Improving Subgrade Properties of Expansive Soils Using Bottom Ash and lime

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Abstract: Due to the presence of potentially hazardous chemicals and minerals, the waste that is produced by thermal power plants poses a significant risk to the environment around it. This study is aimed to enhance the geotechnical characteristics of expansive soil by using bottom ash together with lime. The ultimate objective is to make the composite suitable for usage as a subgrade material. In the laboratory, a number of experiments, including consistency limits, compaction, unconfined compressive strength, permeability and California bearing ratio tests, were carried out on a variety of combinations of expansive soil and admixtures. The results of these tests were analyzed. As an outcome of the findings of the experimental testing, it was found that the geotechnical characteristics of expansive soil enhanced on introducing bottom ash alone and in combination with lime, therefore alleviating its disposal issue and making the environment healthier. According to the findings of the California bearing ratio study, if the optimum combination of bottom ash and lime may be employed effectively as a subgrade material, which would result in financial advantages.

Keywords:Bottom Ash; Lime; Compaction; California bearing ratio; Subgrade.

1. Introduction

Constructing buildings on expansive soils is very challenging due to the huge swelling and shrinking that happens when the moisture content of the soil varies. Structures built on these soils are more susceptible to collapse; hence it is best to avoid constructing on top of these soils wherever feasible. Due to the growing growth of infrastructure and the scarcity of excellent soil, there is a pressing need to develop specific ways for using certain kinds of soil in foundations. Various techniques, such as soil stabilization, pile foundations, and many more, have been developed during the previous few decades. Soil stabilization is a process in which the properties of the original soil are altered by the inclusion of different admixtures, wastes, or chemicals into the soil. Several ways of soil stabilization, including the use of traditional stabilizers such as lime and lime, have been shown to be useful in the past (Dash and Hussain 2012; Sharma and Hymavathi 2016; Bhardwaj and Sharma 2020).

Lime and lime, on the other hand, both have the basic drawback of being more expensive than other building materials, which implies that they are not suitable for broad use. During the past two decades, multiple studies on soil stabilisation utilising discarded materials such as fly ash are being carried out as part of various research projects(Sharma and Sharma 2019; Verma and Abhishek 2018).

The production of bottom ash as an outcome of burning in thermal power plants, heating systems, furnaces, and incinerators results in a substance that cannot be burned. Bottom ash is composed of many components, including calcium oxide and silica, which, when combined with the soil, have the potential to react and form a solid matrix. The process of using bottom ash to stabilise soil entails mixing it with the soil in varied amounts, depending on the intended properties of the stabilised soil. These proportions are determined by the intended characteristics of the stabilised soil. After that, the mixture is compacted so that its strength and durability are increased. Bottom ash has many advantages that make it a good choice for stabilising soil, including the fact that it is cost-effective, sustainable for the environment, long-lasting, and has an increased capacity for bearing loads (Gupta et al., 2017; Singh and Agnihotri 2018; Singh and Agnihotri 2018).

In conclusion, the use of bottom ash as a solution for soil stabilisation is an intriguing possibility that carries with it a number of advantages. However, in order to obtain the anticipated results, it is essential to ensure that the right amounts of the mixture are employed. Additionally, it is critical to closely monitor the process in order to guarantee compliance with all applicable environmental and safety requirements.

Soil stabilisation with lime is a typical way for improving soil characteristics. Lime finds extensive application as a material for soil stabilization and modification due to its ability to enhance the strength, stiffness, and durability of the soil when incorporated into it. Lime also improves the soil's workability, making it easier to place and compact. Numerous investigations on soil stabilisation with lime have been carried out. These studies looked into many elements of lime stabilisation, such as its efficacy, appropriate lime content, durability, and effects on soil characteristics (Coban et al. 2022; Etim et al. 2022; Zada et al. 2023).

The research of the relevant literature led to the conclusion that bottom ash has been utilized on an individual basis in the process of clayey soil stabilization. The purpose of this study is to investigate the possibility of enhancing the geotechnical properties of clayey soil by combining the usage of bottom ash with lime. This would allow the clayey soil to be utilized as a sub-grade material. The investigation will be beneficial by establishing an affordable sub-grade for roads and reducing the adverse impacts of such wastes on the surroundings. Additionally, the study will help provide a cost-effective way to dispose of these wastes.

2. Materials

2.1 Soil

The soil that was utilized in the investigation was gathered from the village of Majra, which is located in the Indian state of Punjab. The soil that was used was then carried to the geotechnical laboratory in bags that were airtight and sealed to prevent the presence of moisture (Figure 1). For the particle size analysis, wet sieve analysis and hydrometer analysis were performed in accordance with ASTM standards. Based on the curve of the particle size assessment, it was determined that the soil possesses high plasticity (CH) and contains montmorillonite mineral. Table 1 details the many different physical characteristics of the soil sample that was used for the research.

2.2 Bottom ash

Bottom ash (BA) was obtained from the Thermal Power Plant in Kalakote, Jammu and Kashmir, and then transported to the geotechnical engineering lab in polythene bags that had been hermetically sealed. This was done to prevent the introduction of any moisture. The BA was allowed to dry in the direct sunlight and aggregates were afterwards broken up with the support of a hammer. After the heavy metals in BA had been removed using the sieve set, BA was again sieved to determine the proportion of particles in line with the specifications established by IS-2720 (Part 4):1985. According to the findings of the sieve analysis (Figure 2), the BA had a grading that fell somewhere in the region of badly graded sand. A number of different physical characteristics of BA are presented in Table 1.

2.3 Lime

In order to avoid the lime from becoming contaminated with moisture over the course of the research, it was purchased from a local lime shop in Kashmir, India, and then kept in a dry location. In the context of this experimental research, lime in the form of a dry, white powder with a specific gravity of 2.42 and a pH of 11.8 was used.

Clay **Bottom Ash** **Lime**

Figure 1. Various materials used in the experimental investigation

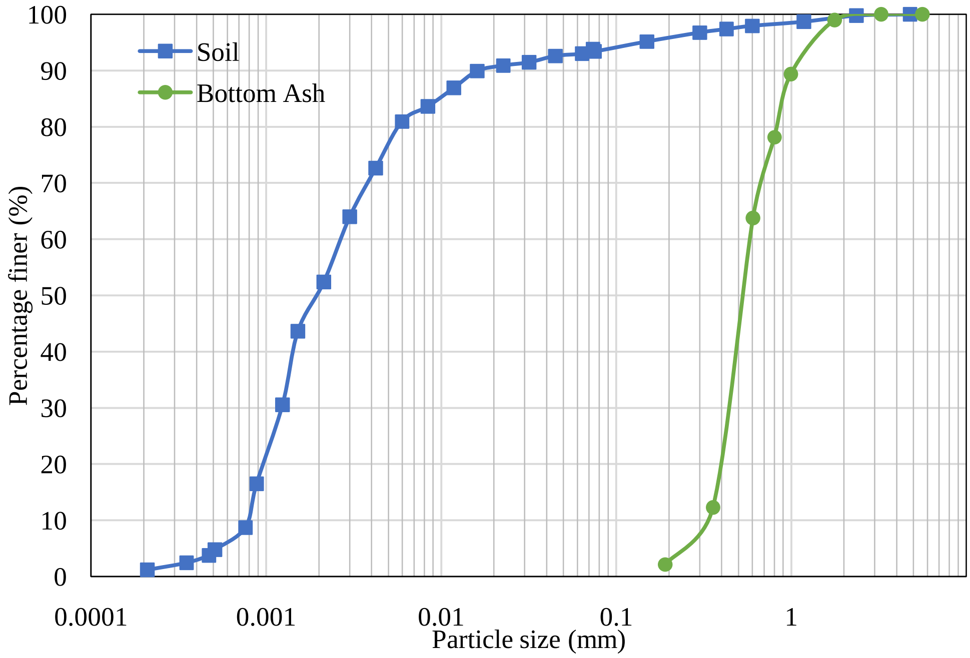

Figure 2. Gradation curve of various materials

Table 1. Geotechnical and physical properties of various materials

Property	**Clay**	**BA**	**Lime**
Specific gravity (IS 2720-3-2 (1980))	2.30	2.06	3.12
Physical appearance	Light brown	Dark grey	Grey
Liquid limit (%) (IS: 2720 (Part 5) 1985)	62.2	-	-
Plastic limit (%) (IS: 2720 (Part 5) 1985)	34.3	-	-
Plasticity Index (%) (IS: 2720 (Part 5) 1985)	27.9	-	-
Coefficient of uniformity, C_u	-	2.53	-
Coefficient of curvature, C_c	-	0.70	-
Optimum moisture content (%) (IS:2720 (Part XXIX)-1975)	22.2	12.3	20.2

Maximum dry density (g/cc) (IS:2720 (Part XXIX)-1975)	1.74	1.65	1.71
pH (ASTM D4972-18)	6.7	7.8	11.2
Differential free swell (%) (IS 2720-1977)	55	-	-
Swell Potential	High	-	-

3. Laboratory tests

The various laboratory tests including physical properties, consistency limits, compaction characteristics, unconfined compressive strength, California bearing ratio and permeability tests are performed on clayey soil alone and various combinations of clayey soil with different admixtures.

3.1 Consistency limit tests

Clayey soil had a liquid limit of 62.2% and a plastic limit of 34.3%, respectively; this resulted in a plasticity index of 27.9%, which is an extremely high value for the soil to have in order for it to be utilized as a sub-grade material. The subsequent sections illustrate how the clayey soil responds, in terms of its plasticity index, to the addition of a variety of different additions.

3.1.1 Clay + BA

In order to find the Atterberg's limits, BA was mixed into the clayey soil in varying concentrations of 5, 10, 15, and 20% correspondingly, and then experiments were carried out. The graph that depicts the various Atterberg's limits that are offered among consistency limits and the corresponding BA percentages applied to the clayey soil is shown in Figure 3. As the amount of BA added to virgin soil increased, the liquid limit of the combination declined at an increasingly rapid rate up to the point where there was an addition of 15% BA. After that point, every additional addition of BA resulted in a modest decrease in the liquid limit of the composite.

It is suitable for use in the building of subgrade pavements because the plasticity index of BA blended clay mixture at 15% BA content is 7.7% (falling in a category of 6-8%). The fact that BA is not plastic contributes significantly to the fall in plasticity index that occurs when it is combined with clayey soil. A limited number of studies observed a decline in the liquid limit and the plasticity index as the BA concentration of the material increased (Gupta et al., 2017; Singh and Agnihotri 2018).

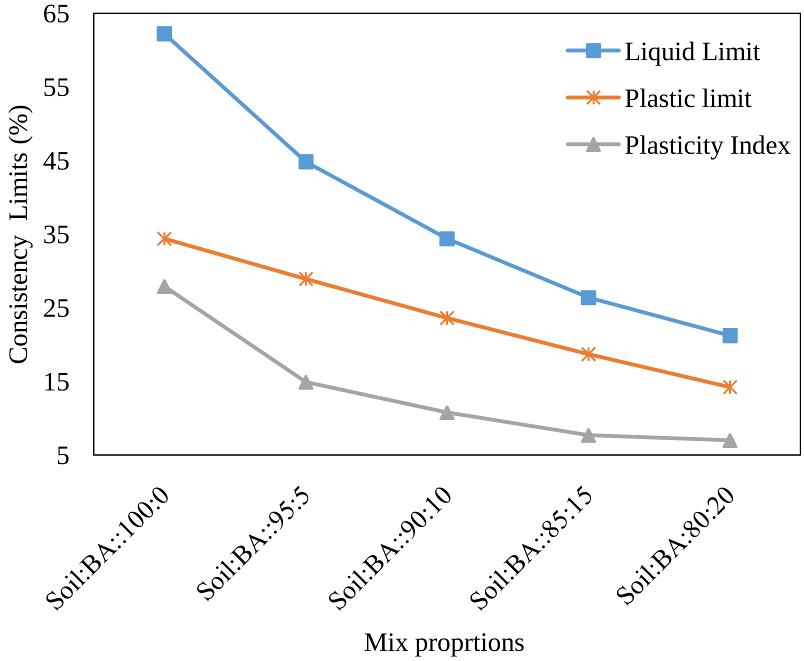

Figure 3. Consistency limit tests for clay: BA

3.1.2 Clay + lime

To test Atterberg's limits, clayey soil was treated with lime at 3, 6, 9, and 12%. Figure 4 shows Atterberg's limitations graphed across consistency limits and clayey soil- lime percentages. The liquid limit of the combination dropped fast up to 9% lime addition in virgin soil and marginally beyond 9%. Lime improved clayey soil plasticity. Lime may lower liquid limit because of the the diffusion of calcium ions entering pore fluids and enhance plastic limit due to improved shear-resistance. Lime blended clay mixture at 9% lime concentration has 7.4% plasticity index, making it appropriate for subgrade (Sudhakaran et al., 2018; Mollamahmutoglu and Avci 2018).

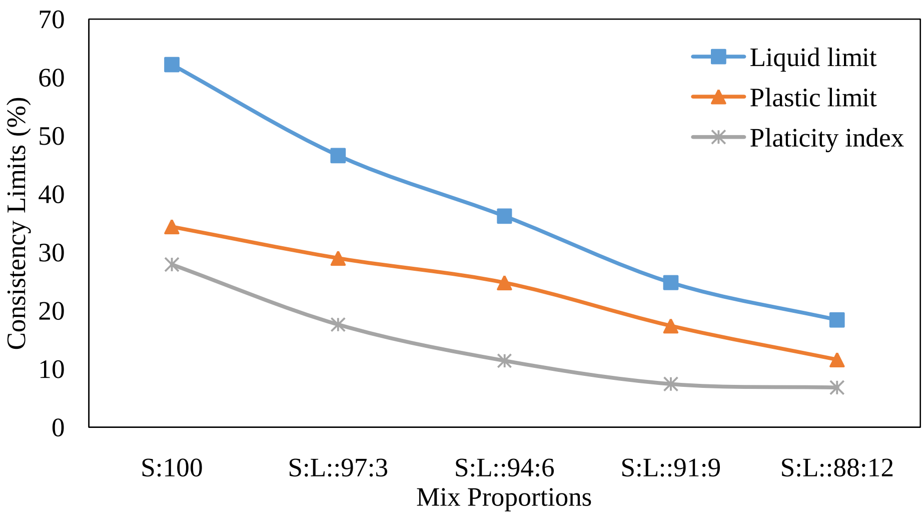

Figure 4. Consistency limit tests for clay: lime content

3.2 Compaction characteristics

3.2.1 Soil: BA mixture

In clayey soil, BA caused a reduction in MDD and OMC of 5–20% (Figure 5). When 5% BA was added to clayey soil, the MDD and OMC values decreased to 1.78 g/cc and 21% accordingly; when 10% BA was added, these values reduced to 1.75 g/cc and 20% accordingly; when 15% BA was added, these values dropped to 1.72 g/cc and 19% correspondingly; and when 20% BA was added, these values lowered to 1.71 g/cc and 18% accordingly The MDD value drops as a result of the decreased specific gravity of BA and the clumping of clayey particles that occurs during cation exchange. It's possible that the OMC value has dropped as a result of BA's reduced OMC value.The similar results on adding BA to clayey soil have been reported in the past (Singh and Agnihotri 2018).

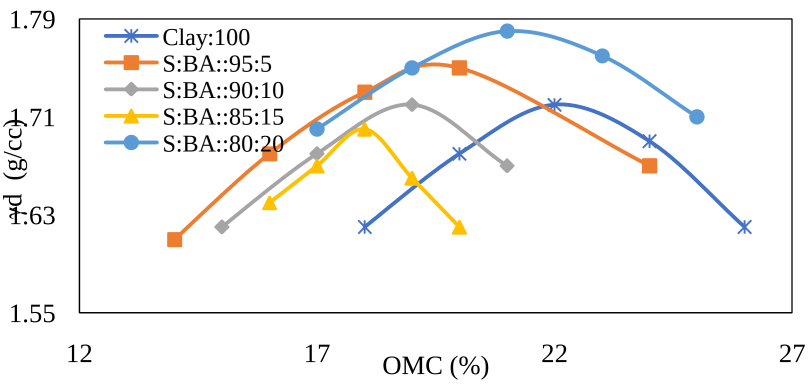

Figure 5. Compaction curves for varying BA content in clayey soil

3.2.2 Soil: lime mixture

When clayey soil was treated with lime at concentrations ranging from 3 to 12%, both the MDD and OMC increased (Figure 6). After the addition of 3% lime to clayey soil, the MDD and OMC amounts raised to 1.79g/cc and 20% correspondingly; after the addition of 6% lime, these values elevated to 1.76 and 21.5% accordingly; after the addition of 9% lime, these values increased to 1.78 and 22.5% respectively; and after the addition of 24% lime, these values raised to 1.8 and 24% accordingly Clay and lime in clayey soil undergo a pozzolanic reaction, which results in an increase in OMC. There is a possibility that MDD will be increased by particles that fill larger spaces. On the other hand, lime's substantial specific gravity may have increased the MDD of the clayey soil. Both Suksiripattanapong et al. (2023) and Jamsawang (2023) conducted research on behaviour that was comparable to one another.

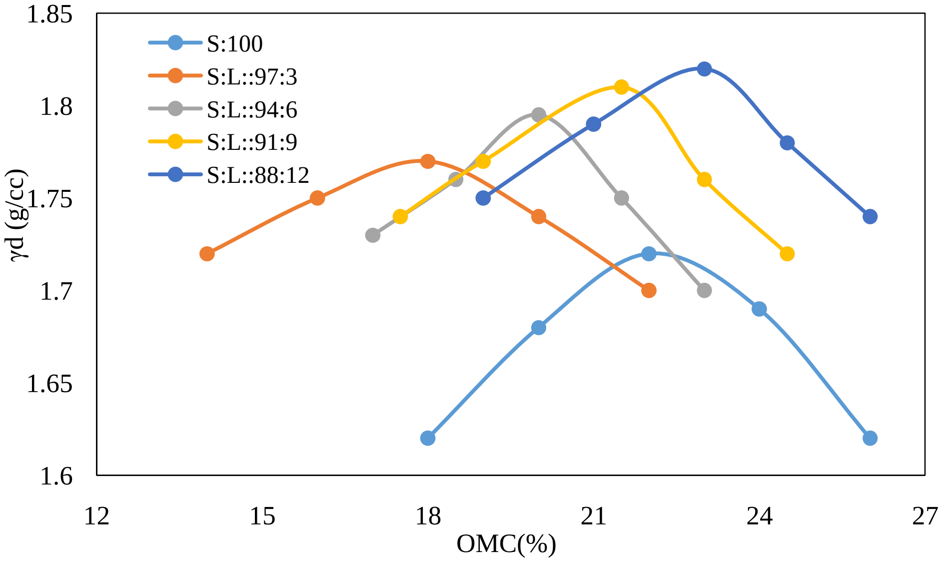

Figure 6. Compaction curves for varying lime content in clayey soil

3.2.2. Soil: BA: lime mixture

Lime added to clay: BA (15%) in increasing amounts (3-12%) enhanced MDD and OMC values (Figure 7). On adding 3% lime to clay: BA (15%), the MDD and OMC values raised to 1.76 g/cc and 18% accordingly; on adding 6% lime, the MDD and OMC values elevated to 1.79 g/cc and 20% accordingly; on adding 9% lime, the MDD and OMC values boosted to 1.80 and 21.5 % correspondingly; and on adding 3% more lime, the MDD and OMC values raised to 1.80 and 23% accordingly The data show that MDD value ascended rapidly up to 6% and then slowly after that. Lime's higher specific gravity than clay and BA increases MDD value. The pozzolanic reaction between lime and clay increases OMC value slightly (Iyaruk et al., 2022; Hanafi et al., 2022).

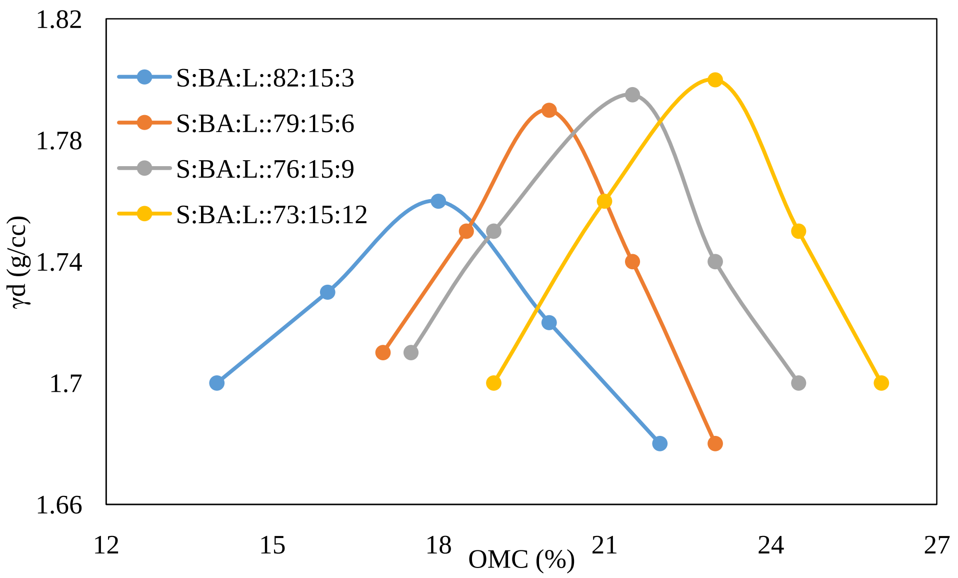

Figure 7. Compaction curves for varying lime content in clay: BA mixture

3.3 Unconfined compressive strength tests

The unconfined compressive strength after 3, 7, and 28 days of curing for different mixtures of clay made with BA, clay made with lime, and clay made with the BA values for lime were calculated using the IS 2720 (Part-10)-1973 standard, and the results are shown in Figures 8, 9, 10, and 11 correspondingly.

3.3.1 Clay: BA mixture

The UCS value of clayey soil after three days is 82 kPa, and it rises to 136, 194, 261 and 334 kPa when additional BA content is added in increments of 5, 10, 15, and 20%. The seven-day unconfined compressive strength (UCS) of clayey soil is 174 kPa, and it rises to 274, 360, 473, and 542 kPa after adding 5, 10, 15, and 20% BA content, respectively (Figure 8). Clayey soil has a UCS of 300 kPa after 28 days, which rises to 382, 425, 524, and 621 kPa when additional BA content is added in increments of 5, 10, 15, and 20%. Both the pozzolanic reaction that takes place between the BA and the clay particles and the increased frictional resistance that the BA particles offer could be responsible for the increase in UCS value that results from adding BA. In previous studies (Ashango and Patra 2016; Liu et al. 2019), researchers found that the addition of BA resulted in a rise in the value of the UCS.

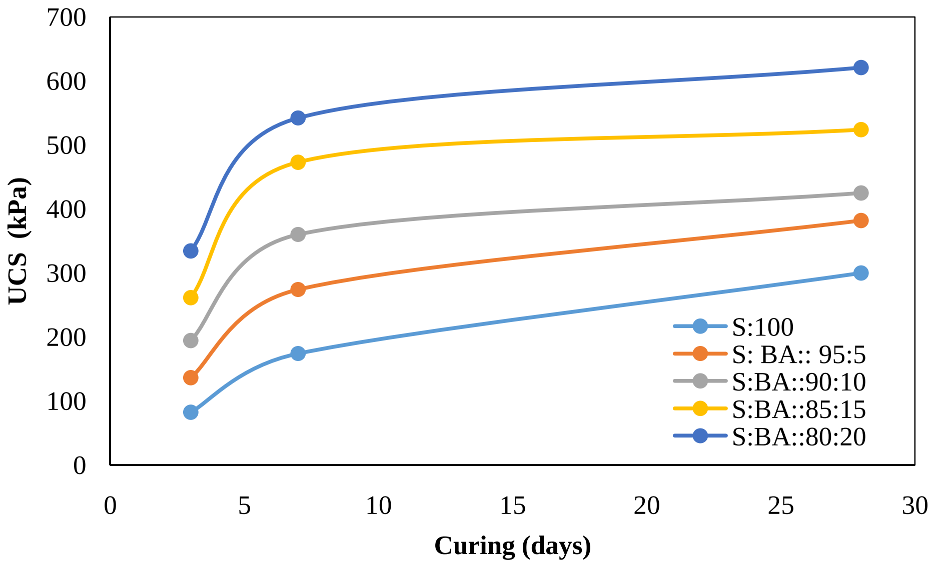

Figure 8. UCS versus curing period for varying BA in clayey soil

3.3.2 Clay: Lime mixture

After three days, the UCS value of clayey soil is 82 kPa. This value increases to 164, 230, 295, and 350 kPa, respectively, with the incorporation of 3, 6, 9, and 12% lime content (Figure 9). The seven-day unconfined compressive strength (UCS) of clayey soil is 174 kPa, and it rises to 300, 400, 495, and 560 kPa, respectively, after the addition of 3, 6, 9, and 12% lime content. The unconfined compressive strength of clayey soil at 28 days is 300 kPa, and it rises to 445, 540, 660, and 720 kPa when 3, 6, 9, and 12% lime concentration are added in accordance. This demonstrates that the incorporation of lime into clayey soil results in an increase in the UCS of the mixture, which can be ascribed to the pozzolanic reaction that takes place between the lime and the soil particles. Previous research (Bekhiti et al. 2019) has shown that there is a consistent upward trend in the UCS of mixtures including both clay and lime.

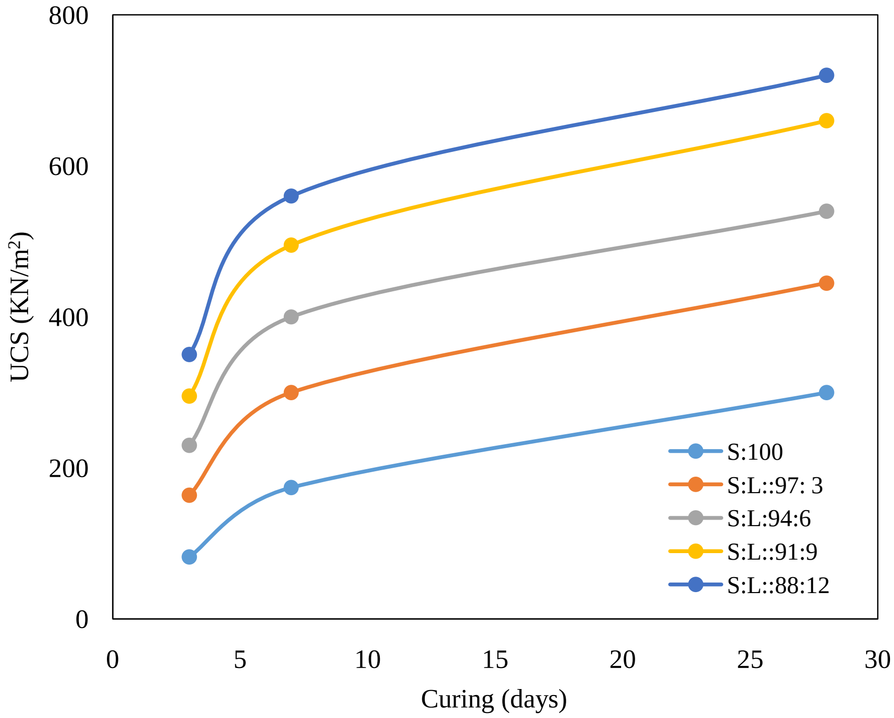

Figure 9. UCS versus curing period for varying lime content in clayey soil

3.3.3 Clay: BA: lime mixture

The UCS value of optimum clay: BA (15%) soil after 3 days is 261 kPa, which rises to 420 and 510 kPa on adding 3 and 6% lime correspondingly, and lowers to 680 kPa on adding 9% lime content (Figure 10). UCS value of optimum clay: BA (15%) soil after 3 days is 261 kPa. The 7-day UCS of optimal clay: BA (15%) soil is 360 kPa, which goes up to 610 and 712 kPa on introducing 3 and 6% lime content respectively, and then reduces to 920 kPa after introducing 9% lime concentration. The 28-day UCS of optimal clay: BA (15%) soil is 524 kPa, which rises to 820 and 920 kPa on introducing 3 and 6% lime content correspondingly. However, adding 9% lime content causes the UCS to decrease to 1124 kPa. As a result, it has been demonstrated that a mixture of clay, BA (15%), and lime with a concentration of 6% lime can be considered to have optimal characteristics. According to Hanafi et al. 2022 and Jamsawang et al. 2023, the pozzolanic reaction that takes place between the clay: BA content and lime particles may be responsible for the increase in the UCS value of the clay: BA mixture that occurs upon the addition of lime.

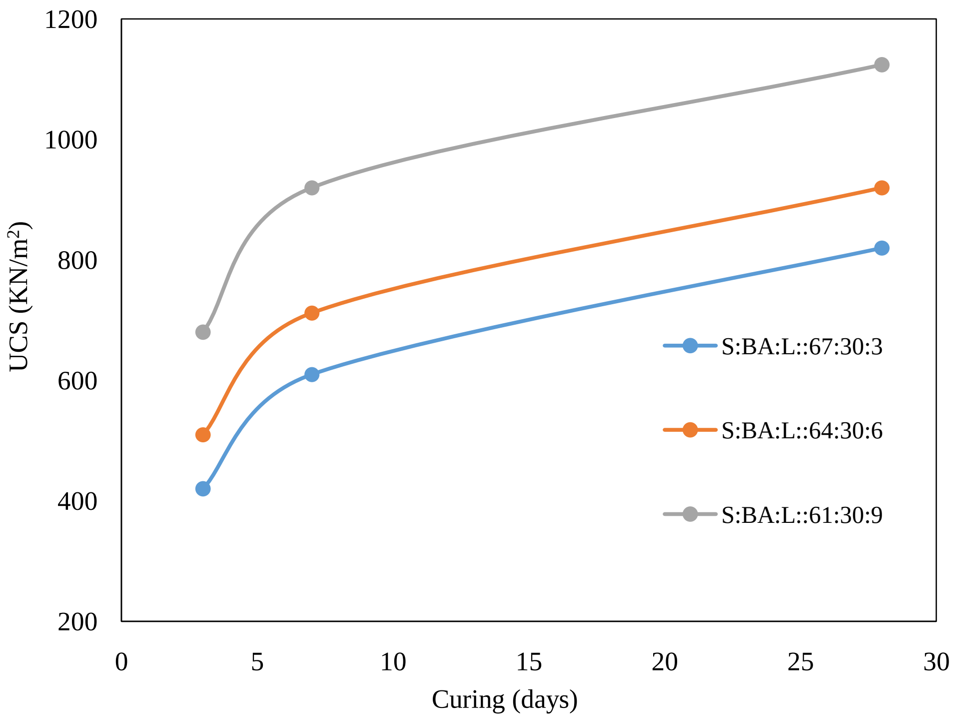

Figure 10. UCS versus curing period for varying lime in soil: BA mixture

3.4 California bearing ratio test

The soaked CBR tests have been carried out on calyey soil, in addition to determining the ideal proportions of a number of different admixtures (Figure 11). After being soaked for 96 hours, the clayey soil had a CBR value of 1.68%, which improved to an extent of 5.4% when 15% BA was added. One possible explanation for the rise in CBR value is that the mixture now contains coarser particles. The value of CBR that was achieved is insufficient to be utilised as a subgrade material. Because lime has a feature that causes it to harden and bind together, increasing the amount of lime added to clayey soil caused the CBR value to rise to 8.6%. This CBR value is sufficient for the material to be utilised as sub-grade material; but, because to the higher cost of lime, the overall cost of construction will be increased, and as a result, it is not suitable for small scale projects. The further testing was carried out on the optimum clay: BA (15%) mixture by adding 6% lime (obtained as optimum from UCS tests), and the reported CBR value was 11.2%, demonstrating a greater CBR value due to the reduced lime content and providing the largest CBR value between all of the mixtures (Iyaruk et al., 2022; Kererat et al., 2022). (Iyaruk et al., 2022; Kererat et al.

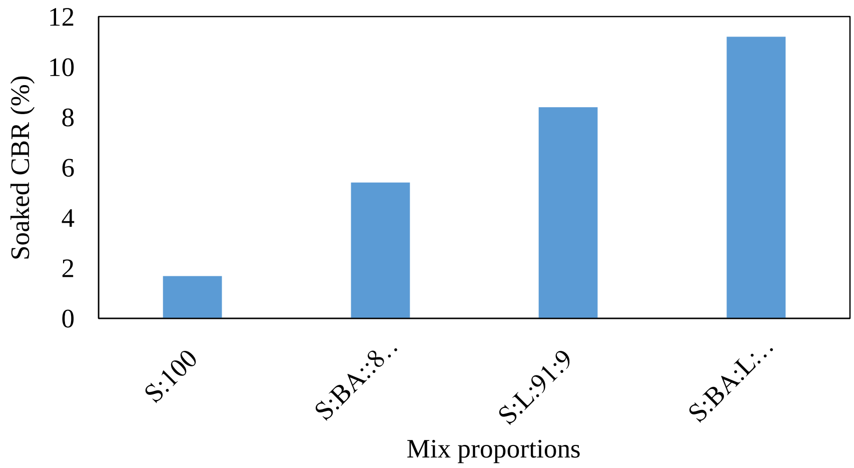

Figure 11. CBR values for various combinations

4. Conclusions

1. On the basis of the laboratory investigation that was conducted on clayey soil alone, clay mixed with BA, clay mixed with lime, and clay mixed with both BA and lime, the following findings can be drawn:
2. At a concentration of 15% BA, adding a dose of BA alone to clayey soil lowered both the liquid limit and the plastic limit of the clayey soil. When lime was added to clayey soil on its own, the plasticity index dropped to 7.4, down from the initial value of 27.9, which was the value of the plasticity index of clayey soil when it had 9% lime content. According to this, both BA and lime are beneficial in enhancing the plasticity behaviour of clayey soils. This is stated in the passage.
3. The MDD value fell when only BA content was added to clayey soil; however it increased when only lime was added to clayey soil. The MDD value was further enhanced by the inclusion of 6% lime to the combination consisting of clay, BA, and 76:20.
4. The OMC value fell when only BA content was added to clayey soil; however it increased when only lime was added to clayey soil. The MDD value, on the other hand, increased after 6% lime was added to the mixture of clay, BA, and Clay: BA:: 85:15.
5. The value of the unconfined compressive strength of clayey soil rose when BA and lime were added, both on their own and in conjunction with each other. Clay has the greatest UCS value that has been observed: BA: lime: 79: 15: 6 mixes.
6. The CBR value improved when BA and lime were added, both by themselves and in conjunction with one another. The mixture of clay, barite, and lime with the proportions 79:15:6 has the largest CBR value (11.2), followed by the mixture of clay and lime with the proportions 91:9.

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