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Influence of Salt-Lime Stabilization on Soil Strength for Construction on Soft Clay

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Abstract

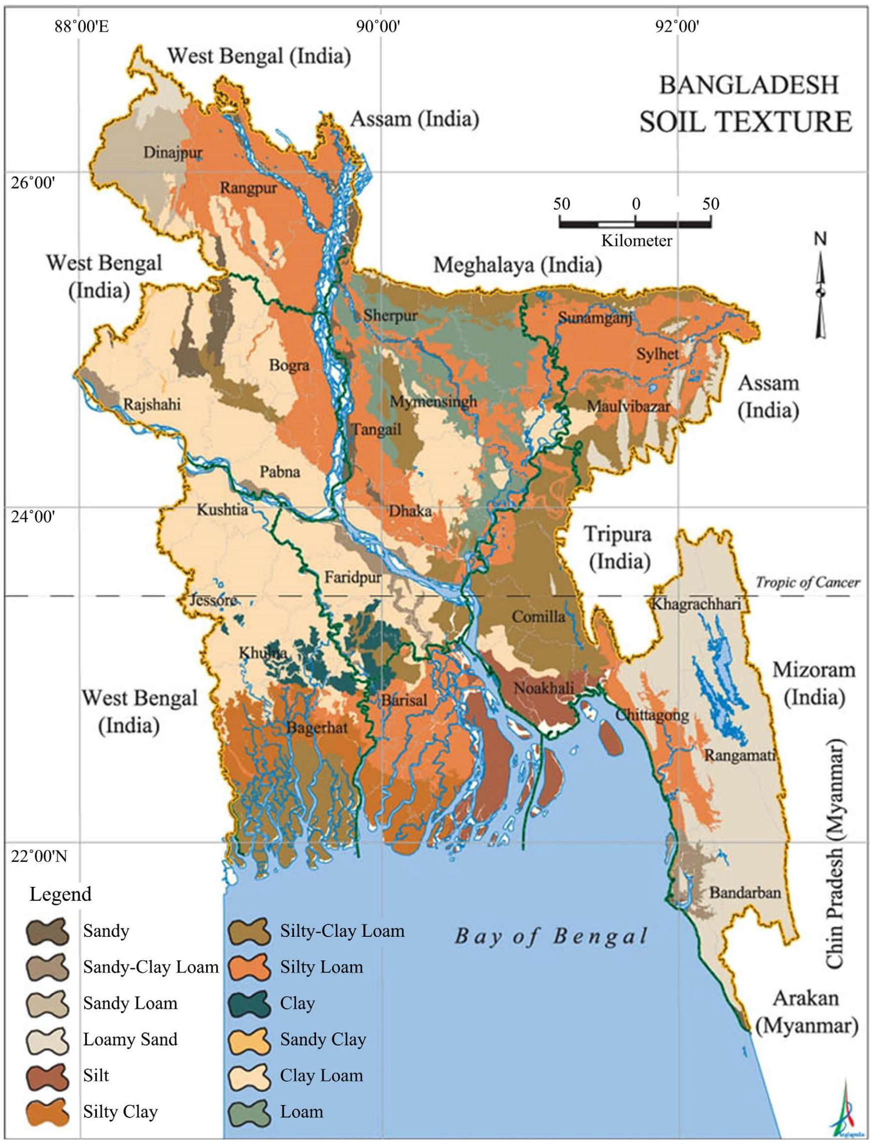
Construction on soft soil is one of the most challenging situations faced by geotechnical engineers. The heterogeneous and complex nature of soil, especially those containing organic clay, often makes it impossible for the construction specification to be addressed properly. Generally, clay exhibits low strength, high compressibility, and strength reduction when subjected to mechanical disturbance. This means that construction on clay soil is vulnerable to bearing capacity failure induced by low inherent shear strength. All these properties can be improved by the effective stabilization of soil. This study analyzed the effectiveness of incorporating salt-lime mixtures at various dosages in improving the strength increment of the soil. The results indicate that among different combinations of salt and lime, the best performance in terms of strength increase was achieved by adding 10% NaCl with 3% lime in the soil. The outcome of this study focuses on enhancing the ultimate strength of soil and its implementation in the field of foundation engineering.

Keywords

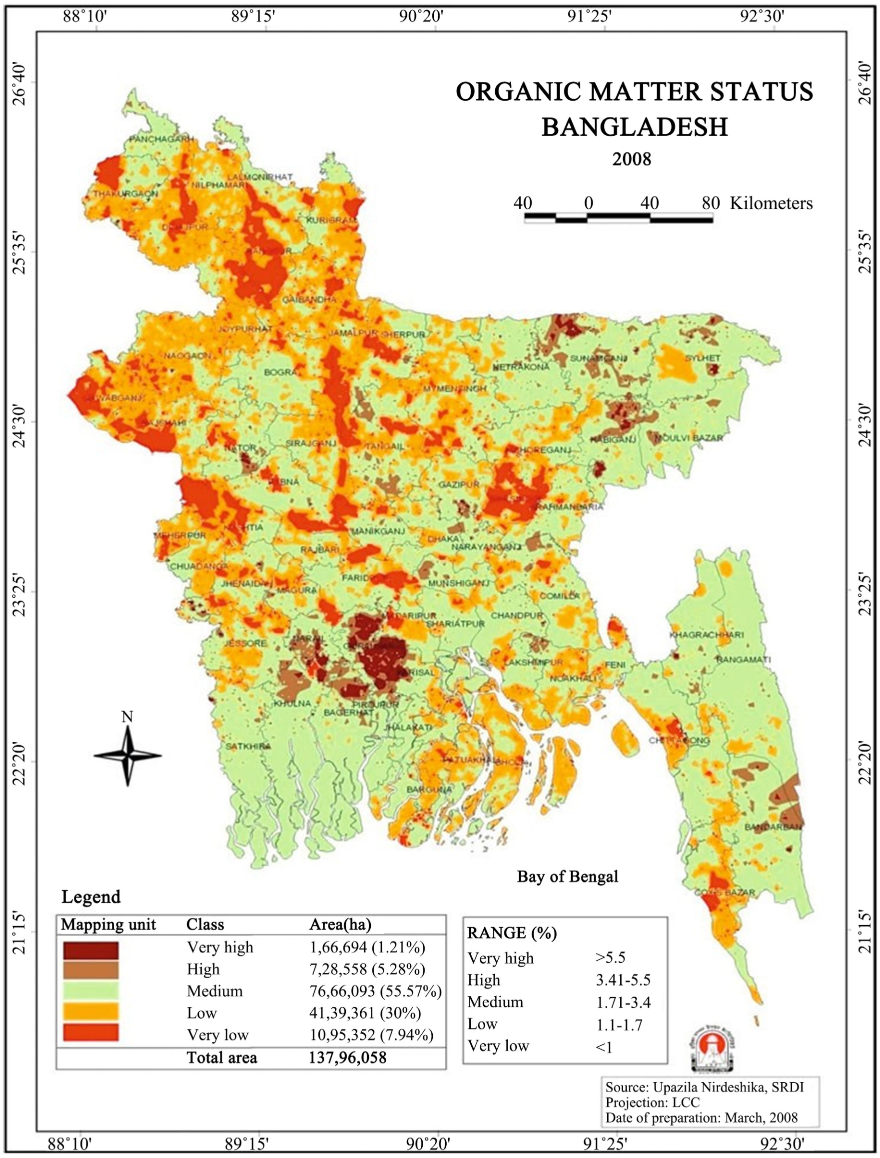
Organic Soil, Bearing Capacity, Soil Improvement, Salt-Lime, Unconfined Compressive Strength

1. Introduction

From the perspective of geotechnical engineering, organic soil is a type of cohesive soil that is particularly weak. Organic clay is a clay soil that contains enough organic matter to impact its engineering capabilities, making it slightly different from clay soil. It is common knowledge that any organic soil with a high organic matter content has a low bearing capacity or strength [1]. This is because toxic substances like humic acid and humates are present in organic matter [2] [3]. In low-lying places where the water table is close to or above the ground surface, organic soils are typically found [4]. As illustrated in **Figure 1(a)**, the generalized soil texture map of Bangladesh shows that the country's southwest part contains clay, sandy clay, and clay loam soils. According to the book "The Soils of Bangladesh" [5], generally, organic matter deposition in Bangladesh is irregular and characterized as very low to low to medium. As per **Figure 1(b)**, the organic matter content (OM content) of Bangladesh is one of the poorest as it contains less than 1% of OM content ranging from 0.05% to 0.9%. Some low-lying areas and peatlands contain OM containing more than 2%. Only the Gopalgonj-Khulna Beel region and some parts of the Sylhet region contain peat materials, whereas the uppermost part of the profiles contains organic matter in these peat soils [5].



(a)



(b)

Figure 1. (a) Soil Texture Map of Bangladesh, (b) Organic Matter Status.

Deposition of organic soil is normally observed in coastal areas and in glaciated regions. This kind of soil possesses moisture content ranges from 200% to 300%, highly compressible in nature and under loading, it is seen to have a substantial amount of settlement from secondary consolidation. Low bearing capacity and low undrained shear strength are the two main issues with organic clay construction [6]. The presence of some organic materials that contain humic acid in concentrations greater than 2% has an impact on this outcome [3]. The main sources of organic clay minerals (silica and alumina) will be covered by organic matter, acting as a "masking," which will alter the pozzolanic reaction throughout the stabilization phase [7] [8]. It is common practice around the world to stabilize clay soil by mixing it with lime to boost its strength and improve its suitability for construction [9] [10] [11]. Due to the cation transfer between the metallic ions surrounding the clay surface particles and the calcium ions of the lime, clay soil undergoes a rapid change in its characteristics when lime is added to it. A second layer of diffuse hydrous that is altered by calcium ion exchange surrounds clay particles [9]. This changes the electrical charge density in the clay particles, which strongly attracts them to one another and initiates the flocculation process. When clay soils are treated with lime, it is essentially this procedure that changes the engineering properties of the soils [12] [13]. The interaction of lime with the soil minerals determines the stabilizing effect. The shear strength and bearing capacity of the soil both increase as a result of this response.

Despite extensive research demonstrating the effectiveness of lime as a ground improvement technique, clay soil's reduced compacted dry unit weight prevents lime from significantly increasing soil strength [14]. This suggests that adding salts to lime as an addition may boost the strength of organic soils significantly more effectively than using lime alone. Numerous studies have also been conducted regarding the stability and behavior of clayey soils [15] [16], seismic site characterization [17], and predicting the bearing capacity of shallow foundations [18]. Moreover, several researches were also done from the perspective of Bangladesh. Shahin *et al.* [19] analyzed seismic hazards at site-specific conditions, whereas Khondokar *et al.* [20] developed a correlation among soil parameters considering a river tunnel project. Zaman *et al.* [21] conducted a numerical finite element simulation approach to determine slope stability. Similarly, research works were also performed considering environmental impacts [22] [23] [24] [25] and structural variety [26] [27] [28]. In previous studies, binders were also incorporated to enhance the performance of concrete and bituminous pavements [29]-[36].

However, there is a research gap considering the effectiveness of salt-lime mixture for organic soil in various percentages considering the strength of the soil, and this research aims to address this gap by incorporating salt-lime mixtures at various dosages in improving the strength increment of the soil. Enhancing the soil strength can improve the conditions at construction sites, especially for the less stable soils found in Bangladesh. This observation has been reiterated across several Finite Element Method (FEM) assessments of diverse geotechnical challenges within the country [37] [38] [39] [40].

2. Test Materials and Methods

2.1. Soil Specifications

The organic soil samples were collected from Koiyakhali Bazar, Botiaghata, Khulna, Bangladesh. The depth of the collected soil sample was 10 feet. The mechanical properties of soil are shown in **Table 1**. The sample preparation process met the industry standard "Standard Specification for Quicklime and Hydrated Lime for Soil Stabilization" (ASTM C977-10) [41]. The suitability of

Table 1. Basic mechanical properties of collected soil sample.

Sp. Gravity, G_s	Consistency index			Compaction result		Grain size distribution (mm)
	Liquid limit, W_L/%	Plastic limit, W_P/%	Plasticity index	Maximum dry density (mg/m^3)	Optimum water content, W/%	
1.611	104.69	85.94	18.75	0.879	37	0.01 to 0.4

stabilization with lime was checked based on the AASHTO classification system (*i.e.*, soil types A-4, A-5, A-6, A-7, and some of A-2-6 and A-2-7).

2.2. Experimental Procedure

Utilizing an unconfined compression test, this study concentrated on the strength characteristic of the organic soil. For the purpose of stabilizing organic soil, various ratios of sodium chloride (NaCl) were combined with varied ratios of lime. Previously, Results obtained will be compared among the three different mixtures of organic soil, lime, and salts. Since hydrated lime is less exothermic and damaging to the skin than quicklime, it will be used in this study. The percentage of lime used are 3%, 6%, and 12% & variable concentrations of sodium chloride (NaCl) as 2.5%, 5% and 10% at the curing period of 0, 7, 14, and 28 days have been used to observe the strength increment of soil.

3. Analysis of Results

3.1. Constant NaCl Concentration

For 2.5% NaCl concentration (**Figure 2**), initially, the strength of the soil is the same for all the lime percentages used. Soil strength at 7 days is the same for lime at 3% and 6% but higher for 12% lime. At 14 days lowest soil strength is found for 3% lime & highest for 6% lime. At 28 days soil strength is highest for 12% lime and lowest for 6% lime content. Here 2.5% NaCl and 12% lime combination shows higher values of strength among these three combinations considering curing period.

For 5% NaCl concentration (**Figure 3**), initially, the strength of the soil is the same for all the lime percentages used. Soil strength at 7 days soil lowest for lime at 12% but highest for 6% lime. At 14 days the lowest soil strength was for 12% lime and the highest for 6% lime. At 28 days soil strength is highest for 6% lime & lowest for 12% lime content. Here 5% NaCl and 6% lime combination shows higher values of strength among these three combinations considering the curing period.

For 10% NaCl concentration (**Figure 4**), initially, the strength of soil is higher for 12% than other percentages. Soil strength at 7 days is lowest for lime at 6% but highest for 3% lime. At 14 days lowest soil strength was for 6% lime & highest for 3% lime. At 28 days soil strength is highest for 3% lime & lowest for 6% lime content. Here 10% NaCl and 3% lime combination shows the best result among these three combinations.

Among these combinations, when sodium chloride (NaCl) percentages are fixed the 10% NaCl and 3% lime combination shows higher values of soil strength.

3.2. Constant Lime Concentration

For 3% lime concentration (**Figure 5**), initially, the strength of the soil is the same for all the NaCl percentages used. Soil strength at 7 days same for 2.5% and 5% NaCl but highest for 10% NaCl. At 14 days soil strength same for 2.5% and 5% NaCl & highest for 10% NaCl. At 28 days soil strength is highest for 10% NaCl and lowest for 5% NaCl. Here 3% lime and 10% NaCl combination show higher values of strength among these three combinations considering the curing periods combinations, when sodium chloride (NaCl) percentages are fixed the 10% NaCl and 3% lime combination show higher values of soil strength.

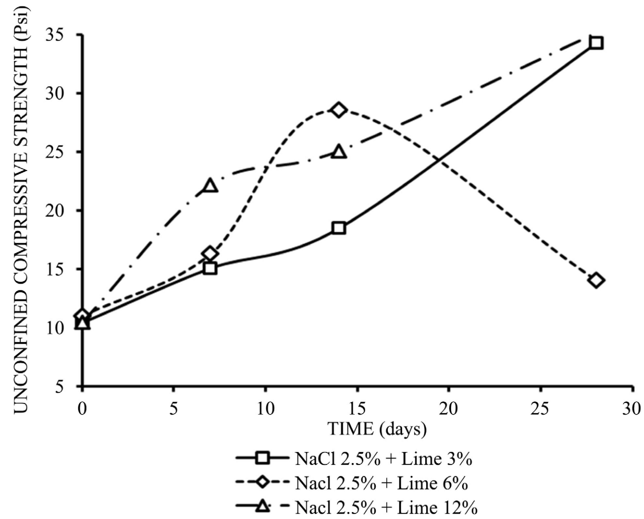


Figure 2. Unconfined Compressive strength (2.5% NaCl concentration).

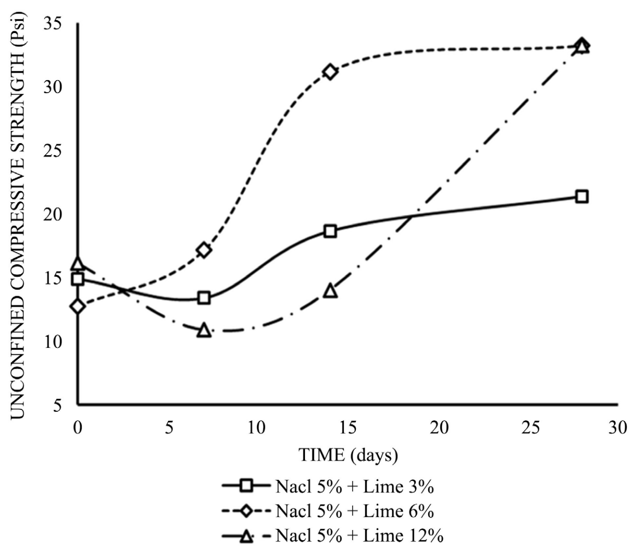


Figure 3. Unconfined Compressive strength (5% NaCl concentration).

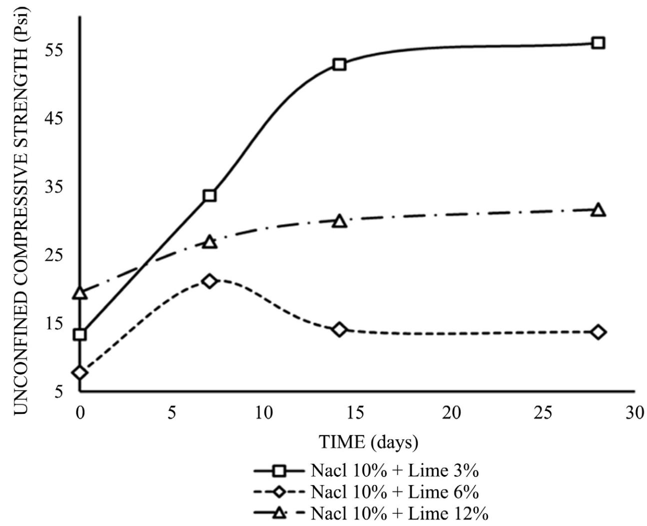


Figure 4. Unconfined Compressive strength (10% NaCl concentration).

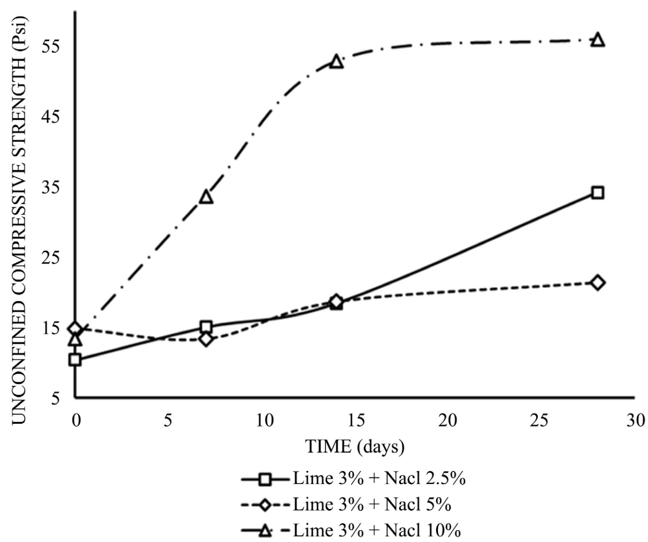


Figure 5. Unconfined Compressive strength (3% Lime concentration).

For 6% lime concentration (**Figure 6**), initially, the strength of the soil is higher for 5% NaCl than the other two percentages. Soil strength at 7 days same for NaCl 2.5% and 5% but highest for 10% NaCl. At 14 days soil strength is lowest for 10% NaCl & highest for 5% NaCl. At 28 days soil strength same for 10% and 2.5% NaCl & highest for 5% NaCl. Here 6% lime and NaCl 5% combination shows higher values of strength among these three combinations considering the curing period.

For 12% lime concentration (**Figure 7**), initially, the strength of soil is higher for 2.5% NaCl than the other two percentages. Soil strength at 7 days lowest for NaCl 10% but highest for 2.5% NaCl. At 14 days soil strength is lowest for 10% NaCl and highest for 2.5% NaCl. At 28 days soil strength is lowest for 10% NaCl& highest for 5% NaCl. Here 12% lime and NaCl 5% combination shows higher values of strength considering the curing period.

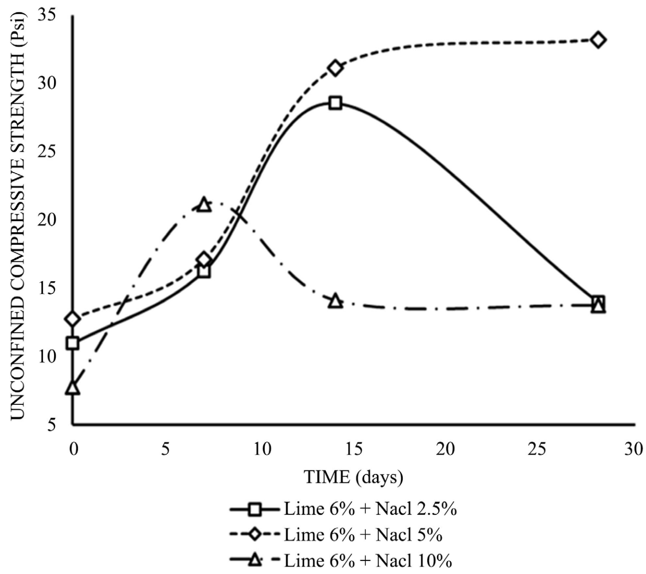


Figure 6. Unconfined Compressive strength (6% Lime concentration).

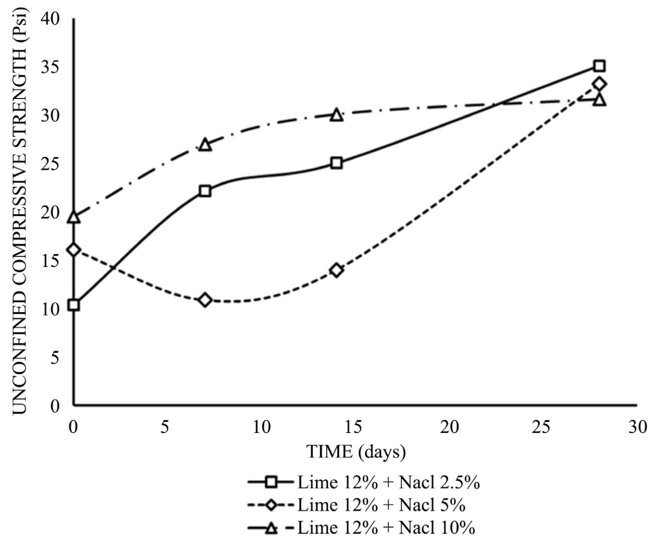


Figure 7. Unconfined Compressive strength (12% Lime concentration).

Among these combinations, when lime percentages are fixed the 10% NaCl and 3% lime combination shows higher values of soil strength.

3.3. Comparison of Results

SAMPLE	UCS (P) 0 day	UCS (PSI) 7 days	UCS (PSI) 14 days	UCS (PSI) 28 days
Organic soil + 2.5% NaCl + 3% lime	10.38	15.05	18.47	34.26
Organic soil + 2.5% NaCl + 6%lime	10.97	16.27	28.55	14.02
Organic soil + 2.5% NaCl + 12% lime	10.44	22.16	25.06	41.75
Organic soil + 5% NaCl + 3% lime	14.89	13.49	18.65	21.37

Continued

Organic soil + 5% NaCl + 6% lime	12.77	17.13	31.14	33.22
Organic soil + 5% NaCl + 12% lime	16.1	10.89	14.02	12.98
Organic soil + 10% NaCl + 3% lime	13.35	33.74	52.94	56.05
Organic soil + 10% NaCl + 6% lime	7.79	21.16	14.02	13.49

4. Conclusions

In this paper, lime induced stabilization mechanism of organic clay was investigated. NaCl was used as an additive. Based on the experiment carried out, the conclusions are listed below:

From the test result, it is noticed that the strength generally increases with respect to the curing period irrespective of the % of admixture used except for two cases (5% NaCl + 12% lime + organic soil) and (10% NaCl + 6% lime + organic soil).

The lowest strength is observed for (10 % NaCl + 6% lime + soil) and the highest value for (10% NaCl + 12% lime) at zero days of curing.

For 7, 14, and 28 days of curing, the corresponding strength shows minimum values for (5% NaCl + 12% lime + soil) which are 10.89, 14.02 and 12.98 psi respectively.

For the same curing period (10% NaCl + 3% lime + soil) shows the highest value of strength considering all the proportions.

The increment of strength for 7, 14, and 28 days is 209.83%, 277.61% and 331.82%, respectively.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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