Strength Development in Clay Soil Stabilized with Fly Ash

Shriful Islam [1], Nur Hoque [2], Md. Uddin[3] and Mohammod Chowdhury [4]

[1] Shahjalal University of Science and Technology, Bangladesh.
E-Mail: sharif_sust_cee@yahoo.com
[2] Engineer, Shahjalal University of Science and Technology, Bangladesh. E-Mail: snmr.hoque@gmail.com
[3] Engineer, Newcastle University College, Bangladesh. E-Mail: mku.kafil@gmail.com
[4] Professor, Shahjalal University of Science and Technology, Bangladesh. E-Mail: aic-cee@sust.edu

ABSTRACT

The presence of optimum fly ash content in soil to increase the unconfined compressive strength (UCS) of clayey soil has been studied in the present work. Two types of fly ash, collected from coal combustion in an electric power plant, are used; one is Bangladeshi and the other one is Indian. The soil, collected from paddy field of Shahjalal University of Science and Technology (SUST), is classified as a mixture of inorganic silts and organic clays of medium to high plasticity. UCS tests have been conducted on moulds prepared with soil only and with soil containing fly ash with optimum moisture content (OMC) of 19%~24% at a curing time up to 3, 7, 14, 28 and 90 days. Observations showed that maximum dry density (MDD) and OMC of pure soil are 1.615 g/cm^3 and 20.30%, respectively. The addition of fly ash content decreases MDD and increases OMC of the soil. With the increase in fly ash content, two zones of strength development have been observed: the active zone and the deterioration zone. The optimum fly ash content is found as 5% for both types of fly ash. 5% Bangladeshi fly ash content in the soil-fly ash mix produces 430.96 kPa and 474.53 kPa UCS at 28 and 90 days, respectively, while Indian fly ash generates 424.63 kPa and 434.01 kPa UCS, respectively.

KEYWORDS: Soil strength, Fly ash, Stabilization, Standard proctor test, Unconfined compressive strength (UCS) test.

INTRODUCTION

Soft clays cover large areas of Bangladesh including many low lands and coastal regions, where many urban and industrial hubs are located, and are frequently used for construction purposes. These poor sites are characterized by low bearing capacities and large settlements. As subgrade material, most of the soils are classified as AASHTO A-4 to A-7-6, meaning that they are predominantly fine-grained silt and clay soils. These clay soils exhibit poor strength, high instability and durability problems. It is crucial to increase the strength of soil for construction of roads and buildings.

Soil stabilization techniques are well recognized and used in several applications of soil improvement, like development of shear strength, soil stabilization, load bearing capacity, filter drainage systems,… etc. Cement, lime, fly ash…, etc. are used independently as admixtures of different combinations for soil stabilization in different studies. Shah et al. (2003) carried out a research on contaminated soil and found the best unconfined compressive strength (UCS) of soil with a combination of 10% lime, 5% fly ash and 5% cement. An investigation was carried out in detail on clay soil by the addition of both fly ash and lime in order to elucidate the stabilization mechanism and found optimum fly ash content to be 20% considering UCS

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(Sharma et al., 2003). Senol et al. (2006) studied four types of soft subgrade to be stabilized by different types of self-cementing fly ash considering three factors; ash content (0 to 20%), molding water content (8%-38%) and compaction delay (2 hours). Ngoma and Chirwa (2011) used fly ash and lime (quicklime) for stabilizing low-volume unpaved roads in alignments dominated by cohesive soil which is an inorganic clay of high plasticity (CH) or fat clay (expansive clay) and maximum UCS was found for 20% fly ash content. Takhelmayum et al. (2013) used fine and coarse fly ash with black cotton soil and found the optimum content to be 25% of fine fly ash. Zha et al. (2008), Cetina et al. (2010), Reddy and Gourav (2011) and many other researchers investigated the development of soil strength in different conditions and admixtures.

In Bangladesh, six potential coal fields have been identified, where the annual fly ash production is about 1 million tons, 65% of which from the Barapukuria coal-fired thermal power plant (Tamim et al., 2013). In India, around 131.09 million tons of fly ash have been produced in 2010-2011, where around 73.13 million tons of fly ash were utilized (Haque, 2013). These huge amounts of fly ash occupy enormous areas of land for their disposal and cause air, land and water pollution.

Due to unavailability of high land, many infrastructures are built in low land. A structure constructed on soft clay could undergo excessive settlements. For the purpose of road construction and development of residential and industrial structures, it is always important to provide a strong and durable basement soil. An attempt of this study is to bring such unpredictable behavior under control. Therefore, a number of laboratory experiments are conducted to ascertain a host of soil engineering properties of a naturally available clay soil from paddy field before and after soil-fly ash mix. Fly ash employs less overburden pressure and lateral pressure due to its low dry density (Sumesh et al., 2013). Thus, the usage of fly ash in geotechnical engineering applications, such as construction of highway pavements and embankments and backfilling for retaining walls,… etc., holds great potential for overwhelming large amounts of fly ash in an environmentally suitable manner and at substantially economic profit. In this study, fly ash is uniquely used in soil strength development. Using fly ash as a ground improvement, soil admixtures are found technically viable, cost-effective and environmentally beneficial with considerably less capital investment. Fly ash can improve compressive strength of these poor sites. Pozzolanic reactivity of fly ash is the main reason for the development of unconfined compressive strength of soil (Sridharan et al., 1997; Joshi and Lohtia, 1997). The objective of this study is to optimize fly ash content in the soil-fly ash mix by measuring unconfined compressive strength at optimum moisture content. In presence of fly ash, soil behavior is inspected through Atterberg limit and compaction test.

MATERIALS AND METHODS

The soil sample has been collected from the paddy field of Shahjalal University of Science and Technology, Sylhet in Bangladesh at a depth of 3 m following the studies of Horpibulsuk et al. (2010) and Nontananandh et al. (2004). Two types of fly ash are used in this study: one is from Barapukuria thermal power plant at Fulbari, Dinajpur, Bangladesh and the other is from Farakka super thermal power station at Nabarun in Murshidabad, India. The geotechnical characteristics of the soil sample have been evaluated before compaction and unconfined compressive strength tests.

Compaction Test

The soil sample is oven-dried for 24 hours and pulverized with a wooden hammer. The sample passed through sieve no. 4 is taken for compaction test, then water content is adjusted for standard proctor test. At least five compaction points have been generated for standard proctor test. The compaction test for each soil-fly ash mix is conducted following ASTM D698 (2004) procedure with 600 kN-m/m^3 energy.

Unconfined Compression Strength Test

The 24-hour oven-dried and pulverized sample is also used in UCS testing. Sufficient soil is taken that is passed through sieve no. 10 (2 mm) for mould preparation. For both Bangladeshi and Indian fly ashes, 0%, 2%, 4%, 5%, 8%, 10%, 15%, 20% or 25% fly ash content is added to a sufficient soil sample on mass by mass basis and mixed thoroughly. A sample is taken into a mixing pan with enough distilled water, so that water content meets OMC, following Sumesh et al. (2010). The sample of soil-fly ash mixture and water (OMC) is mixed thoroughly until the color appears uniform. Then, it is kept about 2 hours in order to evaluate the impact of compaction delay that commonly occurs in field construction, following Senol et al. (2006). After 2 hours of delay period, moulds are prepared with a diameter of 38.405±0.055 mm and a length of 77.9±0.6 mm, which ensures the height to diameter ratio to be between 2 and 2.5, as recommended by ASTM D2166 (2004). All the samples are allowed to cure for 3, 7, 14, 28 and 90 days for all percentages of both Bangladeshi and Indian fly ash content in room temperature and at 100% relative humidity conditions in the humid room, following the study of Senol et al. (2006). After curing, specimens are put in the compression device to evaluate compression strength.

RESULTS AND DISCUSSION

Characterization of Soil from Paddy Field

Sieve analysis (ASTM D422 2004) shown in Fig. 1 depicts that the soil is composed of 0.83% gravel, 37.76% sand and 61.42% silt and clay. Specific gravity of the soil solids is 2.58, determined by ASTM D854 (2004) method. The liquid limit and plastic limit are approximately 54.48% and 29.68%, respectively (determined according to ASTM D4318 2004). The soil is classified as inorganic silts of high plasticity (MH) or organic clays of medium to high plasticity (OH) according to the Unified Soil Classification System (USCS). The details of general properties of the soil sample are shown in Table 1. X-ray diffraction is conducted on pulverized air-dried soil solids using Rigaku-MiniFlex II powder diffractometer. The solids for analysis are passed through #200 sieve (74 microns) and the result is plotted in Fig. 2. As shown, the soil solids contain quartz, orthoclase, illite and kaolinite.

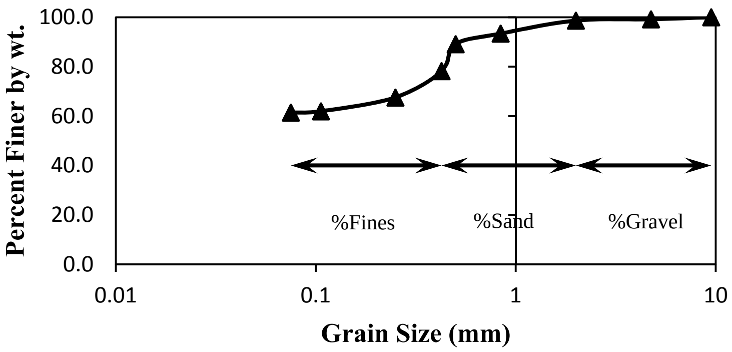

Figure (1): Grain size distribution of soil

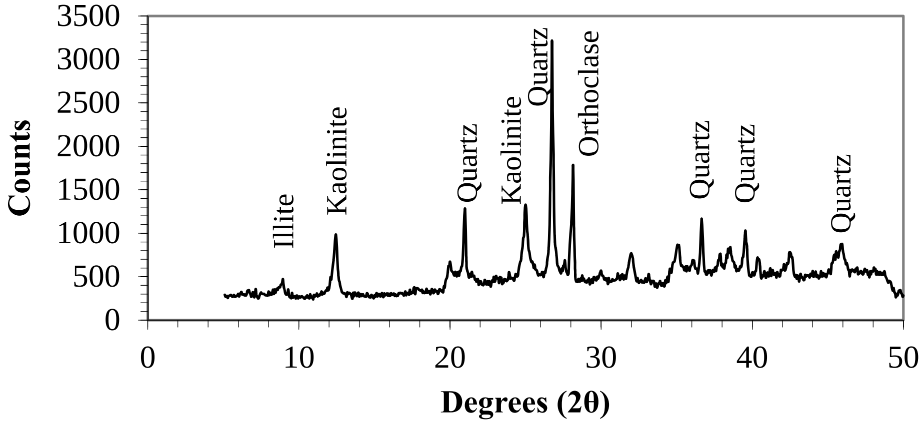

Figure (2): X-ray diffraction of bulk soil sample

Table 1. General properties of soil used in the study

Serial no.	Properties	Values
1	Specific gravity	2.58
2	Grain size analysis (%) Gravel Sand Silt and clay	 0.83 37.76 61.42
3	Atterberg limits (%) Liquid limit Plastic limit Plasticity index	 54.48 29.68 24.79
4	Compaction study Optimum moisture content (OMC), % Maximum dry density (MDD), g/cm^3	 20.30 1.615

Both Bangladeshi and Indian fly ashes are added to the soil as percentages of 2%, 4%, 5%, 8%, 10%, 15%, 20% and 25% (mass/mass). The liquid limit (LL) of soil sample and soil-fly ash mix gradually varies between 54.43% and 52.71%, while the plastic limit (PL) varies between 29.98% and 37.21% with the increase in Bangladeshi fly ash content to the soil. Zha et al. (2008) found similar results. It is well known that the addition of fly ash can reduce the thickness of the diffused double layer of clay particles, causing flocculation of clay particles and increasing the coarser particle content by substituting finer soil particles with coarser fly ash particles (Zha et al., 2008; Sivapullaiah et al., 1996). On the other hand, the addition of Indian fly ash in the soil-fly ash mix with the same percentage shows that LL and PL range between 53.83% and 44.61% and between 29.29% and 26.14%, respectively. As the Indian fly ash content increases, the amount of soil to be flocculated decreases and the finer particles of fly ash may be incorporated in the voids of flocculated soil. Thereby, the water held in pores decreases and the plastic limit is reduced (Ramlakhan et al., 2013). Fig. 3 represents the variation of liquid limit and plastic limit with the change in fly ash content. When Bangladeshi fly ash is mixed with soil, the type of the mixture remains inorganic silts of high plasticity (MH) or organic clays of medium to high plasticity (OH), but due to the mixing of Indian fly ash, the soil changes to inorganic clays of high plasticity (CH) (with fly ash percentage up to 10%) or inorganic clays of low to medium plasticity (CL) (fly ash percentage more than 10%). The detailed results are shown in Table 2. Figs. 4 and 5 show the plasticity charts for soil and different percentages of soil-fly ash mix, respectively.

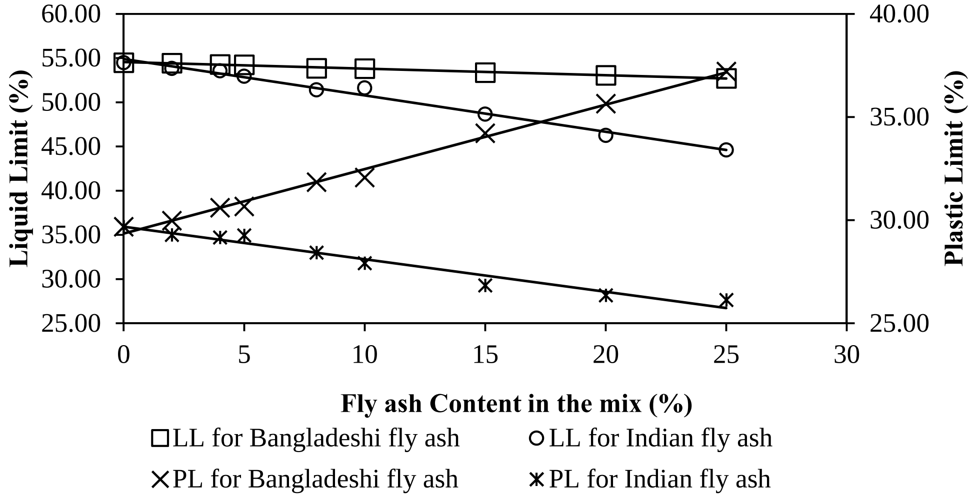

Figure (3): Variation of liquid limit and plastic limit in presence of different percentages of both Bangladeshi and Indian fly ashes

Table 2. Atterberg limits of soil-fly ash mix for both Indian and Bangladeshi fly ashes

Type of fly ash	fly ash (%)	Atterberg limits (%)			USCS
		LL	PL	PI	
N/A	0	54.48	29.68	24.79	MH or OH
Bangladeshi fly ash	2	54.43	29.98	24.45	MH or OH
	4	54.29	30.61	23.57	MH or OH
	5	54.25	30.67	23.58	MH or OH
	8	53.86	31.85	22.01	MH or OH
	10	53.82	32.07	21.75	MH or OH
	15	53.36	34.22	19.14	MH or OH
	20	53.06	35.65	17.41	MH or OH
	25	52.71	37.21	15.50	MH or OH
Indian fly ash	2	53.83	29.29	24.54	CH
	4	53.56	29.17	24.39	CH
	5	52.95	29.26	23.68	CH
	8	51.41	28.43	22.98	CH
	10	51.63	27.92	23.72	CH
	15	48.66	26.84	21.82	CL
	20	46.27	26.36	19.90	CL
	25	44.61	26.14	18.47	CL

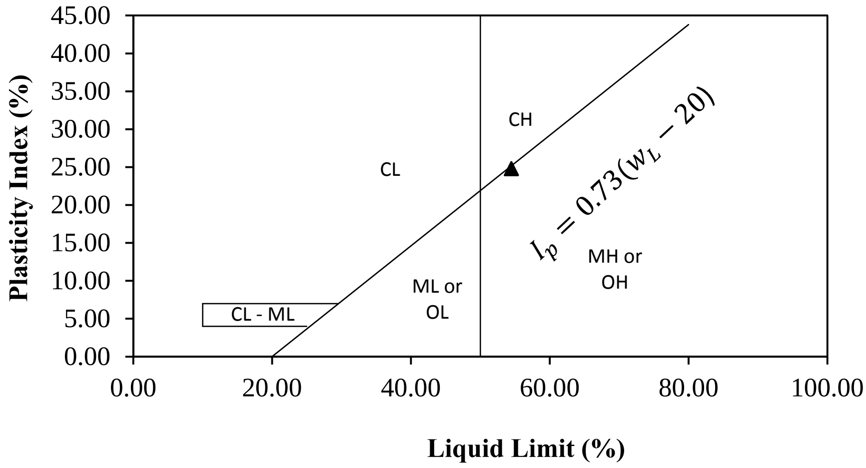

Figure (4): Soil sample classified in the plasticity chart (USC)

Compaction Test

Dry density *vs.* moisture (or water) content curves are plotted in Figs. 6 and 7 for soil-fly ash mix with Bangladeshi and Indian fly ash, respectively, using the values found in several compaction tests with fly ash content of 0% to 25%. Fig. 8 shows the compaction test result of soil-fly ash mix in the presence of 5% fly ash with pure soil. It is found that maximum dry density of soil is 1.615 g/cm^3. Fig. 9 specifies that MDD of all the soil-fly ash mixes gradually decreases with increasing fly ash content in the soil-fly ash mix. Low specific gravity of fly ash compared to that of soil is the main cause for the decrease of MDD (Pandian et al., 1998). Similar results have been found in the studies carried out by Sumesh et al. (2010), Kaniraj and Havanagi (1999) and Zha et al. (2008). OMC of soil is 20.30% and OMCs of soil-fly ash mix for both fly ashes are presented in Table 3. OMC increases with the increase in fly ash content, because the water absorption capacity of fly ash is more than that of the soil. For soil-fly ash mix, the results of MDD and OMC range between 1.59 g/cm^3 and 1.51 g/cm^3 and between 20.52% and 23.74%, respectively, for Bangladeshi fly ash content (2- 25%). Similarly, the results of MDD of soil-fly ash mix range from 1.62 g/cm^3 to 1.55 g/cm^3 and OMC varies from 19.50% to 21.15% for Indian fly ash content (2-25%). Prabakara et al. (2004) found similar results for three types of soil (CL, OL and MH based on the plasticity chart) with the addition of fly ash. However, this decreasing rate of MDD and increasing rate of OMC are relatively low for Indian fly ash compared to those of Bangladeshi fly ash in the soil-fly ash mix. OMC of soil-fly ash (Indian) mixture (2% fly ash) first starts to decrease from OMC of natural soil and then increases. The study performed by Ngoma and Chirwa (2011) showed that the generated MDDs and OMCs are 1830 kg/m^3, 1780 kg/m^3, 1700 kg/m^3 and 1500 kg/m^3; and 15%, 16%, 18% and 19% due to the presence of 0%, 10%, 20% and 30% fly ash content, respectively, in soil. In contrast, Sharma et al. (2012) showed that OMC and MDD increase with the increase in fly ash content in the soil-fly ash mix.

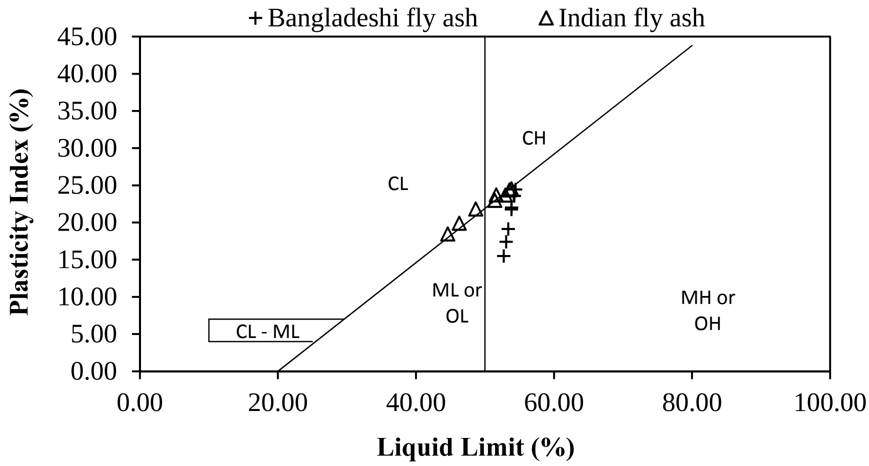

Figure (5): Classification of soil-fly ash mix in the plasticity chart (USCS)

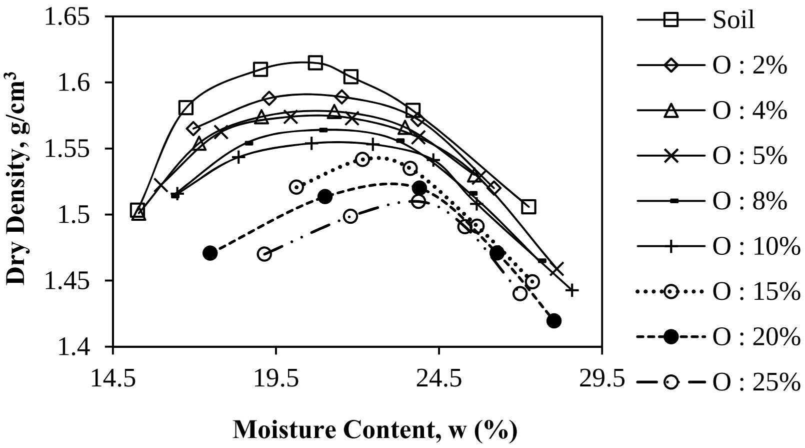

Figure (6): Compaction test results of soil-fly ash mix in presence of Bangladeshi fly ash ("O" represents Bangladeshi fly ash)

Unconfined Compression Strength Test

The unconfined compressive strength of soil is 289.07 kPa and 296.7 kPa at 28 days and 90 days of curing, respectively, without adding any fly ash. Figs. 10 and 11 show the plot between axial stress and time at 28 and 90 days, respectively, for soil and Bangladeshi fly ash-soil mix. Similarly, Fig. 12 presents axial stress *vs.* time plot at 90 days for soil and Indian fly ash-soil mix. Fig. 13 shows the UCS results of soil-fly ash (5%) mix in bar-diagram after 90 days of curing. The plot exposes that curing time and fly ash content up to 5% have a major effect on gaining the unconfined compressive strength, since the pozzolanic reactions enhance the bonding between particles with the addition of fly ash. As the pozzolanic reactions are time-dependent, UCS progresses with time. This means that the quantity of fly ash up to 5% can induce pozzolanic reactions effectively and contribute to the strength development of soil. The addition of fly ash above 5% causes a reduction of UCS of the soil-fly ash mix. This means that the additional quantity of fly ash acts as unbound particles with neither appreciable friction nor cohesion, causing a decrease in strength. The results are similar to those of Zha et al. (2008), Bell (1996) and Kate (2005). Moreover, Fig. 5

shows that the increment of Bangladeshi and Indian fly ash content more than 5% in the fly ash-soil mix provides lower values of plasticity. Fig. 13 shows the strength of soil with that of soil-fly ash mix (5% fly ash) for both Bangladeshi and Indian fly ashes. The values of UCS of 20% and 25% fly ash-soil mix for Bangladeshi fly ash in 3 and 7 days are even lower than that of soil only. On the other hand, UCS values of Indian fly ash for the whole time period (3 to 90 days) with 20% and 25% fly ash-soil mix are less than that of soil only. UCS values of 5% Bangladeshi fly ash in the fly ash-soil mix up to 28 and 90 days are 430.96 kPa and 474.53KPa, respectively. On the other hand, UCS values of soil-fly ash mix containing 5% Indian fly ash at 28 and 90 days are 424.63 kPa and 434.01 kPa, respectively. It is clear from the observations that 5% fly ash is the optimum fly ash content in the soil-fly ash mix for both Bangladeshi and Indian fly ashes in terms of maximum unconfined compressive strength. Shah et al. (2003) found that compressive strength of fuel oil-contaminated soil with 5%, 10% and 20% fly ash is 61.78, 68.65 and 76.49 kPa, respectively for 7 days of curing. Ngoma and Chirwa (2011) found 256.8 kPa, 337.82 kPa, 490 kPa and 375 kPa compressive strength of soil with the presence of 0%, 10%, 20% and 30% fly ash content at 28 days of curing. For 0%, 10%, 15%, 20% and 25% fly ash content, unconfined compressive strengths are 24.73 kPa, 34.73 kPa, 38.83 kPa, 63.38 kPa and 45.11 kPa, respectively, for 0 days of curing, which indicates strength increases up to 20% fly ash content, in agreement with the study of Sharma et al. (2012).

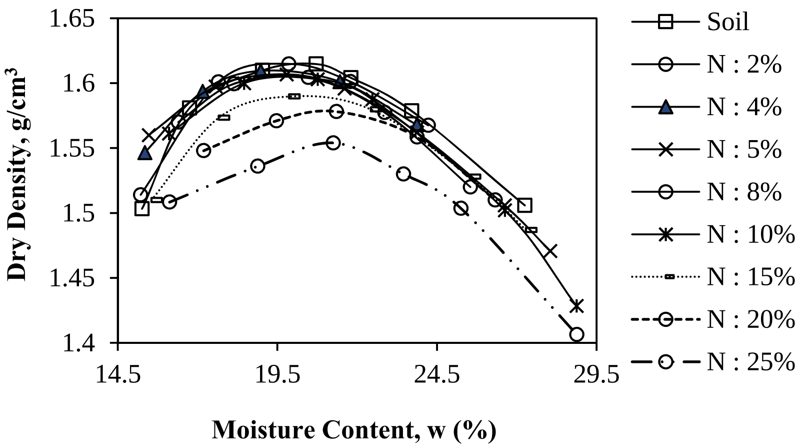

Figure (7): Compaction test results of soil-fly ash mix in the presence of Indian fly ash ("N" represents Indian fly ash)

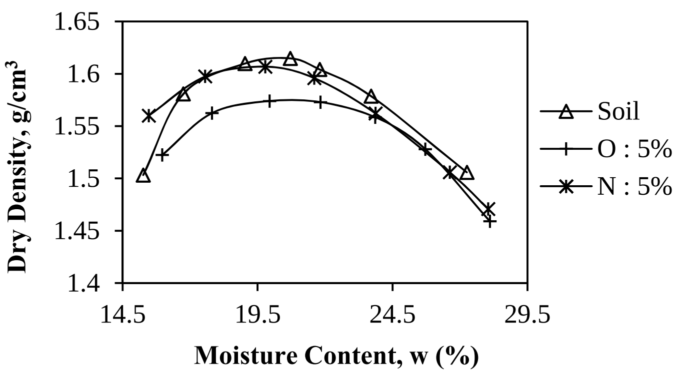

Figure (8): Compaction test results of soil-fly ash mix in the presence of 5% fly ash with pure soil ("O" represents Bangladeshi fly ash and "N" represents Indian fly ash)

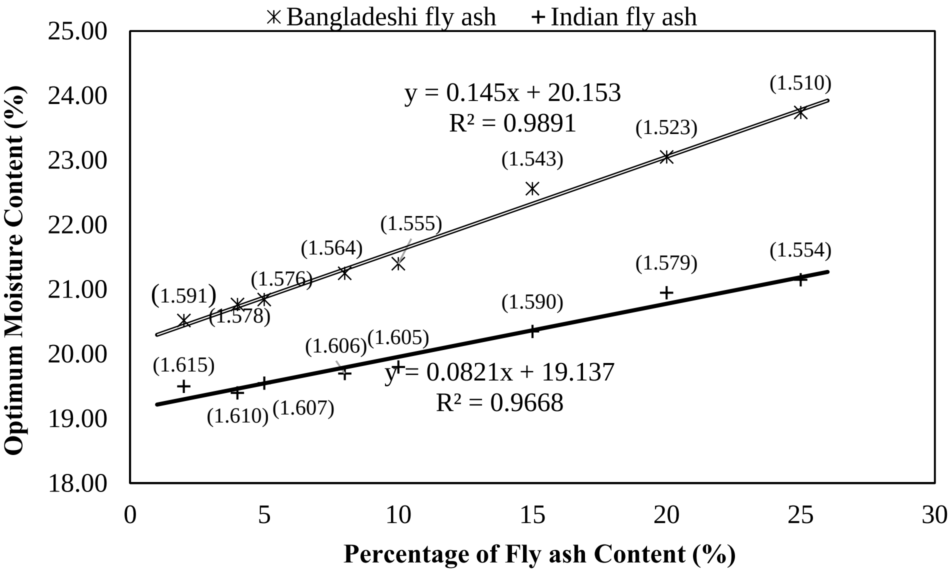

Figure (9): Variation of OMC in the presence of different percentages of both fly ashes (data in parentheses indicates MDD)

UCS of the mix using Bangladeshi fly ash is higher than that of the mix using Indian fly ash in the long run. However, the fly ash-soil mix using Indian fly ash up to 5% content gives more UCS than that using Bangladeshi fly ash in cases of short-time curing (up to 14 days). Figs. 14 and 15 show the axial strength *vs.* fly ash content graph for 28 and 90 days, respectively, for both Bangladeshi and Indian fly ashes, presenting the strength development in the soil-fly ash mix.

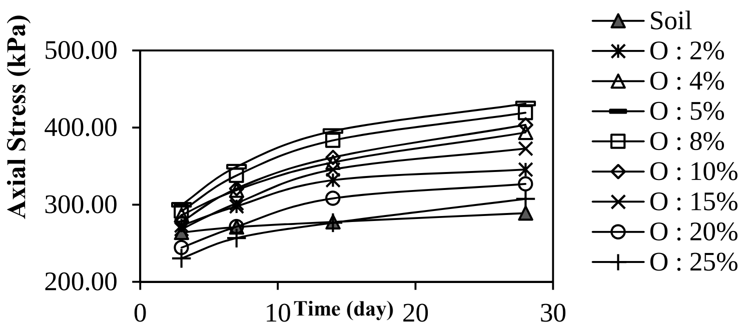

Figure (10): Axial stress *vs.* time up to 28 days for Bangladeshi fly ash with soil

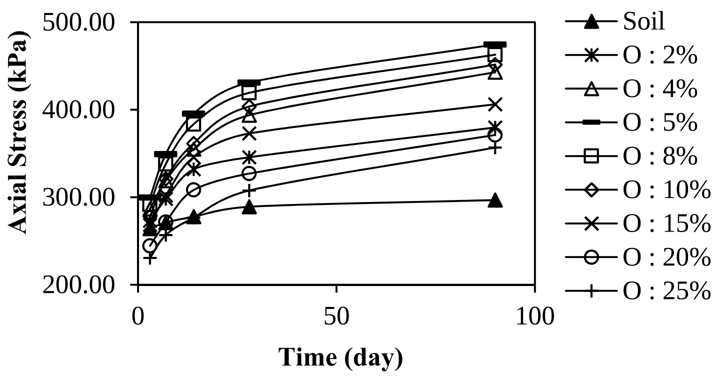

Figure (11): Axial stress *vs.* time up to 90 days for Bangladeshi fly ash with soil

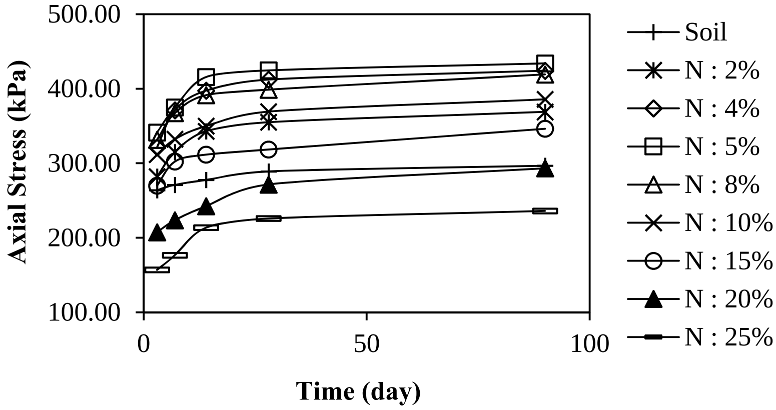

Figure (12): Axial stress and time up to 90 days for Indian fly ash compared with soil

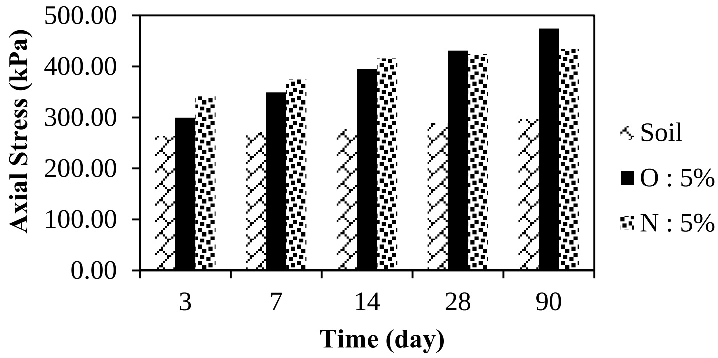

Figure (13): Unconfined compressive strength up to 90 days for 5% Bangladeshi and Indian fly ashes compared with soil

The strength development in the soil-fly ash mix can be classified into two zones; active zone and deterioration zone, following Horpibulsuk et al. (2010). The contact point per grain also increases with the increase in fly ash content in the soil-fly ash mix and the fly ash content of 5% may cover almost all the contact points of soil grains which fill up with fly ash particles. For this reason, strength develops up to 5 % fly ash content and reaches its maximum. This zone is designated as the active zone (0-5% fly ash). The strength of the mix starts to decrease when fly ash content is greater than 5%, which is designated as the deterioration zone.

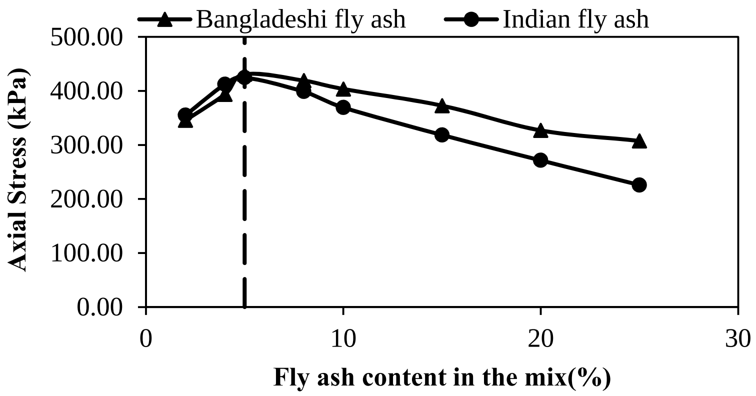

Figure (14): Strength development in soil-fly ash mix for 28 days of curing only

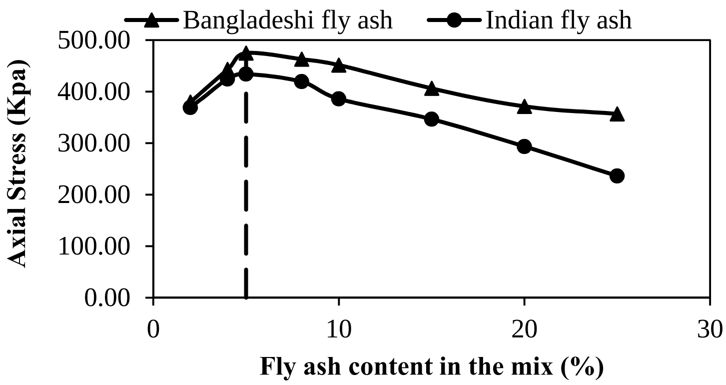

Figure (15): Strength development in soil-fly ash mix for 90 days curing only

Figs. 16 and 17 show the strength increment *vs.* time in bar-diagram for Bangladeshi and Indian fly ash, respectively. In general, with the increase in fly ash content and curing time, the strength is increased up to 20% fly ash content. For 20% and 25% fly ash content, the increment of strength is negative (strength reduces) for Bangladeshi fly ash up to 7 days, while for Indian fly ash with fly ash content of 20% and 25%, the increment is negative during the entire experimental period of 90 days.

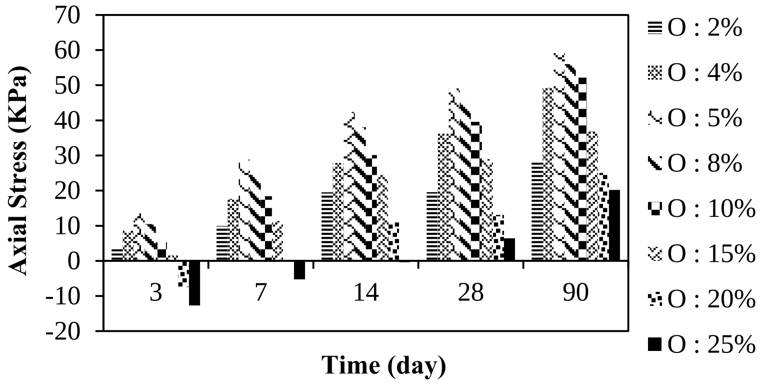

Figure (16): Strength increment column chart for Bangladeshi fly ash-treated soil ("O" represents Bangladeshi fly ash)

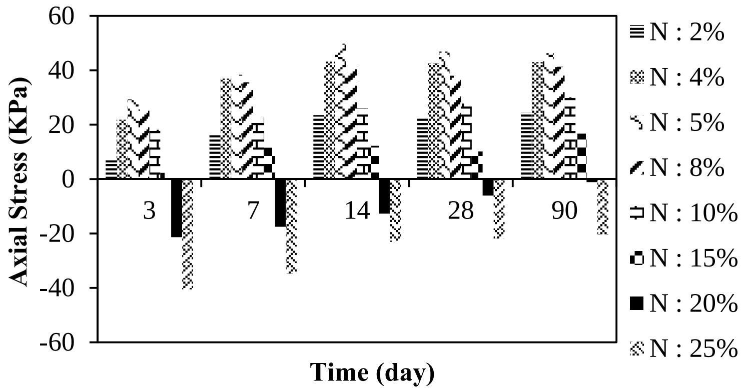

Figure (17): Strength increment column chart for Indian fly ash-treated soil ("N" represents Indian fly ash)

CONCLUSIONS

Experiments are conducted to study the effect of fly ash content on strength development of clayey soil under optimum moisture content and several curing periods. The soil studied consists of 0.83% gravel, 37.76% sand and 61.42% silt and clay, with a specific gravity of 2.58. It is classified as silts of high plasticity or organic clays of medium to high plasticity, consisting of the minerals: quartz, orthoclase, illite and kaolinite. Maximum dry density of soil is 1.615 g/cm^3. Due to low specific gravity, the addition of both Bangladeshi and Indian fly-ash causes the maximum dry density to decrease in the soil-fly ash mix. Maximum dry densities, with the presence of 5% fly ash in the mixture, are found to be 1.57 g/cm^3 and 1.6 g/cm^3 for Bangladeshi and Indian fly ash, respectively. These values further reduced to 1.51 g/cm^3 and 1.55 g/cm^3, respectively, for the presence of 25% Bangladeshi and Indian fly ash.

The strength development with fly ash content for optimum water content is classified into two zones: the active zone and the deterioration zone. The unconfined compressive strength increases up to 5% for both Bangladeshi and Indian fly ashes in the soil-fly ash mix, which is taken as optimum fly ash content of both types. Further increase of fly ash content in the soil-fly ash mix decreases the UCS. For long-term curing, Bangladeshi fly-ash produces higher strength (430.96 kPa and 474.53KPa at 28 days and 90 days, respectively) with 5% fly ash content than that of Indian fly-ash (424.63 kPa and 434.01 kPa at 28 days and 90 days, respectively) in the soil-fly ash mix. For short-term curing (say, 7 days), Indian fly ash (374.96 kPa) in the mix generates higher strength than that of Bangladeshi fly ash (349.15 kPa) with 5% fly ash content.

Finally, it can be concluded from this study that fly ash can be effectively utilized in increasing the strength of clayey soil, but not for improving the compaction properties. As fly ash is harmful to the environment, the use of fly ash in strength development can reduce environmental pollution and it will be a convenient construction material for base, sub-base or sub-grade of roads, pavements and embankments of highways, backfilling of retaining walls, improvement of soil bearing capacity of structures,… etc. This study is conducted in small laboratory scale, which is the major limitation of this work.

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NOTATION

CH	Inorganic clays of high plasticity
CL	Low to medium plasticity
FC or F	Fly ash content
LL	Liquid limit (%)
MDD	Maximum dry density (g/cm^3)
MH	Inorganic silts of high plasticity
N	Indian fly ash
O	Bangladeshi fly ash
OH	Organic clays of medium to high plasticity
OMC	Optimum moisture content (%)
PI	Plasticity index (%)
PL	Plastic limit (%)
UCS	Unconfined compressive strength
USCS	Unified Soil Classification System

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