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Effect of salinity of water in lime-fly ash treated sand

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Abstract

Ensuring sustainable development of coastal areas need improvement of road embankment infrastructure. Being a byproduct of industry, fly ash may be considered as environment friendly and low cost material for this purpose. However, scarcity of fresh water in coastal areas may compel to use saline water. To investigate the effects of sodium chloride content of mixing water on fly ash and lime mixed compacted sand, a series of the unconfined compression tests have been conducted on 50 mm diameter and 100 mm high specimens. Lime content was varied over a range of 1–5% of dry sand weight and fly ash contents were 9, 15 and 30% of dry sand weight. Besides, 0, 4 and 8% of sodium chloride were mixed with tap water, which were used for preparing specimens at 10% moisture content by compaction method. The specimens were cured for 7, 15, 30 and 60 days by spraying method. Experiment results show that, the unconfined compression strength of fly ash and lime mixed compacted sand increases with the increase in sodium chloride content. However, the long term effect of using saline water in fly ash and lime mixed compacted sand should be investigated, which is out of scope of this study.

Keywords: Unconfined compressive strength, Lime, Fly ash, Salt

Introduction

Fly ash is largely used as construction materials as well as for soil improvement over the world [1]. In every day enormous amount of fly ash is produced from coal based power plants and other industrial units. Disposal of fly ash is an environmental concern [2]. Indeed, utilization of industrial by-products brings the environment and economical benefits [3]. Lots of researches have been done on utilizing lime and fly ash for soil improvement as it was done for making durable and economic concrete. Different outcomes were exposed, (i) utilization of lime and fly ash increases the shear strength of soil [1, 3], (ii) maximum strength and stiffness of lime and fly ash treated soil observed on the dry side of optimum moisture content [3], (iii) curing temperature (till 35 °C) increases the tensile and compressive strength, for further increment of temperature no significant influence found. Temperature mainly works as a catalyzer of pozzolanic reactions [1] and (iv) increase of quantity of lime and fly ash increases the strength [4, 5]. However, few research works have been done on the effect of salt content in water on soil improvement by mixing lime and fly ash, though many researches have been conducted on effect of salt water on compressive strength of concrete. For concrete, strength increases with increase of salt content in water [6], [7]). However, some researchers found that compressive strength of concrete (cube specimen) decreases with the increase of salt content in water [8, 9]. Some researchers found that concrete compressive strength for 28 days increases with salt content of water whereas salt content has no effect on long term strength of concrete [10].

In case of Bangladesh, salinity problem in coastal area is tremendous. About 2.85 million hectares of coastal areas [11] consists of 19 districts and accommodates more than 35 million people [12]. All the coastal lands are not being used for crop production due to soil salinity. Each and every year the road damages and embankment collapses due to incessant rain or flood. In this research, the main target is to use lime and fly ash for soil improvement in coastal areas using saline water.

Material

Sand

Sand sample was collected from Mawa, Padma river bank. Collected sand was oven dried before grain size analysis. The result of grain size of sand is shown in Fig. 1. Referring the Fig. 1, the fines content (passes sieve 200) is near about 3% and the fineness modulus (FM) is 1.30. According to the unified soil classification system, the sample is poorly graded sand (SP). To investigate the shape of the sample, scanning electron microscopic (SEM) was performed on sand. The image is exhibited in Fig. 2. The shape of sand particles is sub-angular and specific gravity is 2.67.

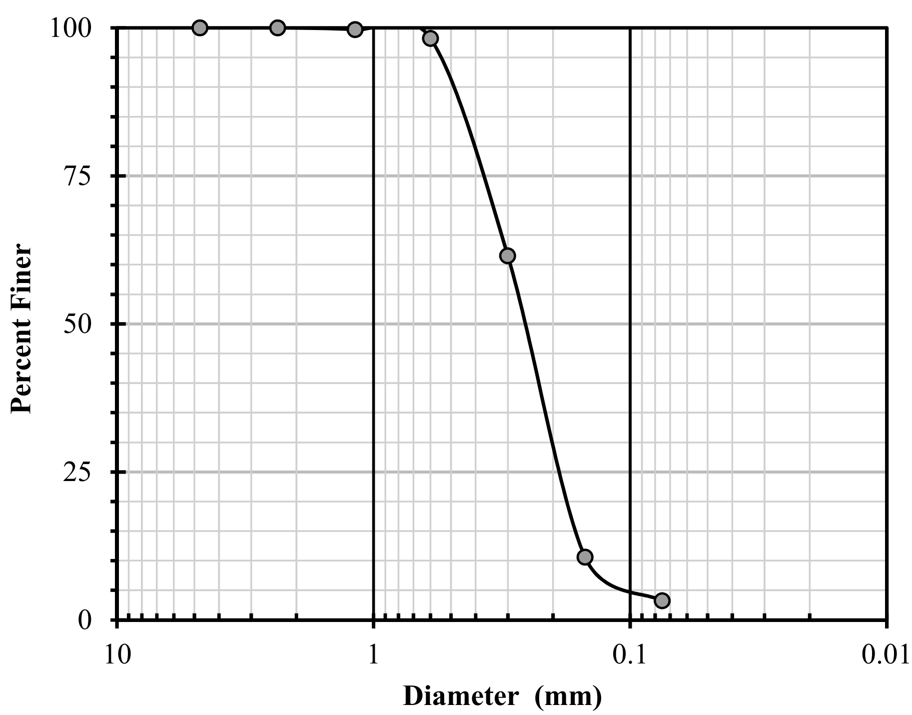

Fig. 1 Grain size distribution of studied sand

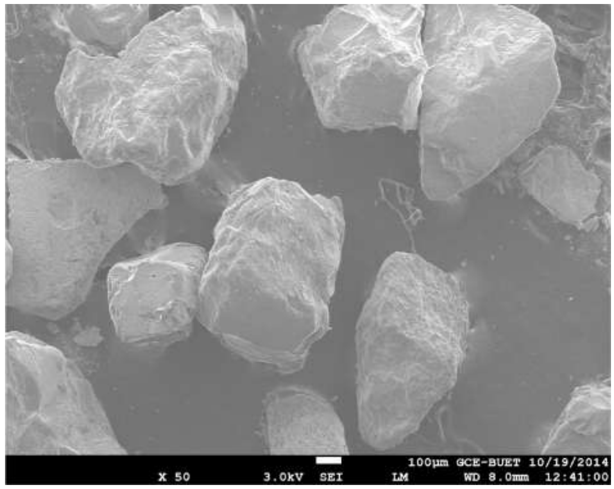

Fig. 2 Scanning electron microscopic view of sand particles

Lime

Lime stones were bought from the local market of Dhaka, Bangladesh. It was in cobble size. Before using, lime stones were crushed to form powder. In powder form it is easier to make a homogenous mixture with sand and fly ash. The specific gravity of lime was 2.57.

Fly ash

Fly ash was collected from Bashundhara Cement Company. The properties of fly ash vary with source [4, 7, 10, 13, 14]. The variation is mainly due to variation of calcium content. Higher calcium content increases the self-hardening value of fly ash [5]. Lower calcium content of fly ash was suggested to use for geotechnical purpose (i.e. soil improvement, filling material). Fly ash was used in this study was classified as class F, because it has no calcium determined by scanning electron microscopy (SEM) with energy dispersive X-ray (SEM/EDX) test. The scanning electron microscopic (SEM) view of fly ash is exhibited in Fig. 3. The shape of fly ash particles is spherical. The specific gravity of fly ash was 2.18.

Salt and water

In Bangladesh the food salt is produced from sea water by evaporation process. Consequently, the food salt was opted to prepare saline water (representative of sea water). The salt was bought from the local grocery shop of Dhaka, Bangladesh. What is more, normal tap water was used to prepare the saline water. The pH value of tap water was 7.48 and for dissolving 4% (4 g/L) and 8% (8 g/L) of salt into the tap water the pH were increased to 7.51 and 7.60 respectively.

Experimental program

In the lime-fly ash treated sand, lime content was 1, 2, 3 and 5% of dry sand weight and fly ash content was 9, 15 and 30% of dry sand weight. The average salt content in sea water is 3–5% [15] and sodium chloride (NaCl) is predominant [16]. In order to investigate the effect of sodium chloride, three NaCl solution in tap water with 0, 4 and 8% (0,

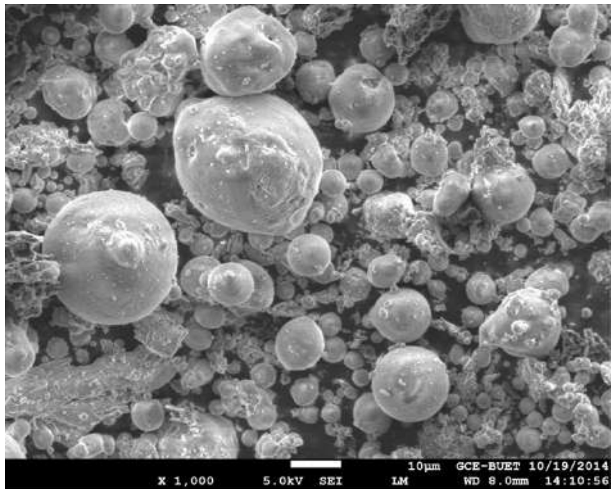

Fig. 3 Scanning electron microscopic view of fly ash particles

40 and 80 g/L) NaCl were used for preparing specimen at 10% moisture content by wet compaction method. The dry density was maintained at 1.283, 1.467 and 1.558 g/cm^3. The required amount of tamping for target density was measured by trial method. Each specimen was prepared within 30 min. The size of the specimen was 50 mm in diameter and 100 mm in height. The prepared specimen was kept in 76 mm inner diameter hollow pipe as shown in Fig. 4; thereafter it was preserved in the curing box. 50 mm diameter specimen was kept in 76 mm hollow pipe so that it can get more surface area for curing to ensure lime, fly ash and salt water reaction in whole specimen. A wet geotextile containing same NaCl solution was placed above hollow pipes and a polythene sheet was used with the lid. Lid locks were used so that the moisture content does not decrease rapidly (see Fig. 4). Curing was done by spraying same NaCl solution 3 or 4 times in a week. 3 or 4 time spraying was found favorable to maintain high moisture content in the specimens. Temperature accelerates the reaction of sand-lime-fly ash mixture. With high curing temperature it is possible to get higher strength within a short time than that of low temperature and long time curing [1]. The temperature in boxes was around 25 to 28 °C. The specimens were cured for 7, 15, 30 and 60 days arbitrarily.

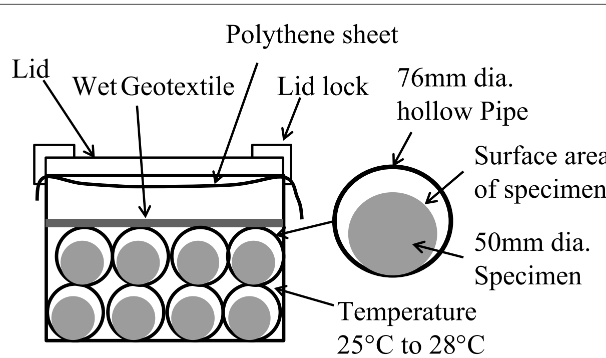

Fig. 4 Specimens in the curing box

Unconfined compression test

After curing, each specimen was submerged for 24 h in the same NaCl solution to get better saturation ratio. In such way it is possible to get the saturation ratio near about 0.89 [4]. Saturation ratio was not determined in this study. Since, for each specimen the dominant material (sand) and submerging method was same, it may be assumed that saturation ratio would be nearly same. However, density, fly ash content and lime content were different. The unconfined compression test was conducted on submerged specimen at an axial strain rate of 1.2% per minute [17] (see Fig. 5). The unconfined compressive strength (q_u) is peak stress. Axial stress verses axial strain graphs of sand treated with 1% lime and 9% fly ash at 0, 4 and 8% salt content after 30 days curing are plotted in Fig. 6. In this three specimens brittle shear failure was observed (as in Fig. 5) and in other specimens the same behavior was observed.

Results and discussion

Effect of lime and fly ash

It is important to understand the reactions in lime-fly ash treated sand. Fly ash having no calcium can not increase shear strength of sand. Silica and alumina of fly ash (glassy portion) react with dissolved lime to form calcium silicate hydrate (C–S–H) and calcium aluminate hydrate (C–A–H). In the normal condition the following hydration reactions occur [18]:

1. $CaO + H_2O \rightarrow Ca(OH)_2$ (Porlandite)

Fig. 5 Submerged specimen for unconfined compression test

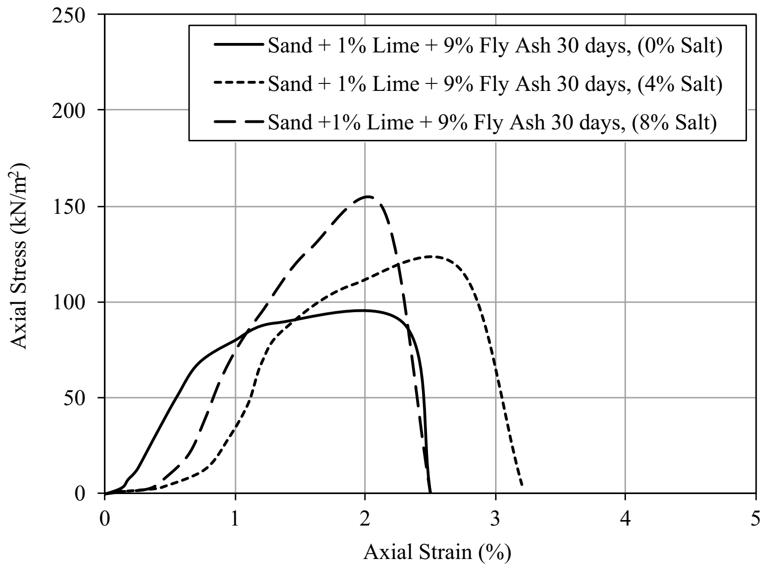

Fig. 6 Axial strain verses axial stress graph

2. $SiO_2 + Ca(OH)_2 + H_2O \rightarrow CaSiO_2{\cdot}2H_2O$ (CSH)
3. $Al_2O_3 + Ca(OH)_2 + H_2O \rightarrow CaO{\cdot}Al_2O3{\cdot}2H_2O$ (CAH)
4. $SiO_2 + Al_2O_3 + Ca(OH)_2 + H_2O \rightarrow CaSiO_2{\cdot}Al_2O_3{\cdot}H_2O$ (CAS)

In Fig. 7, the unconfined compressive strength (q_u) data of two constant dry densities (1.283 and 1.467 g/cm^3) containing equal amount of fly ash (30%) and salt (0%) but different percent (1, 2, 3 and 5%) of lime content is exhibited. It can be observed that the q_u is the function of lime content and dry density. With the increase in lime content the

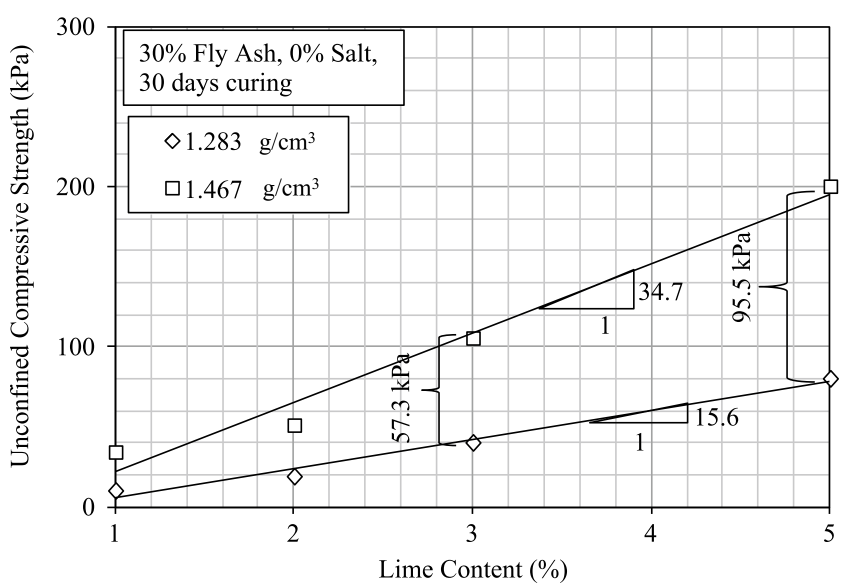

Fig. 7 Effect of lime content on lime and fly ash treated sand

q_u increases at constant fly ash content. However, at higher density rate of increase is higher. At 1% lime content the fly ash was not fully consumed by lime, at 2, 3 and 5% lime content more fly ash was consumed, and consequently the q_u increased. This consumption reduces the pH value with time. Figure 8 traces the pH value verses curing time graph. With long time reaction the p^H value decreases. The SEM micrograph of lime and fly ash is shown in Fig. 9. Here the needle shaped crystal formation is found on spherical fly ash particles. That could be C–S–H or C–A–H.

In Fig. 10, influence of fly ash on compressive strength of lime-fly ash treated sand is shown. At constant lime content, unconfined compressive strength of treated sand increased with increase of fly ash content. At higher dry density, q_u is greater. It could be a reason that at higher density the lime and fly ash get closer and accelerate the pozzolonic reaction therefore the strength increases with the increase of density.

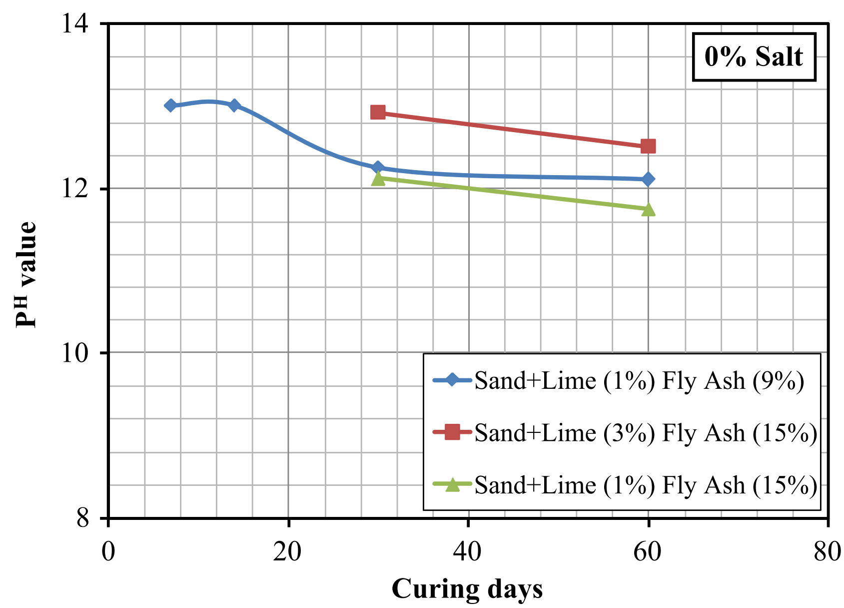

Fig. 8 pH value verses curing days

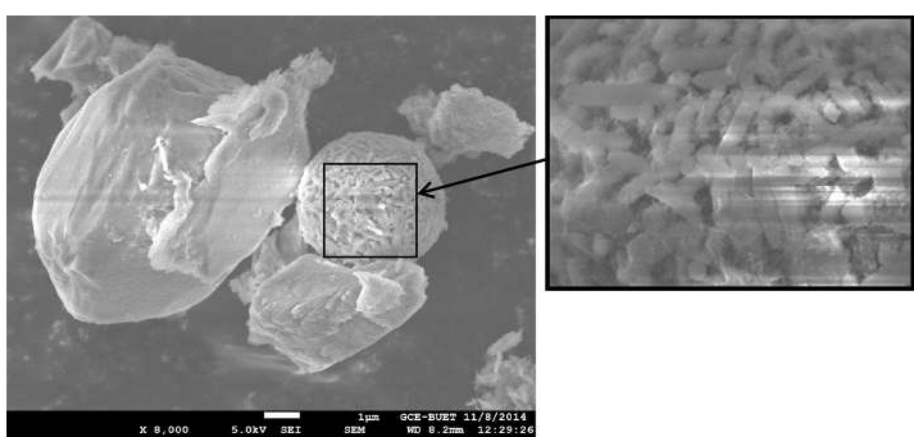

Fig. 9 Scanning electron microscopic view of lime and fly ash after curing

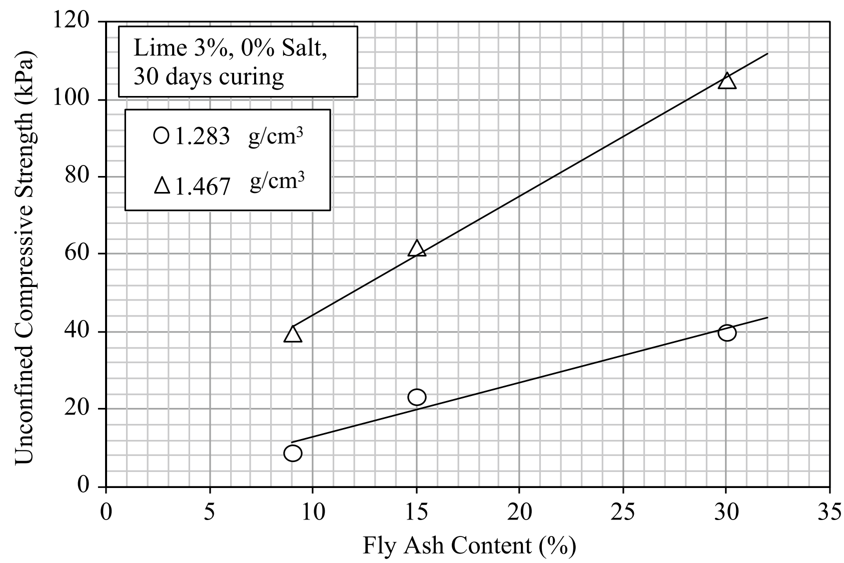

Fig. 10 Effect of fly ash content on lime and fly ash treated sand

Effect of salt content in water

To investigate the effect of salt content in water on fly ash treated sample which was prepared with sand and 10% fly ash (no lime), three specimens at 0, 4 and 8% salt content were prepared and cured with same salt containing water solution for 30 days. When the specimens were put into water the total specimens collapsed. No significant effect of salt content is observed. Without lime, fly ash alone could not contribute to the strength of treated sand. Fly ash had no lime content. It was F class fly ash.

Some lime-fly ash treated sand specimens were prepared using 3% lime and 9, 15, and 30% fly ash. 0, 4 and 8% salt content was used in mixing water solution. The specimens were cured for 30 days. Unconfined compression test results for different percents of fly ash content and salt content are shown in Fig. 11. It is clearly seen that unconfined compressive strength increased with the increase of salt content of mixing water. This increase is due to increase in pH of the mixture by sodium chloride. Davidson et al. [19] proposed that the presence of NaOH increase the pH value.

$$2\text{NaCl} + \text{Ca(OH)}_2 \rightarrow \text{CaCl}_2 + 2\text{NaOH}$$

The higher pH value increases the dissolubility of silicates to interact with calcium and create pozzolanic process to produce cement. Also a calcium-sodium silicate gel improves the cementation faster than a calcium silicate gel [6, 19].

Porosity and b-value correction for best fit curve

In lime-fly ash treated sand, the porosity is a function of sand, lime and fly ash content. The relation was proposed by Consoli et al. [20] as shown in Eq. 1.

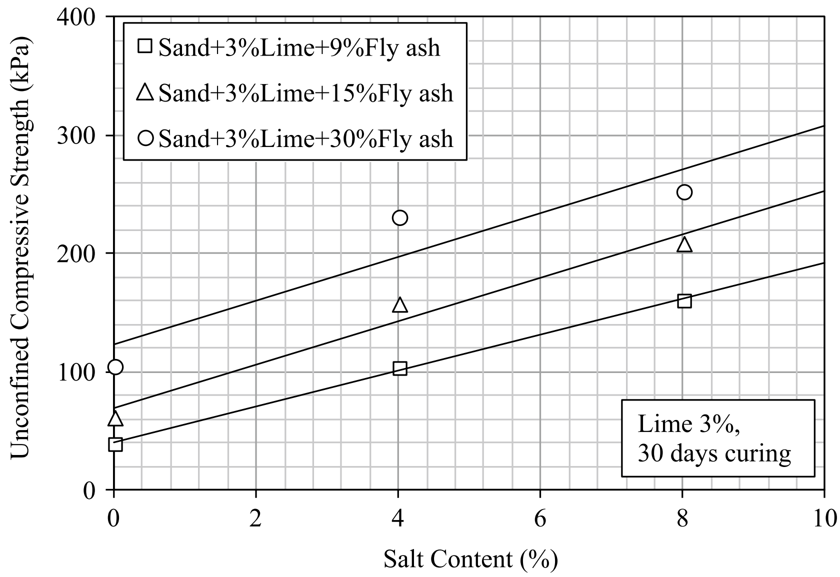

Fig. 11 Effect of salt content on lime and fly ash treated sand

$$\eta = 100 - \left\{ 100 \left[\left(\frac{\left(\frac{\gamma_d V_S}{1+\left(\frac{L}{100}\right)} \right) \left(\frac{S}{100} \right)}{G_{S_S}} \right) + \left(\frac{\left(\frac{\gamma_d V_S}{1+\left(\frac{L}{100}\right)} \right) \left(\frac{FA}{100} \right)}{G_{S_{FA}}} \right) + \left(\frac{\left(\frac{\gamma_d V_S}{1+\left(\frac{L}{100}\right)} \right) \left(\frac{L}{100} \right)}{G_{S_L}} \right) \right] \right\} / V_S \tag{1}$$

where, η = porosity of specimen, FA = fly ash content, L = lime content, γ_d = dry density specimen of Vs = volume of specimen, G_{S_S}, $G_{S_{FA}}$, G_{S_L}, specific gravity of sand, fly ash and lime, respectively. Using this equation Consoli et al. [20] proposed η/L_{iv} ratio [L_{iv}, volumetric lime content] later Consoli et al. [4] used an exponent for L_{iv} and proposed $\eta/L_{iv}^{0.12}$ to best fit, which is more reliable. In Fig. 12, unconfined compressive strength verses $\eta/L_{iv}^{0.12}$ for all lime-fly ash treated sand of 30 days age specimens are exhibited. The unconfined compressive strength increases with the reduction of $\eta/L_{iv}^{0.12}$. At higher density (lower $\eta/L_{iv}^{0.12}$) the salt effect is as significant as that of low density (higher $\eta/L_{iv}^{0.12}$).

In Fig. 12, the best fitted curves of 0, 4 and 8% salt content specimens were tried to bring closer by multiplying the q_u of each specimens. Therefore by back calculation the b-value was determined. The b-value correction is shown in Fig. 13. By multiplying the q_u with b-value all trend curves come closer. Here the b-values were used to normalize all the trend curves which finally fall in a single trend curve (see Fig. 14). This curve can be used for determining the unconfined compressive strength of lime-fly ash treated sand at different percent of salt contents in mixing water. Here Eqs. 2 and 3 are for 4 and 8% salt content respectively are also given below:

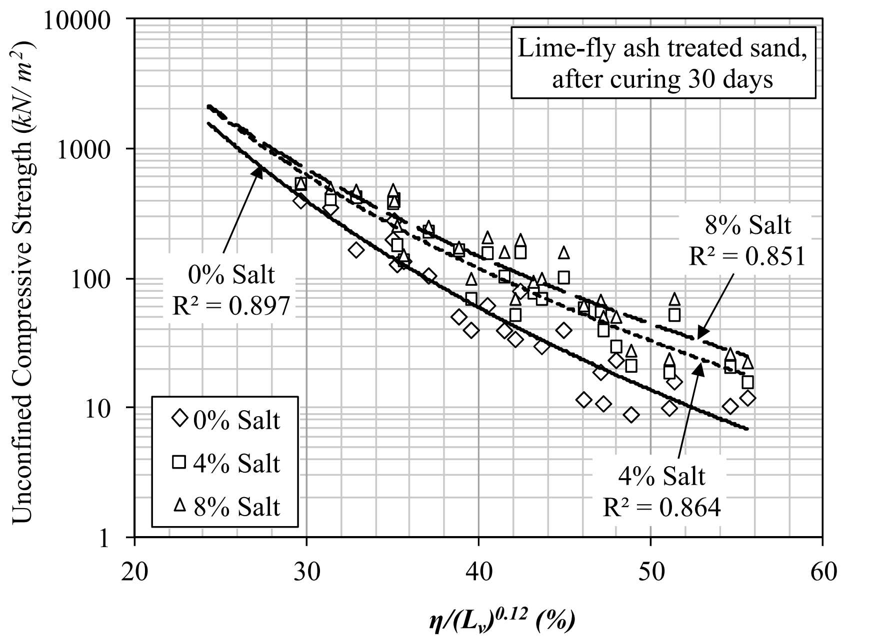

Fig. 12 Unconfined compressive strength verses $\eta/L_{iv}^{0.12}$ graph

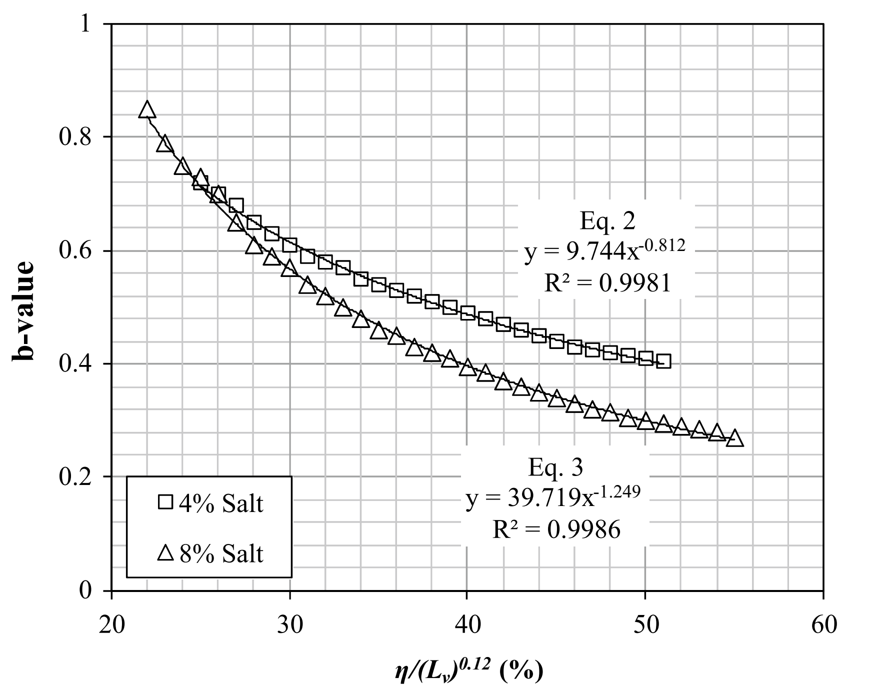

Fig. 13 b-value graph

$$y = 9.744x^{-0.812} \text{ (for 4\% salt content)} \quad (2)$$

$$y = 39.719x^{-1.249} \text{ (for 8\% salt content)} \quad (3)$$

where, $y = b$, $x = \eta/L_{iv}^{0.12}$ (%) and for 0% salt water the b-value is 1.

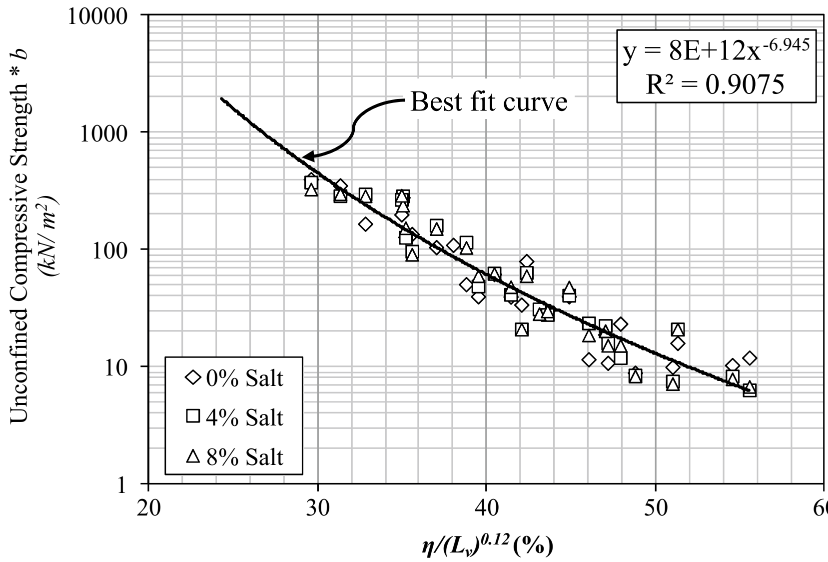

Fig. 14 Best fit normalized curve of unconfined compressive strength for different porosities, lime content and salt contents

Conclusion

A series of unconfined compression tests was conducted on specimens containing different percents of lime and fly ash mixed with sand. Here, for preparing and curing the specimens 0, 4 and 8% percent salt (NaCl) solution were used. The following outcomes were found from the study,

1. With the increase in lime content the unconfined compressive strength of treated sand increased.
2. Salt content of water causes increase of compressive strength of lime-fly ash treated sand.
3. Compressive strength of lime-fly ash treated sand increases with the increase of fly ash content.
4. For fine sand, a correlation among unconfined compressive strength, porosity, volumetric lime content and salt content in water is developed.
5. Fly ash of F class does not have any effect on compressive strength of treated soil without using lime.

Authors' Contributions

MEK has performed experiments, analyse data and written the manuscript. MJA and MSH has supervised the research and revised the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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