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Effect of Fly Ash Content on the Engineering Properties of Stabilized Soil at South-western Region of Bangladesh

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A B S T R A C T

The main focus of this study was to investigate the effect of fly ash content on the engineering properties of stabilized soils. To these attempts, two different types of fly ash, inorganic silt and Portland cement were collected. In the laboratory, the fly ash content of 10, 20 and 30%; inorganic silt of 10, 20 and 30% as well as cement content of 10% was used to stabilize soils. Result reveals that Atterberg limit decreases in relation to the increasing of fly ash content in stabilized soil at varying mixing proportions of fly ash content in soil. The different values of compressive strength of stabilized soils obtained from fly ash of different brand cement. In addition, the stabilized soil with cement content showed the highest value of compressive strength, whereas, stabilized soil with inorganic silt provides lowest value. The result reveals that the optimum content of fly ash was 20 and 30% for elephant and seven rings cement, respectively. The soil with organic content of 16% showed highest value of compressive strength, while, soil with organic content of 12.5% showed lowest value. Furthermore, the stabilized soils with fly ash showed comparatively the higher values of compressive strength than that of stabilized soils with inorganic silt content.

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INTRODUCTION

The problems of soft soil in most of the parts of South-east Asian countries have been one of the major challenges for infrastructure planning and implementation [1]. Soils having lower specific gravity coupled with higher compressibility and significant secondary compression, associated with absurd strength properties (lower bearing capacity, higher swell and shrinkage potential coupled with higher moisture content) with significant organic matter are comprehended as problem soils by civil engineers [2-4]. Hence, the behavior of organic soils usually does not depend on the traditional rules, the construction of civil engineering infrastructures such as foundations, embankments, excavations, and other ground works in problem soils is one of the challenging tasks for the geotechnical engineers [5, 6]. Therefore, the properties of these soils should be improved by proper soil stabilization techniques having engineering perspective. Now-a-days, several additives or soil stabilizers such as cement, lime, bitumen, calcium chloride, magnesium chloride, sodium chloride, rice husk ash, fly ash, or mixture thereof (due to their high pozzolanic reactions and cation exchange capacity) are used especially for weaker and wetter soils [7-10]. Fly ash is the byproduct of coal combustion in power plant for electricity production or industrial boilersis widely used for soft soil stabilization in place of cement or lime due to the outcomes of comparative less shrinkage. The main benefit is that fly ash is cheaper than cement or lime and robust availability from the construction industry. Furthermore, it can be used to increase the shear strength, CBR value and bearing capacity of soil by reduction of plasticity and free swelling [11]. Fly ash is not only increase the capacity of soil but also prevents the harmful effects on environment by reducing greenhouse gas and other adverse air emissions when replaced with cement or lime [12].

Bangladesh is the eight largest countries in the world in terms of population, located in the north-eastern part of South Asia. Khulna is the third largest and south-western divisional metropolitan city in Bangladesh, near the world heritage site, Sundarbans, circumscribed by Bay of Bengal on the south, Jessore and Narail district on the north and Bagerhat and Satkhira district on the east and west, respectively. It is situated at latitude of 22°48'35.24" north and longitude of 89°33'51.8" east about 48km away from second largest port of Bangladesh.The ground of this region consists of coarse to very fine sand, silty clay, clay and very soft silt, which can be defined as ‘compressible and collapsible sediments’ having

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the thickness of top soil is about 6 to 20 m or more [13, 14]. However, in most of the places, the soil layer consists of considerable amount of organic matter (about 5 to 70% or more at some cases) at a depth of 10 to 25 ft (3m to 7.5m) from the existing ground surface outcomes obsessive settlement due to the characteristics of exalted compressibility and low shear strength [15, 16]. In addition, fly ash can be used as an effective stabilizing agent for increasing the strength of soft inorganic soils in Bangladesh as well as different parts of the globe [1, 17-23]. However, numerous researches have been carried out concerning the effectiveness of stabilization of soft organic soils with fly ash, showed satisfactory results [24, 25]. Moreover, for the stabilization of organic soil in Bangladesh significant researches are yet to be done. Therefore, attention may be drawn to look at the results of fly ash to envision whether or not it may be accustomed stabilize the organic soils of Bangladesh. The objectives of this study are to determine the unconfined compressive strength of stabilized soil at varying fly ash content and to compare the unconfined compressive strength of different stabilized soil with fly ash, cement content and inorganic silt. The outcome of this study will help the other researchers in this line.

MATERIAL AND METHOD

In this study, the methodology comprises of collection of the soil samples, fly ash and the preparation of stabilized soils as well as hence discussed in the following articles.

Collection of soil samples

In this study, three organic soils were collected from two distinct locations namely Beel Dakatia and Rupsha of Khulna region. The organic contents of soil samples were about 49, 16 and 12.5% for Beel Dakatia, Rupsha-1 and Rupsha-2, respectively. According to USCS, Beel Dakatia Soil can be classified as peat with basic nature having high ash content. However, Rupsha Soil (both samples 1 and 2) can be designated as highly plastic basic organic clay having high ash content. However, inorganic silt was collected from KUET campus. All the soil samples were collected about 1 m depth from the existing ground surface. The collected soil samples were kept in a large polyethylene bag and tied tightly to prevent the escape of the moisture. In the laboratory, the index properties of the collected soil samples were measured through standard testing methods provided in Table 1. The physical and index properties of soils are summarized in Table 2.

TABLE 1. Properties of soil and their corresponding testing standards

Soil parameters	Unit	Analytical method
Moisture content (w_N)	%	ASTM D2216 [26]
pH		ASTM D4972 [27]
Liquid limit (LL), plastic limit (PL) & placticiy Index(PI)	%	ASTM D 4318 [28]
Organic content Ash content	%	ASTM D2974 [29]
Specific gravity		ASTM D854 [30]
Optimum moisture content Maximum dry density	% kN/m^3	ASTM D698 [31]

The in-situ water contents were typically found about 15% wet of optimum moisture content (OMC) of the soil samples of Rupsha location, while, 200% for Beel Dakatia soil sample. Different associations around the world are in charge of soil order frameworks proposed to be utilized by geotechnical engineers.The objective of all these characterization frameworks is to give the way to depict soils through a perceived framework gathering them in classifications, such that the soils inside a given classification might be required to show analogous engineering characteristics by and large depends on the execution of index tests. The measurement of acidity or alkalinity of soils, pH is a dominant parameter that controls most of the chemical processes that take places in soil. In this study, the values of pH in soil are measured using pH-meter (HACH Sension 2) through and data provided in Table 2. For all the tests, the dry solid to distilled water ratio is maintained at a ratio of 1 to 1 and direct readings of the pH values of the soil samples suspensions in water are obtained from the pH meter. The result of pH depicts that the organic soils are acidic and inorganic silt is alkaline in nature.

Fly ashes

In this study, two types of locally available fly ash and Portland composite cement (Type I) were collected as admixtures for the stabilization of organic soil. Ferguson [19] has defined fly ash as fine spherical silt, sizes in the range of 0.074 to 0.05 mm. In this study, fly ashes were collected from two local cement factory specified as Elephant fly ash and Seven Rings fly ash having CaO and CaO/SiO_2 ratio of about 2% and 0.04, respectively. The general properties of the fly ashes are provided in Table 3. According to ASTM C618 [32], these fly ashes are classified as Class F ash based on the properties of fly ash. In addition, fineness is an important property of fly ash at the time of application in Portland cement concrete [24]. A study conducted by Yazici and Arel [33] the strength of concrete increases in relation to the increasing of the fineness of fly ash due to pozzolanic reactivity of fly ash. However, IS 3812:2013 part-I specifies that the fineness of fly ash (Blaine's permeability method) should be more than 320 m^2/kg and IS 3812:2013 part II specifies 200 m^2/kg corresponding to the maximum residue of 50% on 45 micron sieve. Furthermore, the fineness of fly ash samples in this study is well agreed with the requirements.

Preparation of stabilized soils

The fly ashes are added to the soils at the percentages of 10, 20, and 30 (by dry weight). However, soil-cement blends (using 10% cement) are prepared at very wet conditions to furnish an immediate correlation with 10% fly ash content.

TABLE 2. Physical and index properties and classification of soils

Properties of soil	Beel Dakatia soil	Rupsha soil-1	Rupsha soil-2	Inorganic silt
LL (%)	339	73	53	34
PL (%)	290	48	41	31
PI (%)	49	25	12	3
OC (%)	49.0	16.0	12.5	2.0
AC (%)	51.0	84.0	87.5	98.0
G_s	1.79	2.40	2.50	2.71
pH	7.8	4.0	4.8	8.2
w_N(%)	306	52	45	30
w_{opt} (%)	105.8	38.0	29.0	16.0
γ_d(kN/m^3)	5.6	11.2	12.8	15.8
USCS classification	PT	OH	OH	ML

TABLE 3. Properties of fly ashes used in this study

Parameters	Elephant	Seven Rings
CaO (%)	2	1.64
SiO_2+Al_2O_3+Fe_2O_3	89	95
MgO (%)	1	0.47
SO_3 (%)	1	0.21
LOI (%)	5	1.99
Blaine fineness (cm^2/gm)	3000	3498
Moisture content (%)	2	0.34

According to Tremblay et al. [34], organic soil-cement mixture having pH lower than 9, precludes cementing process due to the inability of auxiliary mineral development and the chances of pozzolanic activity diminishes. The pH of all the soil-cement mixtures of this study are above 9, which presents that cementitious responses are not prone to be hindered.

Different tests are conducted on soil-fly ash and soil-cement mixtures to determine the variations of atterberg limits, organic content (OC), pH, and atterberg compressive strength (qu) as well-controlled conditions to evaluate the impact of water content. The majority of the tests are conducted on specimens are prepared at a very wet condition to reenact the natural water contents, corresponding to 13-30% wet of the OMC for the Beel Dakatia soil, 17–30% wet of the OMC for the Rupsha soil-1, and 22–35% wet of the OMC for the Rupsha soil-2.

The unconfined compressive strength test is conducted on both the untreated soil and the treated soil with fly ash, silt, and cement following ASTM D5102 [35]. Test specimens are prepared by first mixing the dry soil with the specified percentage of fly ash on dry weight basis. Then the required amount of water is added and the sample mixture is kept for two hours to simulate the field conditions. After that, the samples were compacted in a PVC mold having a diameter of about 42 mm and height of about 70 mm, at their corresponding OMC and maximum dry density (MDD) by static compaction [31]. After the compaction, the samples were kept for one day as the soil is very soft to extrusion. On the next day the sample is extruded from the mold using a hydraulic jack and cured for seven days in desiccators. Notwithstanding, the assessments were finished on specimens cured seven days to simulate the early curing conditions all through the creation, each organic and inorganic soils are expected to have noteworthy strength improvements with increasing curing time for calcium-primarily based additives [21, 36].

RESULTS AND DISCUSSION

In this study, the engineering properties of soil such as qu, LL, PL, pH and OC of stabilized soil were measured and provided in Table 4. The effects of fly ash content on the properties of soil were analyzed and hence discussed in the following articles.

Effects of fly ash on Atterberg limits

Atterberg limits of an organic soil rely upon two restricting qualities of higher water adsorption capacity of organic matter and molecule collection from organic substances [37]. In addition, the water adsorption capacity and soil mineral fraction has a tendency to increase and decrease of Atterberg limits in soil correspondingly. The water contents corresponding to the transition from one state to another usually differ for clays having different physical properties in the remolded state. Moreover, the Atterberg limits vary with the amount of clay present in a soil, organic content on the type of clay mineral and on the nature of the ions absorbed on the clay surface. In general, water adsorption capacity of the organic matter, as a rule, surpasses the decrease caused by organic matter prompted accumulation. The variations of Atterberg limits with varying proportions of fly ash contents are provided in Table 4 and also shown in Figures 1 to 3. The variation of LL in soil with the changes of ash content is shown in Figure 1. The values of LL decreases in relation to the increasing of fly ash content in stabilized soil at varying mixing proportions of fly ash in soil. The decreasing tendency of LL and PI with the addition of fly ash may be due to the reduction of the thickness of diffuse double layer of soil particles owing to cation exchange capacity causing flocculation of soil particles and expanding the coarser molecule content with coarser fly ash particles by substituting finer soil particles [37, 38].

Furthermore, the PL decreases due to the reduction of flocculated soil particles and incorporation of finer particles of fly ash in the voids of flocculated soil; therefore, water holding capacity in the pores diminishes [39].

In addition, rapid and immediate changes of plasticity with the addition of fly ash content is occurred due to the formation of cementitious and pozzolanic gels which agglomerates the soil particles and fill out the pore spaces to reduce the water absorption [24, 40]. Moreover, Casagrande [41] deduced that the wL changes depend on the aggregates or the clusters of the basic units that interact to develop the strength in the soils, the average adsorbed water layer thickness and the average size of intermolecular pores in the soils.

Effects of fly ash on unconfined compressive strength

The variation of unconfined compressive strengths (qu) of stabilized soil from Beel Dakatia at various mixing proportion of fly ash, inorganic silt and cement is shown in Figure 4(a).

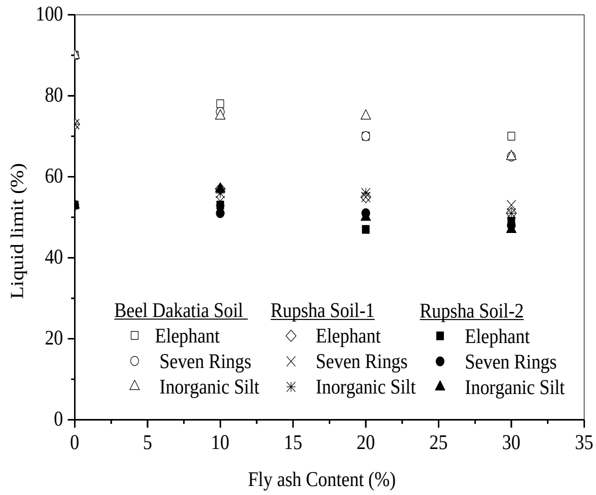


Figure 1. Variation of liquid limit with fly ash content in soil.

TABLE 4. Summary of the results of laboratory work

Types of Soil	Types of binder		LL	PL	PI	OC	pH	q_u
	Identification			%				kPa
	control	0	90	77	13	49.0	7.9	172
	cement	10	76	55	21	31.5	10.1	130
		10	78	65	13	33.5	5.7	85
	Elephant fly ash	20	70	58	12	31.0	5.5	115
		30	70	58	12	27.5	5.6	88
Bee lDakatia soil		10	76	45	31	34.0	6.1	71
	Seven rings fly ash	20	70	44	26	31.5	6.1	58
		30	65	46	19	28.0	5.6	90
		10	75	63	12	30.5	6.0	92
	Inorganic silt	20	75	58	17	28.5	5.4	47
		30	65	49	16	25.0	6.2	60
	control	0	73	48	25	16.0	4.0	101
	cement	10	65	39	26	0.0	10.0	481
		10	57	44	13	10.3	4.2	307
	Elephant fly ash	20	55	44	11	11.3	2.4	239
		30	51	46	4	9.5	3.7	229
Rupsha Soil-1		10	55	37	18	13.4	3.8	61
	Seven rings fly ash	20	55	35	20	11.1	3.8	97
		30	53	33	20	11.1	3.9	119
		10	56	46	10	31.0	5.1	69
	Inorganic silt	20	56	38	18	1.5	4.7	65
		30	51	42	9	25.5	5.4	62
	control	0	53	41	12	12.5	4.8	130
	cement	10	60	41	19	14.0	10.5	291
		10	53	21	33	13.5	5.7	88
	Elephant fly ash	20	47	33	13	12.0	6.0	87
		30	49	28	21	11.5	5.2	98
Rupsha Soil-2		10	51	23	28	18.5	6.5	94
	Seven rings fly ash	20	51	30	21	18.0	6.3	97
		30	48	30	18	15.5	6.1	127
		10	57	39	18	12.5	5.4	64
	Inorganic silt	20	51	37	14	11.0	6.7	60
		30	47	31	16	11.5	6.4	95

soil with highly reactive Portland cement (Type I) (Figure 4). Moreover, it is evident that the stabilized soil with 20% fly ash blends from Elephant brand cement showed the maximum value of qu, whereas, the stabilized soil with 10% fly ash blends showed the minimum value of qu. However, the stabilized soil with 30% fly ash blends of Seven Rings provides highest strength in soil. Here, it was observed that the stabilized soil with 20% fly ash blends of Elephant showed comparatively the higher value of qu than that of stabilized soil with 20% fly ash blends of Seven rings cement. The variation of qu of stabilized soil namely Rupsha soil 1 and 2 with fly ash, inorganic soil and cement is shown in Figures (4b) and (4c), respectively. The stabilized soil (Rupsha soil-1) (Figure 4b) with 20% fly ash from elephant and (Rupsha soil-2) (Figure 4c) with 30% fly ash from seven rings showed comparativly the higher values of qu than that of other mixing proportions of fly ash. In addition, the stabilized soil with cement shows the highest value of qu, whereas, stabilized soil with inorganic silt provides lowest value of qu.The result reveals the optimum content of fly ash is 20 and 30% for elephant and seven rings, respectively. According to Tastan et al. [24], adding of fly ash in organic soils brings about noteworthy increment in qu with respect to the unstabilized soil in extremely wet condition.

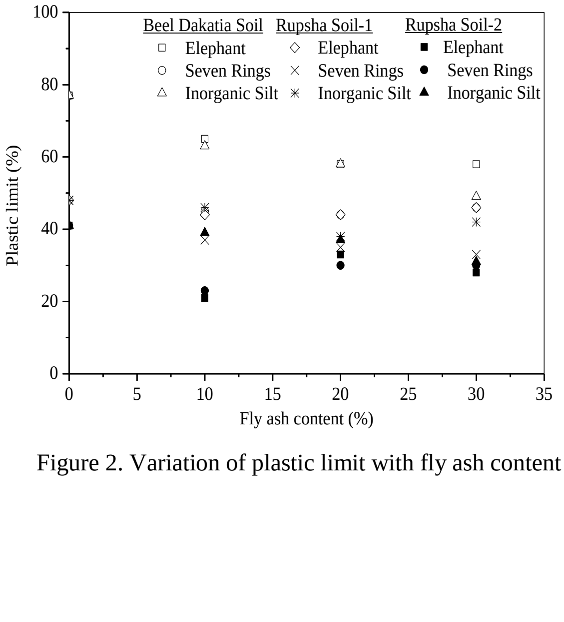
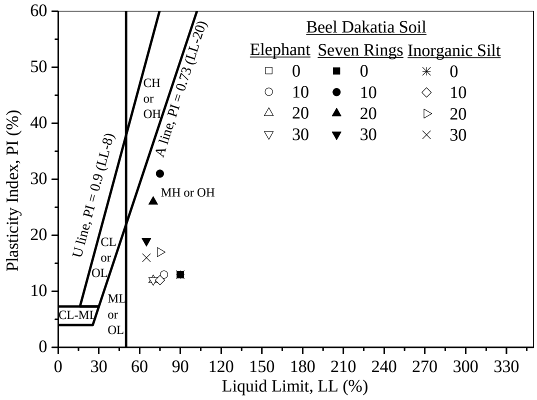


Figure 2. Variation of plastic limit with fly ash content



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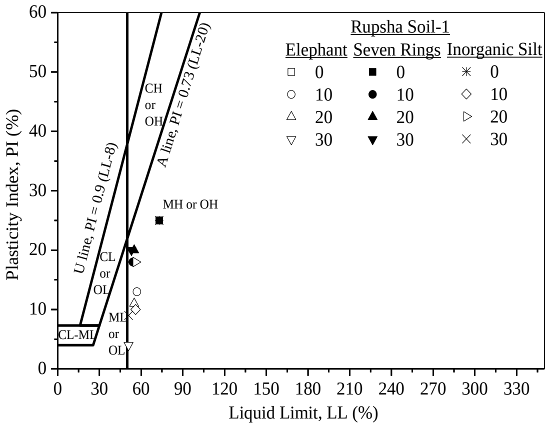

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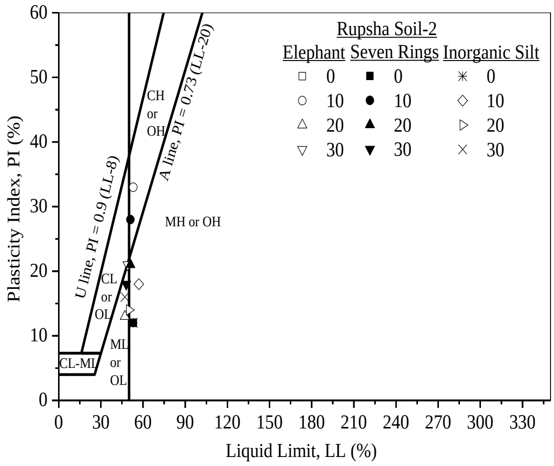
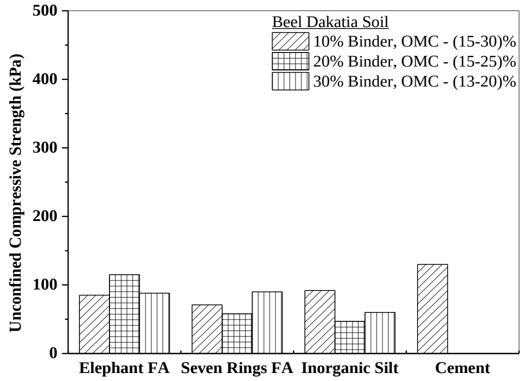


(c)

Figure 3. Plasticity chart showing the original and fly ash treated soil: (a) Beel Dakatia Soil; (b) Rupsha Soil-1; (c) Rupsha Soil-2.



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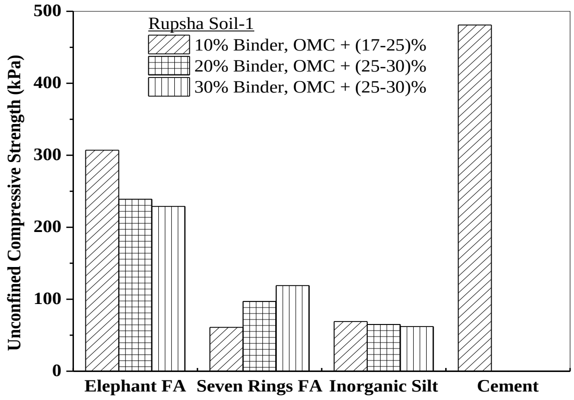

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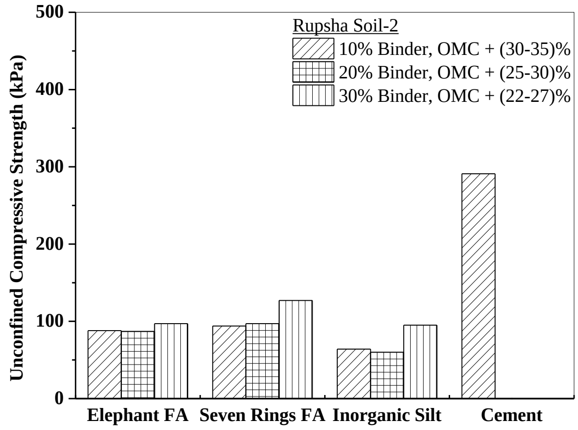


(c)

Figure 4. Unconfined compressive strength (qu) of mixtures prepared with various fly ashes, Type I portland cement, and Inorganic silt at very wet water content: (a) Beel Dakatia Soil; (b) Rupsha Soil-1; (c) Rupsha Soil-2

The stabilized soil with nonreactive inorganic silt showed comparatively lower value of qu than that of stabilized The presented results indicate that the soil with high OC shows not as much of increase of (qu) even after stabilization due to their high compressibility and settlement characteristics and/or low pH or very strongly acidic condition. Moreover, stabilized soil with cement provides greater value of qu than that of stabilized soils with fly ash or silt. Soil stabilized with high cement content provides more strength than stabilized with low amount of cement [42]. Besides, the value of qu likewise relies upon the water content of the blend and more or the less on the compactive effort. An amount of water is required for the hydration that can increase the quantity of cementitious products. On the contrary, if the water content is in abundance of the amount than it needs, the quality abatements with the increase of water content in soil.

The variation of qu in stabilized soil from different location with 10% fly ash from different brand is shown in Figure 5(a). The soil with OC 16% showed highest value of qu, while, soil with OC 12.5% showed lowest value of qu (Figure 5a). In addition, the soil (Rupsha soil-1) shows qu with 83 kPa, while soil (Rupsha soil-2) shows qu with 88 kPa and the variation of qu due to the amount of OC presence in soil. In all cases, the qu of Rupsha soil-1 is greater at the same binder content (Figure 5).

However, the qu of Rupsha soil-1 is greater than that of BeelDakatia soil using different percentages of binder, because the water content of BeelDakatia soil-binder mixes are not adequate. On the other hand, strength diminutions are occurred for the Rupsha soil-2 than Rupsha soil-1 as the water content increases.

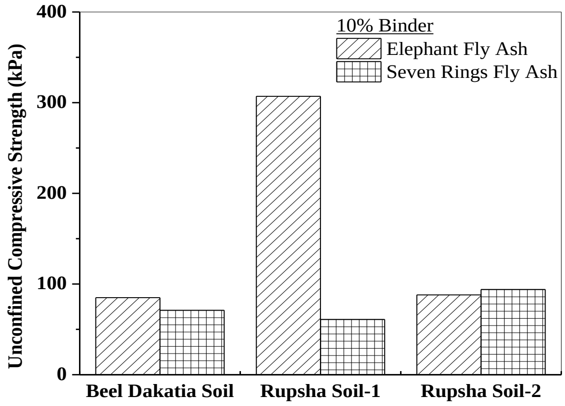
With the addition of fly ashes, in most of the cases, qu increased than that of silt (Figure 6). Therefore, the increase in quality acquired by fly ash adjustment, for the most part, is owing to pozzolanic reactions and the decrease in water content got by introducing dry solids, basically relies upon the fly ash and the soil type [24].

Effects of pH on unconfined compressive strength

The effect of pH on the unconfined compressive strength of soil-fly ash blends are presented in Figures 7 and 8. Tastan et al. [24] stated that there is no evident connection between qu and blend pH. However, Tremblay et al. [34] reported that organic soil having pH not more than 9, indicates lower strength as stated above. They also stated that unconfined strength is not always representing the proportional relationship with pH. The presented results seem to verify the statement of Tastan et al. [24] and Tremblay et al. [34].

Effects of silt on unconfined compressive strength

Silt is the sort of fine materials found in in river sand containing particles smaller than 60 µm that are reduced in view of the regular procedures of weathering [43]. The illustration of Figure 9 presents the relationship between



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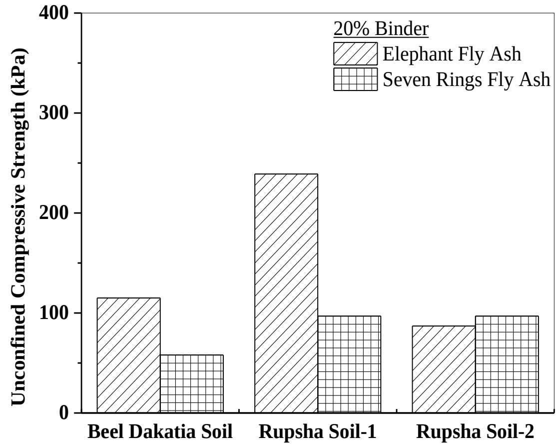

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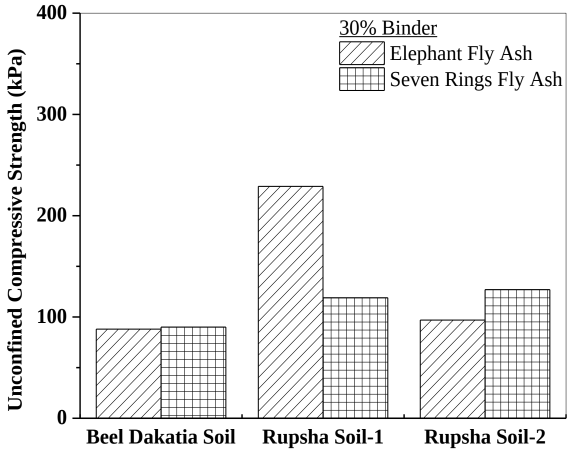

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Figure 5. Variation of unconfined compressive strength (qu) of soil with different fly ash compositions with the same binder content and similar water content: (a) 10% binder; (b) 20% binder; (c) 30% binder

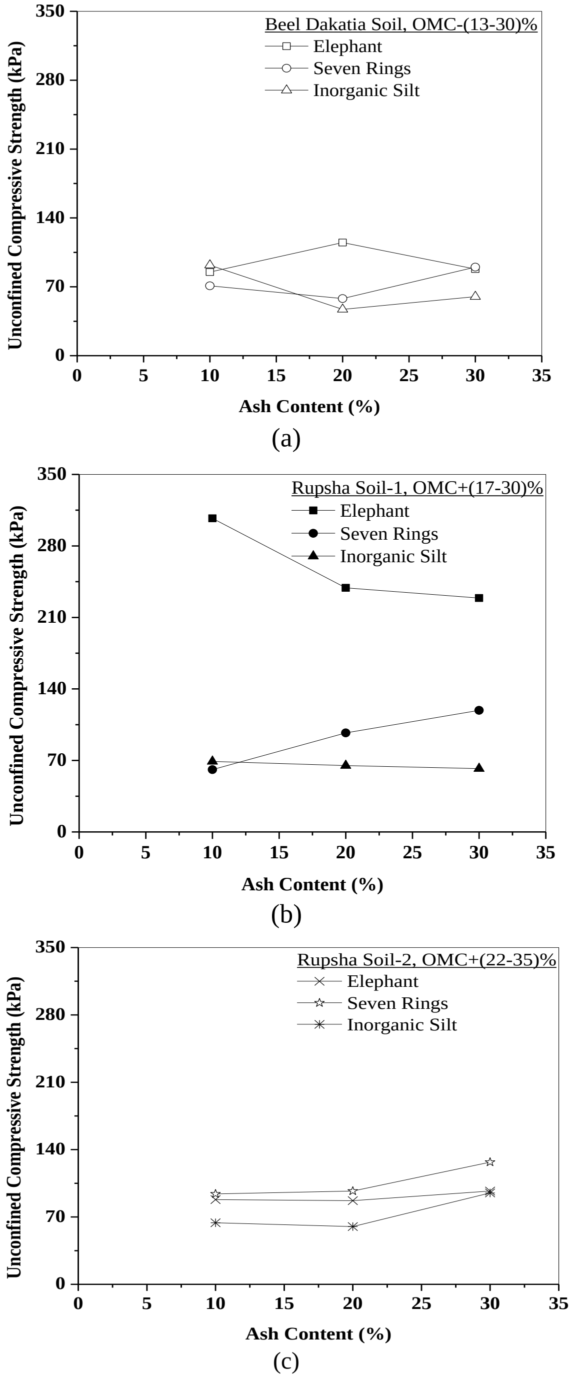


Figure 6. Unconfined compressive strength (qu) of organic soil–fly ash mixtures as a function of fly ash percentage in the mixture: (a) stabilized BeelDakatia Soil; (b) stabilized Rupsha Soil-1; (c) stabilized Rupsha Soil-2

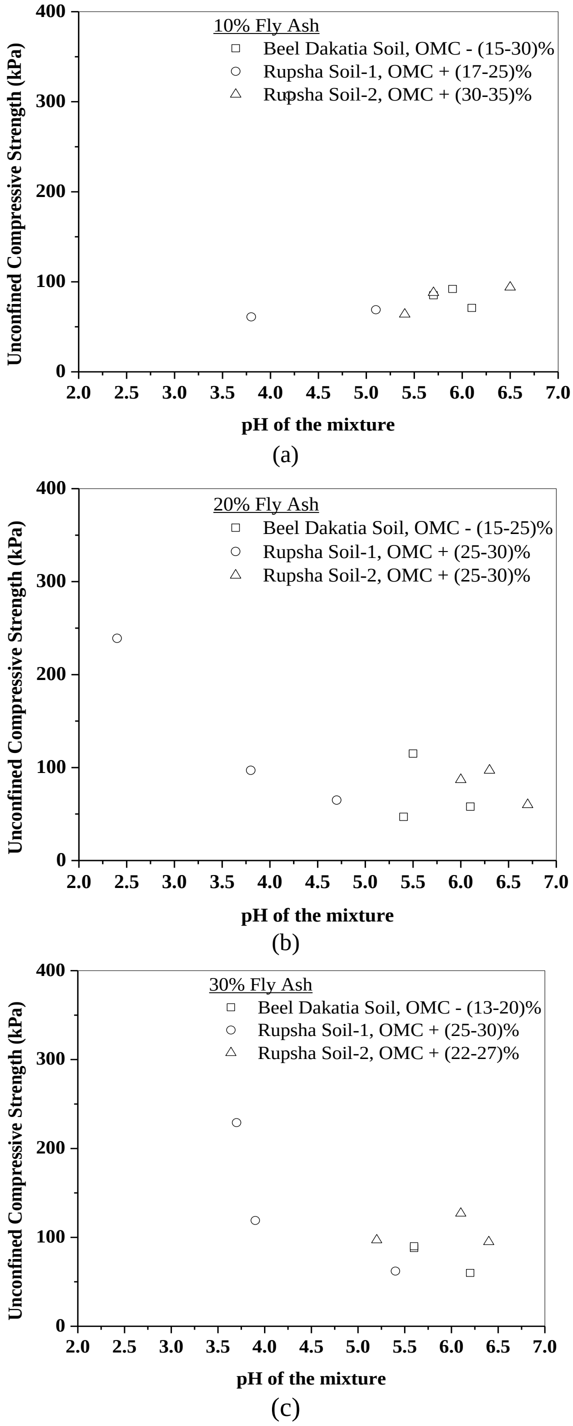
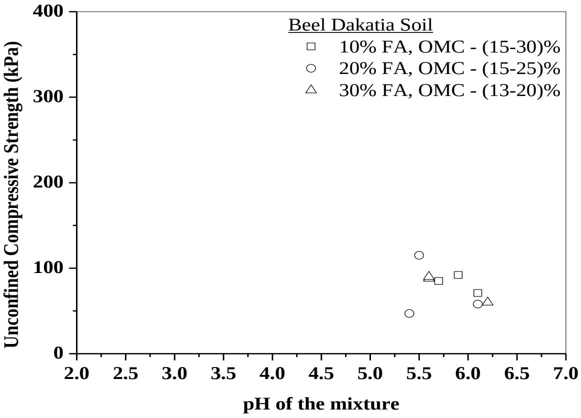


Figure 7. Unconfined compressive strength (qu) as a function of pH of soil-fly ash mixture: (a) 10% fly ash; (b) 20% fly ash; (c) 30% fly ash

unconfined compressive strength of soil-inorganic silt and soil-fly ash mixture. The qu of fly ash stabilized soil provides almost more strength than the mixtures prepared with inorganic silt at very wet condition as reported by Tastan et al. [24].

CONCLUSIONS

Result reveals that Atterberg limit decreases in relation to the increasing of fly ash content in stabilized soil at varying mixing proportions.



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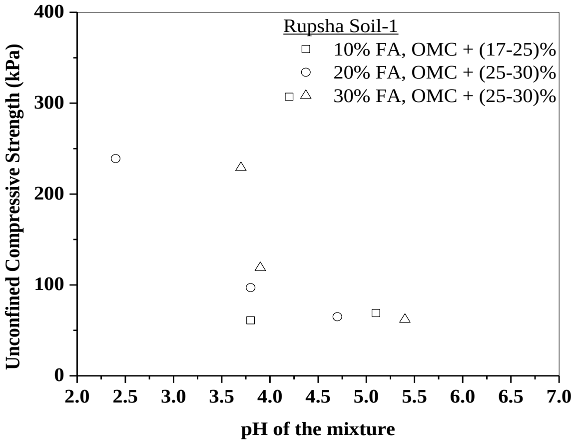

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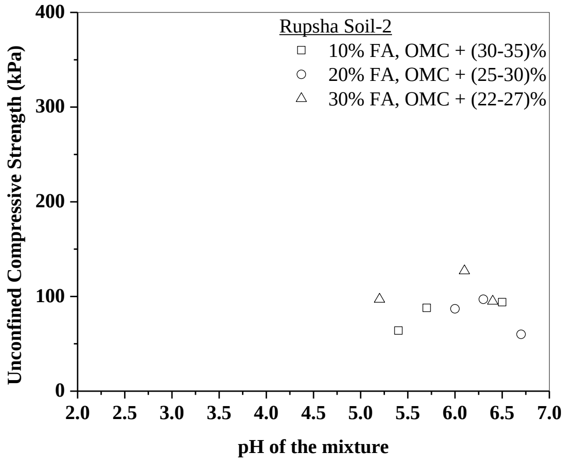

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Figure 8. Unconfined compressive strength (qu) of soil–fly ash mixtures prepared at very wet water content as a function of mixture pH after 2 h: (a) Beel Dakatia Soil; (b) Rupsha Soil-1; (c) Rupsha Soil-2

The different values of compressive strength of stabilized soils obtained from fly ash of different brand cement. In addition, the stabilized soil obtained from fly ash of different brand cement. In addition, the stabilized soil with cement content showed the highest

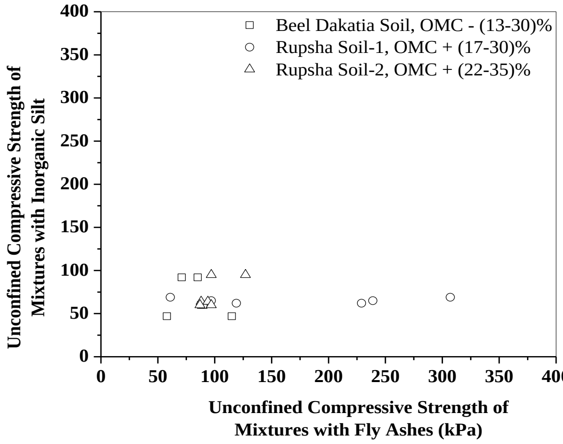

Figure 9. Comparison of unconfined compressive strength (qu) of mixtures prepared with Inorganic silt and fly ashes at the same binder content and similar water content

value of compressive strength, whereas, stabilized soil with inorganic silt provides lowest value of compressive strength. The result reveals that the optimum content of fly ash was 20 and 30% for Elephant and Seven Rings cement, respectively. Moreover, the soil with organic content of 16% showed highest value of compressive strength, while, soil with organic content of 12.5% showed lowest value of compressive strength. The stabilized soils with fly ash showed comparatively the higher values of compressive strength than that of stabilized soils with inorganic silt content. Finally, the outcome of this study can easily be used to characterize the stabilized soils at varying content of fly ash.

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Persian Abstract

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چکیده

تمرکز اصلی این مطالعه بررسی اثر محتوای خاکستر بر خصوصیات مهندسی خاک های تثبیت شده است. برای این تلاش ها، دو نوع مختلف خاکستر، خاکستر معدنی و سیمان پرتلند جمع آوری شد. در آزمایشگاه، محتوای خاکستری پرواز ۱۰. ۲۰ و ۳۰ درصد؛ نمک معدنی ۱۰، ۲۰ و ۳۰ درصد و همچنین میزان سیمان ۱۰ درصد برای ایجاد ثبات در خاک استفاده می شود. نتایج نشان می دهد که محدودیت آتتربرگ در رابطه با افزایش مقدار خاکستری خاک در خاک ثبات یافته در مقادیر مختلف مخلوط خاکستریت خاکستری کاهش می یابد. مقادیر مختلف مقاومت فشاری خاک های تثبیت شده حاصل از خاکستر سیما سیمان با نام تجاری متفاوت است. علاوه بر این، خاک تثبیت شده با محتوای سیمان بالاترین مقدار مقاومت فشاری را نشان می دهد، در حالیکه خاک ثبات داده شده با نمک معدنی کمترین مقدار را فراهم می کند. نتایج نشان می دهد که محتوای مطلوب خاکستر پرواز به ترتیب ۲۰ و ۳۰ درصد برای سیمان فیل و هفت حلقه است. خاک با محتوای آلی ۱۶٪ بالاترین مقدار استحکام فشاری را نشان داد، در حالی که خاک با محتوای آلی ۱۲/۵٪ کمترین مقدار را داشت. علاوه بر این، خاک های تثبیت شده با خاکستر پرواز مقادیر بالاتر مقاومت فشاری نسبت به خاک های تثبیت شده با محتوای سیلتی غیر معدنی را نسبتا نشان دادند.