCC strength of soil with 4% lime             |
| Soil + 4% lime + 30% GGBS      | 83.108             | 2.11 times UCC strength of CS              | 0.77 times UCC strength of soil with 4% lime             |
| Soil + 4% lime + 35% GGBS      | 63.271             | 1.6 times UCC strength of CS               | 0.54 times UCC strength of soil with 4% lime             |
| Soil + 4% lime + 40% GGBS      | 44.272             | 1.12 times UCC strength of CS              |                                                          |
| Soil + 4% lime + 40% GGBS      | 44.272             |                                            |                                                          |
From the results, it can be observed that adding GGBS to SC soil mixed with 4% quick lime was not very effective as far as enhancement in shear strength was concerned. Maximum UCC strength of 83.108 kPa was observed for SC soil mixed with 4% lime and 30% GGBS as compared to the UCC strength of 82.378 kPa observed for SC soil with 4% lime after 3 days curing. Increase in UCC strength of 1.01 times that of soil with 4% lime and 2.11 times that of CS was observed. Decrease in UCC strength on addition of GGBS to SC soil with 4% lime may be attributed to the fact that 3 days curing period may not be sufficient for the pozzolanic reaction to complete between silica, alumina and calcium to form cementitious products like CSH and CAH which are responsible for the strength gain within soil. According to [20], maximum improvement in strength for lime treated soil was achieved for 14 days of curing period and no substantial change in soil strength was observed beyond 14 days curing period. In forthcoming experimental studies on soil treatment with lime and GGBS, the effect of curing period on the strength of soil can be investigated in detail and included in the future scope of the work.

2.2.2. Soaked CBR test conducted on SC soil with 4% lime and varying GGBS content
Soaked CBR test was carried out as per IS:2720 (Part 16) – 1987 [42] for SC soil mixed with 4% quick lime and varying percentage of GGBS (20%, 25%, 30%, 35% and 40%). Soil specimen for soaked CBR test was prepared by mixing the soil, 4% quick lime and varying percentages of GGBS in dry state and then adding water equal to OMC slowly to this dry mixture of soil-lime-GGBS to form a homogenous mixture. Soil specimen for soaked CBR test was then prepared at 97% relative compaction based on the MDD value obtained from SPC test by means of dynamic compaction. Prepared soil specimen was soaked in water for a period of 3 days and after 3 days curing the soaked CBR test was conducted and the results were compared with that of CS and with soil containing 4% lime. Figure 5 shows the load penetration curves obtained from soaked CBR test conducted on SC soil mixed with 4% lime and varying percentage of GGBS after 3 days curing. Table 5 shows the soaked CBR value of SC soil mixed with 4% lime and varying percentage of GGBS after 3 days curing which has been represented graphically in Figure 6.

Figure 4. UCC Strength of SC soil with 4% lime and varying percentage of GGBS.
Figure 5. Load Penetration curves of soaked CBR test for SC soil with 4% lime and varying percentage of GGBS.

Table 5. Soaked CBR value of SC soil with 4% lime and varying percentage of GGBS.

| Soil Specimen             | Soaked CBR values (%) | Increase in soaked CBR w.r.t CS | Increase in soaked CBR w.r.t soil with 4% lime |
|---------------------------|-----------------------|---------------------------------|-----------------------------------------------|
| CS                        | 2.98                  | -                               | -                                             |
| Soil + 4% lime            | 2.56                  | 0.86 times CBR of CS            | 6.11 times CBR of soil with 4% lime           |
| + 20% GGBS                | 15.63                 | 5.24 times CBR of CS            | 7.44 times CBR of soil with 4% lime           |
| Soil + 4% lime + 25% GGBS | 19.04                 | 6.39 times CBR of CS            | 8.66 times CBR of soil with 4% lime           |
| Soil + 4% lime + 30% GGBS | 22.17                 | 7.44 times CBR of CS            | 7 times CBR of soil with 4% lime              |
| Soil + 4% lime + 35% GGBS | 17.91                 | 6.01 times CBR of CS            | 4.44 times CBR of soil with 4% lime           |
| Soil + 4% lime + 40% GGBS | 11.37                 | 3.82 times CBR of CS            |                                               |
From the results, it can be observed that addition of GGBS to SC soil with 4% lime had a positive effect on the CBR strength of the soil. As per [24], the common hydration products in all GGBS-stabilized soils were CSH like compounds. According to [27, 28], lime-activated GGBS was a better binder for clay than cement-activated slag and GGBS required only small quantities of lime for activation to stabilize clay. As the percentage of GGBS increased, CBR value of the SC soil with 4% lime also increased up to 30% GGBS beyond which the CBR value decreased. Maximum CBR strength of 22.17% was attained for SC soil with 4% lime and 30% GGBS and the increase in CBR strength of 7.44 times CBR of CS and 8.66 times CBR of soil with 4% lime was observed. Addition of 4% lime to SC soil decreased the CBR strength to 2.56% from that of 2.98% observed for CS thus concluding that addition of lime to SC soil had a negative effect on the CBR strength of SC soil after 3 days of curing but addition of GGBS along with 4% lime improved the CBR strength drastically within 3 days of curing. Also addition of GGBS to SC soil with 4% lime showed prominent improvement in CBR strength but not much increase was observed in the UCC strength after 3 days curing. This may be due to the presence of excess water in soaked CBR test to complete the pozzolanic reaction between silica, alumina and calcium to form CSH and CAH whereas in case of UCC test, quantity of water equal to OMC added to prepare the soil specimen may not be sufficient to complete the pozzolanic reaction to form CSH and CAH. Thus it can be concluded that addition of GGBS to SC soil with 4% lime is more suitable for enhancing the CBR strength of subgrade soil consisting of SC soil for the design of flexible pavements. Increased CBR strength of the SC subgrade would decrease the thickness of the flexible pavement, thus decreasing the construction cost and also reducing the quantity of materials required in the base and sub-base course of flexible pavement leading to the preservation of natural resources for future generations. As per [3], lime stabilized soil showed significant improvement in CBR strength, which, when incorporated in flexible pavement design, reduced the pavement thickness resulting in substantial savings.

3. Conclusion
Addition of quick lime to SC soil increased the UCC strength but reduced the soaked CBR strength of SC soil after 3 days curing. Maximum UCC strength of 82.38 kPa was attained for SC soil mixed with 4% lime and the increase in UCC strength of 2.09 times that of CS was observed. For SC soil mixed with 4% lime, soaked CBR strength of 2.56% was attained and the decrease in CBR value of 0.859
times that of CS was observed thus concluding that addition of lime to SC soil had a negative effect on the CBR strength of SC soil after 3 days of curing.

For SC soil mixed with 4% lime and 30% GGBS, maximum UCC strength of 83.108 kPa was observed and the increase in UCC strength of 1.01 times that of soil with 4% lime and 2.11 times that of CS was observed. Thus addition of GGBS to SC soil mixed with 4% lime was not very effective as far as enhancement in shear strength was concerned but it had a positive effect on the CBR strength of the soil. Maximum CBR strength of 22.17% was attained for SC soil with 4% lime and 30% G and the increase in CBR strength of 7.44 times CBR of CS and 8.66 times CBR of soil with 4% lime was observed. Thus it can be concluded that addition of GGBS to SC soil with 4% lime is more appropriate for enhancing the CBR strength of SC subgrade soil for the purpose of designing flexible pavements.

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