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EVALUATION OF ENGINEERING PROPERTIES OF THERMAL POWER PLANT WASTE FOR SUBGRADE TREATMENT

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Abstract — Soft cohesive soils have low strength, high plasticity, and a large expansion ratio making them unsuitable as a road subgrade. This study aims to evaluate the potential of power plant waste (fly ash) from the Barapukuria Thermal Power Plant, Dinajpur, Bangladesh to improve the characteristics of such soft cohesive soil. X-ray fluorescence test conducted to classify the power plant fly ash and the type was identified as "Class F" according to "American Association of State Highway and Transportation Officials" and "American Society for Testing and Materials". Laboratory tests were conducted on clay soil obtained from Dinajpur region modified by the collected power plant waste. As the Class F fly ash has low cementing property, 3% cement was added with it. Cement mixed soil was modified with 5%, 10%, 15%, and 20% fly ash respectively. Specific Gravity, Atterberg limits, Modified Proctor Compaction, Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) tests were conducted. The study reveals that there is a decrease in specific gravity, dry density, and plasticity index with the addition of power plant waste. On the other hand, there is an increase in optimum moisture content, UCS, and CBR value. UCS and CBR values were found to be improved remarkably. Soaked CBR value of soil is found to be improved from 2.79% to 92.59% when treated with 5% fly ash and 3% cement. The UCS value of this modified soil was 560.36 kPa. The stabilized soil thus obtained meets the requirements for subgrade as specified by the Local Government Engineering Department (LGED)'s design manual (2005), Bangladesh. Since there is a possibility of leaching by dumping a large quantity of fly ash in the pond, the use of fly ash from the power plants to improve soft cohesive soils for road subgrade may be an environment-friendly alternative to its disposal in the ponds.

Keywords: Cohesive soils, fly ash, X-ray fluorescence, subgrade improvement, CBR.

1.0 INTRODUCTION

Power generation is the priority sector for the Government of Bangladesh to meet the gradually increasing demand for electricity. Among the thermal power plant, the coal-fired power plant is going to be the highest number in Bangladesh. The first coal-based power plant in Bangladesh, Barapukuria power station (250 MW), is running after commissioning in 2006. Thermal power stations generally use coal of lower grades and higher grades of coal are reserved for metallurgical applications. When pulverized coal is burned in a furnace at the power stations, it produces very fine ash called "Fly ash". Fly ash was considered a waste in past. The coal used at Barapukuria Coal Fired Thermal Power Plant has an ash content of about 12.42%. Every year, about 0.08 million metric tons of fly ash is produced from Barapukuria Coal Fired Thermal Power Plant [1]. This massive amount of fly ash is disposed into nearby ponds rather than utilized. The utilization of fly ash would have considerable environmental benefits reducing land, air, and water pollution.

Subgrade soil is an integral part of the road pavement as it provides support to the pavement from beneath. The subgrade soil and its properties are important in the design of pavement structures. The main function of the subgrade is to give adequate support to the pavement and for this, the subgrade should possess sufficient strength under adverse climatic and loading conditions. Bangladesh Government allocates a huge amount of funds each year to repair or to construct roads. A major portion of construction cost is being spent on the preparation of subgrade. There is a remarkable history of using soil stabilization admixtures to improve poor subgrade conditions. This can be achieved by increasing the strength of the subgrade and controlling volume changes. Mostly lime and cement are used conveniently in recent decades. Nowadays, researchers are trying to improve the subgrade soil from different waste like power plant waste, coal mining waste, etc. [2]. Combustion of coal produces self-cementing fly ash that can be used for soil stabilization in absence of admixtures [3].

The aim of this investigation is to evaluate the properties of fly ash obtained as power plant byproduct, find the possibility of using it as a subgrade treatment option, and quantify the optimum dosage of it to improve soft cohesive soil as road subgrade. According to ASTM C 618 fly ash is classified into two classes, class C and F, according to their chemical composition. In order to improve the engineering properties of soft subgrade soil class C fly ash can be used without any other activator [4].

In recent years, the various study was performed to improve road subgrade using different methods and materials. It is revealed that weathered coal mine waste rocks can be successfully used alone as a sustainable alternative material for the embankment [5]. Coal combustion fly ash was found to have excellent potential for use in rammed earth construction as a low-cost alternative to Portland cement and other stabilizers because of its pozzolanic properties [6]. A significant change of mechanical properties was found with the addition of fly ash and optimum moisture content was increased. This increase of optimum moisture content increased the capability of stabilized soil. So, using fly ash for soil stabilization is recommended as a possible operation to improve the road condition with a minimum cost [7]. The engineering properties of subgrade soil such as unconfined compressive strength, California Bearing Ratio (CBR), Modulus of Resilient were substantially increased after soil stabilization with fly ash [4]. The potential benefit of stabilizing clayey soils with high calcium fly ash but depends on the type of soil, the amount of stabilizing agent, and the age [8]. The reuse of fly ash generated from coal combustion in highway construction has a potential benefit to minimize the number of disposed waste materials, reduce solid waste disposal cost and landfill requirements [9]. Use of a secondary additives like lime, cement, enzyme and polymers with class F type fly ash was also evaluated by scholars and found to be beneficial in reducing the thickness of pavement [10]. As in present days, the waste fly ash generated from the Barapukuria coal mine is being dumped in the ponds without any potential use, the possibility of using it as a treatment option may be beneficial both from an economic and environmental point of view. The present study is taken into consideration with the objectives of classifying the fly ash generated from Barapukuria coal mine, evaluating its potential in subgrade treatment and finding the optimum dosage of it to improve soft cohesive subgrade soil.

2.0 MATERIALS AND METHODS

2.1 Materials for the Study

The project involves soil improvement with power plant waste and hence three types of materials are used such as power plant waste (fly ash), the soil to be improved and cementing material (Portland Composite Cement).

2.1.1 Fly Ash

For the accomplishment of this research, the power plant waste or fly ash was collected from Barapukuria Coal Fired Thermal Power Plant (BTPP) is located in Parbatipur Upazila, Dinajpur district. According to the Bangladesh topographic sheet no. 78C/14 (scale 1:50,000), the plant area lies between the latitudes 25°33′57″ to 25°33′24″N and the longitudes 88°56′71″ to 88°56′43″E [1].

2.1.2 Soil

The soil was collected from Dinajpur Sadar Upazilla, Dinajpur, Bangladesh. The area lies between Latitude-25.695524 Longitude- 88.659172. According to USCS classification the soil is CL, inorganic clays of low to medium plasticity.

2.1.3 Cement

The cement was collected from the locally available market in the Dinajpur district. Portland Composite Cement (PCC) is used in this research due to its availability and economy. The chemical properties provided by the manufacturer are as follows-

Clinker: 65-79%; Fly ash, Slag & Limestone: 21-35%; Gypsum: 0-5%.

2.2 Designation of Test Specimens

In this research, the soil was mixed with constant 3% cement and 5%, 10%, 15%, and 20% fly ash by dry weight respectively. 3% cement was used as an activator with fly ash and soil sample. The reason behind using 3% cement is based on the previous studies that 3% cement with fly ash exhibits the maximum CBR value [8,11,12].

For convenience, the soil mixes are designated as presented in Table 1.

Table 1 Sample Designations

Sample Designation	Description
Mix M_1	Fresh Fly Ash
Mix M_2	Fresh Soil Sample
Mix M_3	Soil Sample with 3% Cement and 5% Fly Ash
Mix M_4	Soil Sample with 3% Cement and 10% Fly Ash
Mix M_5	Soil Sample with 3% Cement and 15% Fly Ash
Mix M_6	Soil Sample with 3% Cement and 20% Fly Ash

2.3 Laboratory Tests

Laboratory investigation such as specific gravity test, grain size analysis, Atterberg limit test, modified proctor compaction test, unconfined compressive strength (UCS) test and the California Bearing Ratio (CBR) tests were performed to determine the physical and engineering properties of fresh soil and soil with stabilizer (fly ash, cement). All the tests were performed according to ASTM and AASHTO standards.

Required amount of fly ash and cement were mixed thoroughly with soil. The mixed compound was kept in plastic bags for 24 hours with 98±2% relative humidity. Then, specific gravity, grain size distribution and Atterberg limit tests were performed according to the code ASTM D 854, ASTM D 422 and ASTM D 4318 respectively [13-15].

For Modified proctor compaction test, dry soil sample were initially mixed according to mix ratio in dry state. Then water was added to the sample. The mixing was carried out for 2 minutes and samples were put into the plastic bags. The bags were sealed and stored for curing for a period of 24 hours with 98±2% relative humidity. Before testing the materials were remixed again and the test was conducted according to ASTM D 1557 [16]. The procedure is similar to a previous study [8].

For Unconfined compressive strength test, samples were prepared under the optimum moisture contents. Each specimen had a diameter 30mm and height 70mm. The soil, amount of stabilizer and water were mixed thoroughly and transferred into a compaction mold with detachable collar. Then the specimen was subjected to a static compaction by gradually pushing a plunger from top and bottom. After extruding the sample from the mold, all the specimens were cured for 1 and 7 days to determine the effect of curing. The specimens were cured in a desiccator maintaining 100% humidity. The method is like previous study by Zha [17].

The California bearing ratio (CBR) test is used to evaluate the stability of soil subgrade and other flexible pavement materials. The CBR is defined as the ratio of the load sustained by the specimen at 2.5 mm or 5.0 mm penetration to the load sustained by standard road aggregates at the corresponding penetration level. The CBR value of different mixes of soil, cement and fly ash were determined as per AASHTO T 193-99 Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils [18]. The CBR specimens were prepared by adding water at their OMC and compacted to their MDD using heavy compaction method. For each mixture, two identical specimens were prepared. One was tested after 1 day curing maintaining 100% humidity and another one was soaked in water for 4 days. After completion of soaking period, the sample was tested.

3.0 RESULTS AND DISCUSSION

3.1 Classification of Soil and Power Plant Waste

For identifying the type of soil and power plant waste used in the study, their chemical analysis, physical property determination, and grain size analysis were performed. The power plant waste or fly ash collected from BTPP was analyzed chemically by XRF test. The result is shown in Table 2.

Table 2 Chemical Composition of Fly Ash

Element	Content in Fresh Fly (%wt)	Element	Content in Fresh Fly (%wt)	Element	Content in Fresh Fly (%wt)
SiO_2	48.368	MgO	0.279	NiO	0.023
Al_2O_3	36.808	SrO	0.149	Cl	0.022
Fe_2O_3	5.467	ZrO_2	0.118	PbO	0.018
TiO_2	4.216	Na_2O	0.096	ZnO	0.016
K_2O	1.671	BaO	0.085	Ga_2O_3	0.013
CaO	1.079	Y_2O_3	0.069	Rb_2O	0.012
P_2O_5	0.674	MnO	0.068	ThO_2	0.009
Cr_2O_3	0.347	CuO	0.040		
SO_3	0.318	CeO_2	0.038		

According to ASTM C 618, a class F fly ash should contain at least 70% by weight of Silicon (SiO_2) + Aluminum (Al_2O_3) + Iron (Fe_2O_3) [19]. The fly ash obtained from BTPP contains 90.643% by weight of SiO_2+ Al_2O_3+ Fe_2O_3. This classifies the fly ash in this research work as Class F and Non-plastic fine silt as it has no plasticity. Kumar also classified fly ash as non-plastic fine silt [20].

To understand the nature of soil the grain size distribution of that soil is needed. The grain size distribution of coarse-grained samples is determined by sieve analysis and for fine-grained soil samples, hydrometer analysis is needed. For Mix M1 (Fresh fly ash) and Mix M2 (Fresh soil sample) both sieve and hydrometer analysis according to ASTM D 422 is performed and the result is shown in Figure 1.

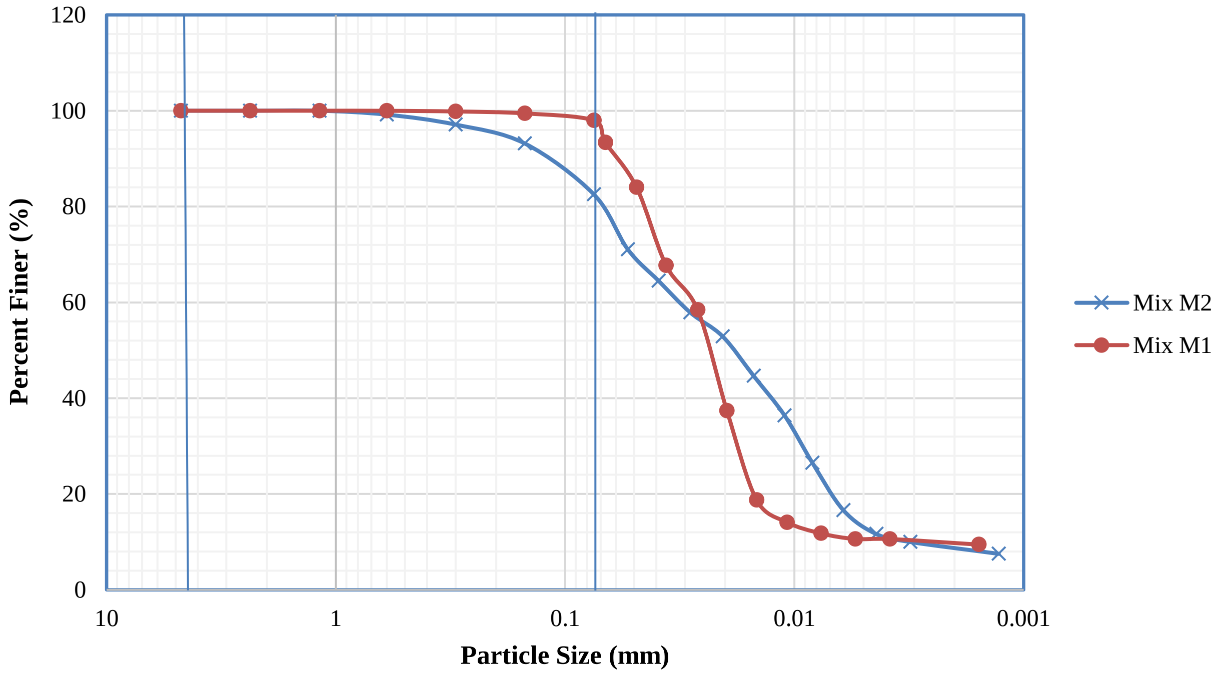

Figure 1 Particle size distribution curve for fresh fly ash and fresh soil

From Figure 1, it is observed that for fly ash the percentage of gravel, sand, and fines are 0%, 2.04%, and 97.96% respectively which is in line with the result obtained in another study [21]. For the soil sample, the percentage of gravel, sand, and fines are 0%, 17.44%, and 82.56% respectively. Thus, fly ash is finer than the soil sample tested.

Several physical properties of the power plant waste and the soil under consideration are presented in Table 3. From the result, the soil sample collected from the field is found to be of CL type, inorganic clays of low to medium plasticity, which exhibits a soaked CBR value of 2.79%. According to the Local Government Engineering Department (LGED) manual-2005, the minimum soaked CBR value required for a road subgrade material is 4%. So, the collected soil is unsuitable to use as road subgrade material. Also the expansion ratio more than 1% in this case makes the soil unacceptable for being used as the subgrade.

Table 3 Physical Properties of Fresh Fly Ash and Fresh Soil

Tests	Characteristics	Standards	Unit	Result	
				Fly Ash	**Soil**
Sieve Analysis	Sand content Silt and Clay content	ASTM D 422	% %	2.04 97.96	17.44 82.56
Specific Gravity	G_s	ASTM D 854	-	2.10	2.65
Atterberg Limits	Liquid limit (LL) Plastic limit (PL) Plasticity index (PI)	ASTM D 4318	% % %	49.93 N/A N/A	42.28 18.72 23.56
Modified Proctor Compaction	Optimum moisture content (OMC) (%W) Maximum dry density (MDD) (ρ_d max)	ASTM D 1557	% kN/m^3	29 11.7	13.10 18.19
CBR	Soaked CBR Expansion ratio	AASHTO T 193-99	% %	-	2.79 1.60
USCS	Classification	ASTM D2487	-	Non-plastic fine silt	CL

As the power plant waste collected from BTPP is F type fly ash, which exhibits negligible cementing properties, additives should be used to improve its performance to treat the CL type soil under consideration. Several additives are found to be benificial for this improvement [10]. A significant gain in strength is reported when a small amount of cement is added with F-type fly ash was observed by researchers [11]. Therefore, a discision is made to use 3% cement to improve the performance of the power plant waste for treating soft subgrade soil.

3.2 Specific Gravity Test Results

Specific gravity tests were performed for all the mixes from M1 to M6 according to ASTM D 854 and the results are tabulated in Table 4.

Table 4 Specific Gravity of Different Mixes

Sample Designation	Sample Mixing Ratio	Specific Gravity, Gs
Mix M_1	Fresh Fly Ash	2.10
Mix M_2	Fresh Soil Sample	2.65
Mix M_3	Soil Sample with 3% Cement and 5% Fly Ash	2.63
Mix M_4	Soil Sample with 3% Cement and 10% Fly Ash	2.60
Mix M_5	Soil Sample with 3% Cement and 15% Fly Ash	2.56
Mix M_6	Soil Sample with 3% Cement and 20% Fly Ash	2.51

From the test results, it is observed that the maximum specific gravity is obtained for fresh soil as 2.65. The fly ash has a lower specific gravity of 2.10. When fly ash is mixed with the soil sample, the specific gravity of the mix decreases with the increase of fly ash content as the fly ash has lower specific gravity. A similar observation was also found in an earlier study by Das and Parthi [22]. With the addition of fly ash and cement in different percentages, the specific gravity of soil is decreased from 2.65 to 2.51. The result is in line with a previous study [23].

A graphical presentation of the changes in specific gravity is shown in Figure 2.

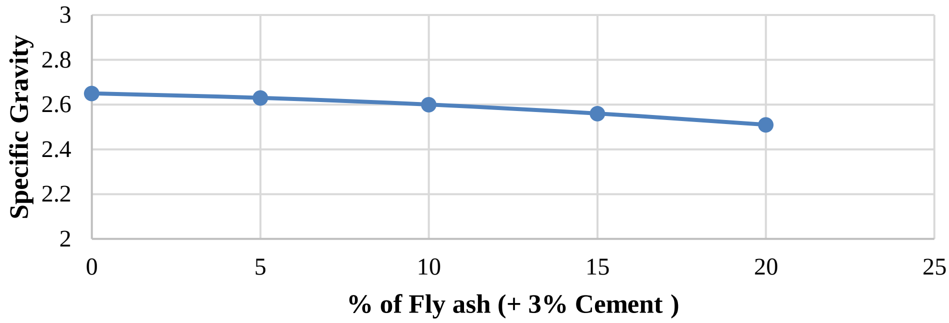

Figure 2 Relationship between specific gravity and % fly ash addition (with 3% cement).

3.3 Atterberg Limit Test Results

Liquid limit and plastic limit tests were carried out according to ASTM D4318, on mix samples. The outcomes are included in Table 5.

Table 5 Atterberg Limit Test Results

Sample Designation	Liquid Limit, LL (%)	Plastic Limit, PL (%)	Plasticity Index = LL-PL (%)
Mix M_1	49.93	Non-plastic	-
Mix M_2	42.28	18.72	23.56
Mix M_3	40.64	19.77	20.87
Mix M_4	39.06	20.26	18.80
Mix M_5	38.20	21.74	16.46
Mix M_6	36.95	22.85	14.10

Effects of fly ash and cement addition with soil sample show that liquid limit and plasticity index are decreased and the plastic limit is increased. This is due to the reduction of the thickness of the defused double-layer clay particles and caused flocculation of clay particles. When fly ash is added to the soil, the activity of the soil is reduced. The decrease in activity represents the lower water affinity and consequently the lower liquid limit [17]. The graphical representation of the Atterberg limit test of this research is shown in Figure 3.

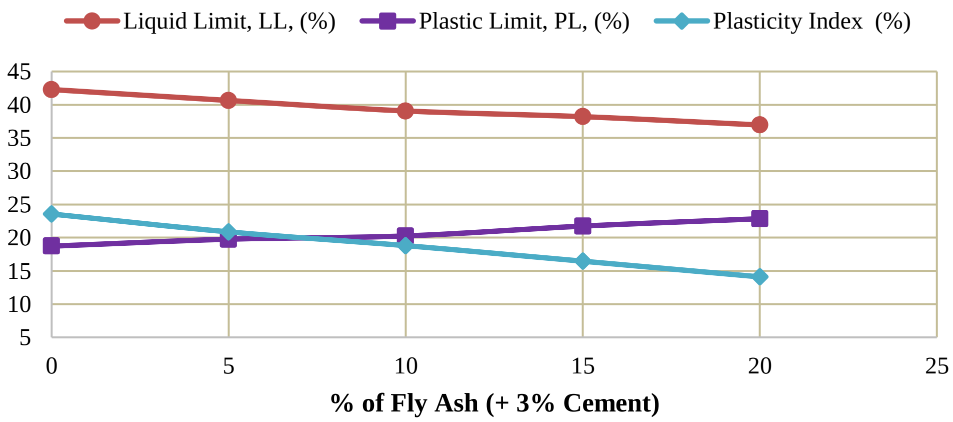

Figure 3 Relationship between LL, PL and PI and % of fly ash (with 3% cement)

The plasticity index of the fresh soil sample was 23.56%. With the addition of 20% fly ash 3% cement, the plasticity index reduces to 14.10%. So, by this stabilization process, the plasticity index is reduced by 40.15%, the similar results were obtained in the previous studies by Cokca, Ferguson and Parsons respectively [3, 24, 25]. The soil becomes medium plastic from high plastic as classified by Burmister [26].

3.4 Compaction Test Results

According to ASTM D1557, The modified proctor compaction tests were performed on soil mixes with different percentages of fly ash content and a stationary 3% cement content. The results are listed in Table 6.

Table 6 Modified Proctor Compaction Test Results

Sample Designation	MDD (kN/m3)	OMC (%)
Mix M_1	11.70	29.00
Mix M_2	18.19	13.10
Mix M_3	17.42	14.80
Mix M_4	17.32	15.25
Mix M_5	17.03	16.00
Mix M_6	16.08	17.00

Graphical representation is shown in Figure 4 and Figure 5.

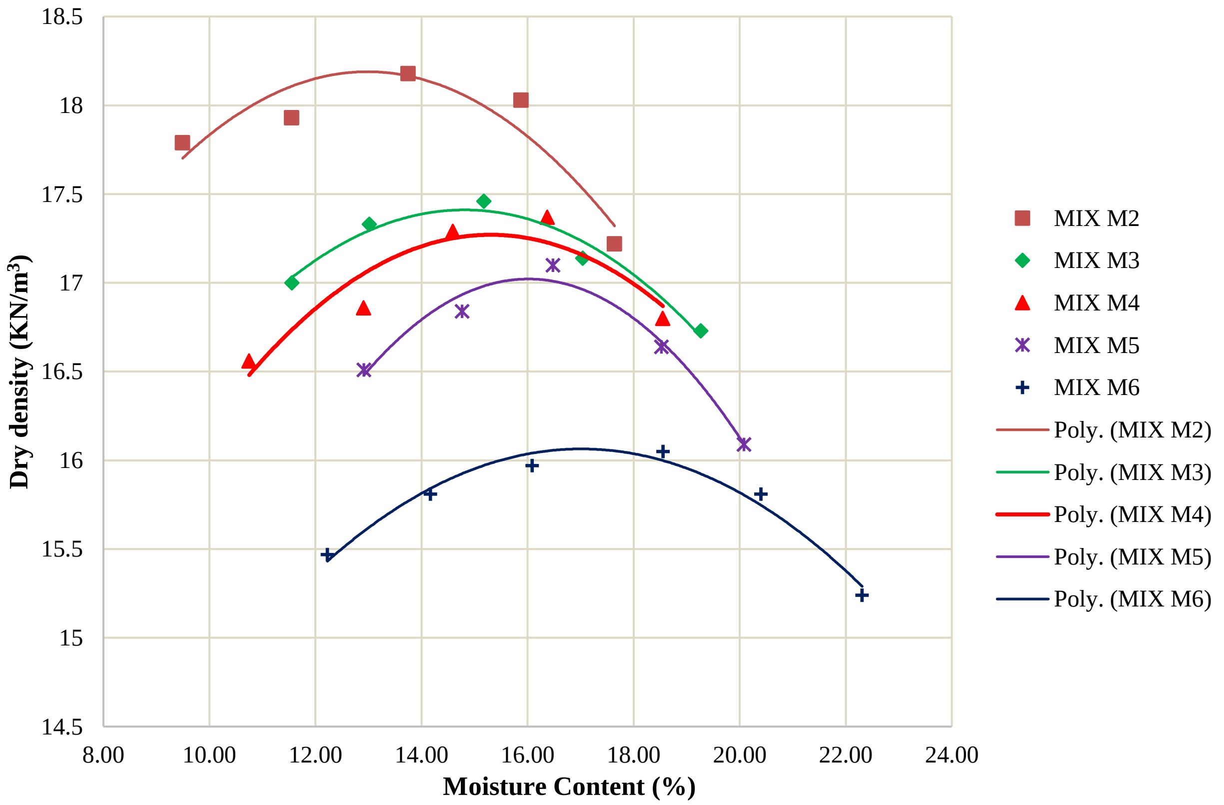

Figure 4 Relationships between MDD and OMC.

As the fly ash content increases, a gradual decrease in maximum dry density and a gradual increase in optimum moisture content is noticed. One possible reason for this trend is the lower specific gravity of fly ash compared with adapted soil, which reduces the density of the treated soil. By the addition of 20% fly ash and 3% cement with soil sample reduces the maximum dry density by 11.60% and increases the moisture content by 29.77%.

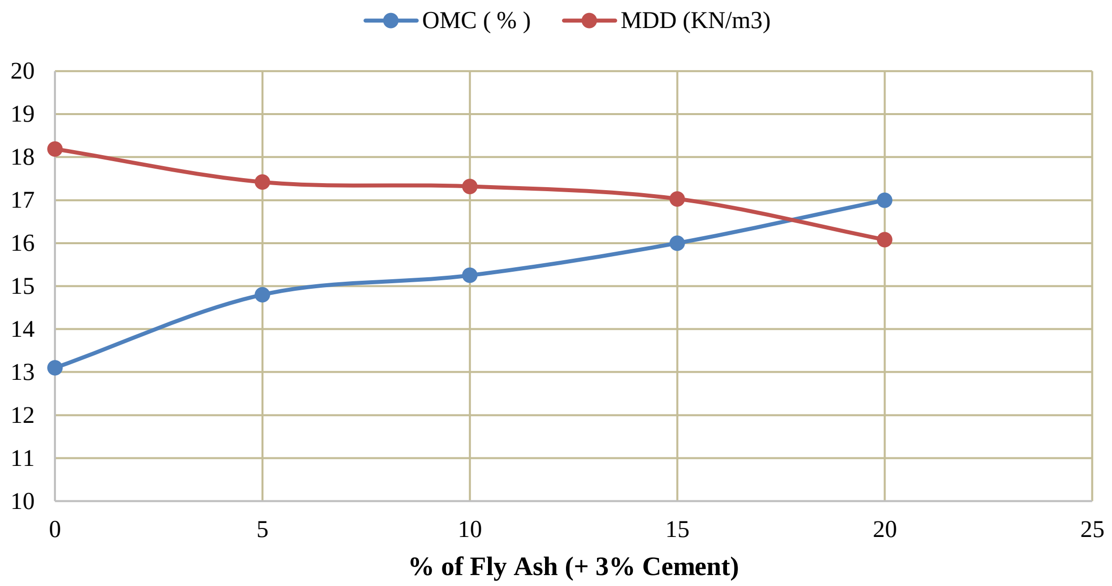

Figure 5 Relationship between MDD, OMC and % fly of ash.

Decrease in MDD and increase in OMC as a result of adding fly ash to the soil is also reported by Al-Naje et. al. and the possible reason was mentioned as the lighter weight of fly ash and its lower specific gravity [27]. The results are in line with previous works by Senol and Santos respectively [4, 28].

3.5 Unconfined Compressive Strength Test Results

The unconfined compressive strength test for both 1 day and 7 days cured sample was performed in the laboratory. The curing (7days) was not applied for mix M2 as cement was not added in this case. The results of the test are summarized in Table 7.

Table 7 Unconfined Compression test results

Sample Designation	Unconfined Compressive Strength, (kPa) Day-1	Unconfined Compressive Strength, (kPa) Day-7
Mix M_1	-	-
Mix M_2	127.97	-
Mix M_3	217.55	560.36
Mix M_4	231.41	581.84
Mix M_5	245.36	600.13
Mix M_6	238.72	583.55

Variation due to curing is presented graphically in Figure 6.

The unconfined compressive strength of fresh soil was very low and it is not suitable as road subgrade unless some treatments are made. Similar findings are presented by Shirin et. al. [29]. The UCS value is increased with the addition of fly ash and cement content. A maximum increase in unconfined compressive strength is found with the addition of 15% fly ash with 3% cement. Further increase in fly ash content decreases the unconfined compressive strength of stabilized soil, which is in line with the previous result given by Zha [17]. The quantity of fly ash up to optimum content induces the pozzolanic reaction and cemented materials effectively resulting increase in shear strength. By the addition of further fly ash compounds act as unbound silt particles that show no cohesion causing a reduction in shear strength [30]. Improvement of UCS value with the addition of fly ash was reported by Shirin et al. [29]. Another important observation is that the gain in unconfined compressive strength is greatly affected by the curing time as cement is involved. More than two times increase in UCS is noticed for a curing of 7 days as compared to that of 1 day curing.

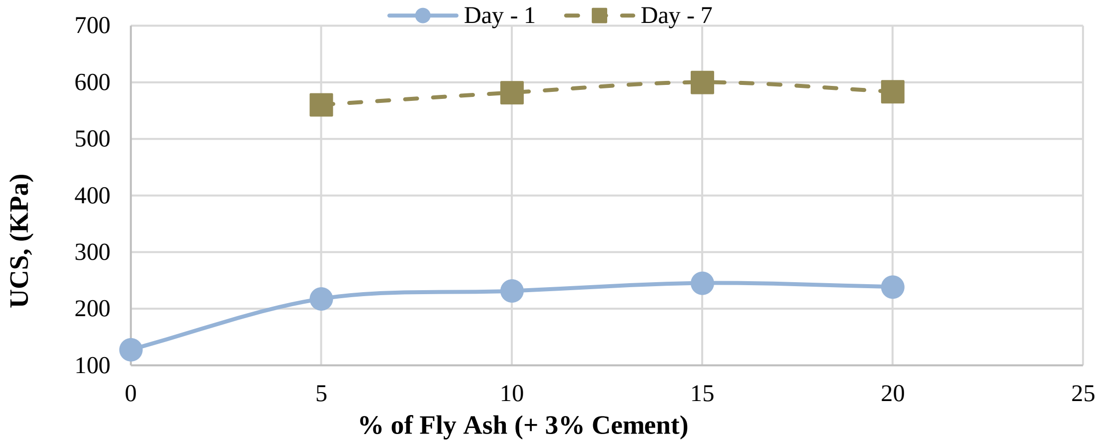

Figure 6 Relationship between UCS and % of fly ash (+3% cement)

3.6 California Bearing Ratio (CBR) Test Results

The practical application of pavement structure, the values of CBR are needed, the thickness of the pavement mainly depends on the CBR value of the material. Kolias et al. experimented on various types of soil with the addition of 25% fly ash with lean clay type soil [8]. By using activator as cement CBR values was increased from 10% to 185% after 91 days curing and for fat clay CBR value raised from 10% to 110%. According to AASHTO T 193-9, the CBR tests were performed and the result of the CBR tests are listed in Table 8.

Table 8 California Bearing Ratio (CBR) Test Results

Sample Designation	Sample Condition	Penetration (mm)	CBR (%)	Expansion Ratio (%)
M_1	Un-soaked	2.5	N/A	3.05
		5.0	N/A	
	Soaked	2.5	N/A	
		5.0	N/A	
M_2	Un-soaked	2.5	41.69	1.60
		5.0	38.34	
	Soaked	2.5	2.79	
		5.0	2.70	
M_3	Un-soaked	2.5	98.76	0.62
		5.0	93.62	
	Soaked	2.5	92.59	
		5.0	82.30	
M_4	Un-soaked	2.5	91.05	0.73
		5.0	84.36	
	Soaked	2.5	86.42	
		5.0	74.07	
M_5	Un-soaked	2.5	87.96	0.85
		5.0	78.19	
	Soaked	2.5	80.24	
		5.0	73.04	
M_6	Un-soaked	2.5	78.70	0.97
		5.0	76.13	
	Soaked	2.5	72.53	
		5.0	63.78	

The result is graphically shown in Figure 7.

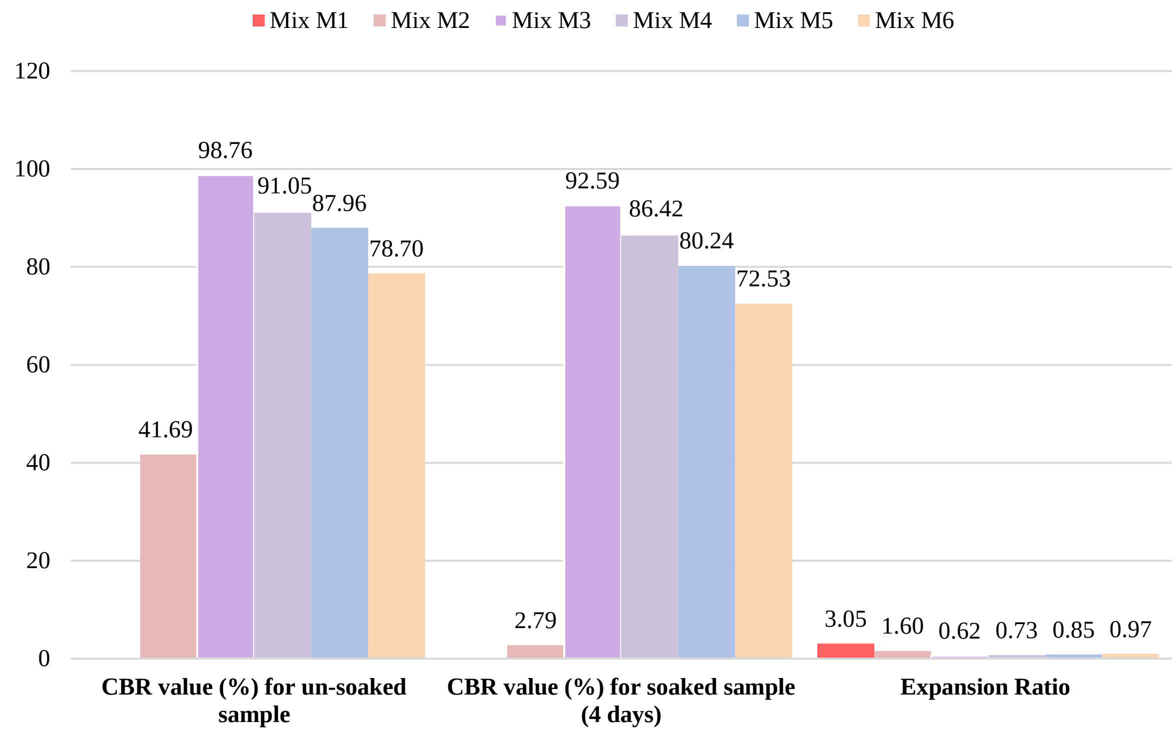

Figure 7 Changes in CBR values and expansion ratio for different mixes

Normally the design practice is to prefer soaked CBR values. The fresh soil exhibits a CBR value of only 2.79% in soaked conditions and an expansion ratio of 1.60%. According to the Local Government Engineering Department (LGED) manual-2005, the minimum soaked CBR value for a road subgrade material is 4% and maximum expansion ratio 1%. So, the collected soil is unsuitable to use as road subgrade material. The addition of fly ash and cement with soil showed a remarkable increase in CBR value, which is maximum for 5% fly ash and 3% cement. Further increase in fly ash content with 3% cement reduces the CBR value and increases the expansion ratio gradually. The reason behind this, the expansion ratio of fresh fly ash collected from BTPP is very high. In this research, the soaked CBR value of fresh soil sample is increased from 2.79% to 92.59% by addition of 5% fly ash and 3% cement with it. Similar results were observed earlier by researchers. A 400% of improvement of CBR value was reported in literature for the treatment of soil with fly ash and NaOH resulting in a 40% decrease in pavement thickness [31]. From the observed CBR values, the mixes M3, M4 and M5 can be used as road subgrade. M5 should be rejected as its expansion ratio is closed to 1%.

4.0 CONCLUSION

This research investigated the effect of fly ash addition on cohesive soil. The fresh fly ash, collected from Barapukuria Coal Fired Thermal Power Plant, is Class F type and collected soil sample is classified as inorganic clay of low to medium plasticity. Grain size analysis both sieve and hydrometer show that fly ash is finer than the collected soil. According to the results of the experimental study, the findings are as follows:

- Specific gravity of fresh soil decreases with the addition of fly ash. The specific gravity of the fresh soil decreases from 2.65 to 2.51 as a result of being modified with 20% fly ash and 3% cement. The plasticity index also decreases from 23.56% (fresh soil) to 14.10% (modified with 20% fly ash and 3% cement).
- Maximum dry density obtained from modified proctor test decreases from 18.19 kN/m^3 to 16.08 kN/m^3 and optimum moisture content increases from 13.10% to 17.00% for an addition of 20% fly ash content.
- Unconfined compressive strength increases up to the addition of 15% fly ash, further addition of fly ash reduces the UCS value of soil mix. After 7 days of curing, the increase in UCS value of fresh soil is as high as 368.96% for the addition of 15% fly ash and 3% cement, which is the maximum unconfined compressive strength.

- The mixes M3, M4 and M5 meets the requirements of road subgrade. However, best performance can be obtained from the mix M3 that contains soil mixed with 5% fly ash and 3% cement. It shows the maximum CBR value of 92.59% in soaked (4 days) condition where the soaked (4 days) CBR value of fresh soil was 2.79%. The minimum expansion ratio is also found for this combination and the UCS value is also within an acceptable range.

All the above findings indicate that fresh cohesive soil improved with 5% fly ash (collected from BTPP) and 3% cement is found to be effective as road subgrade. The treated soil thus obtained has a high UCS value of 217.55 kPa (1 day) and 560.36 kPa (7 days), an appreciable soaked CBR value of 92.59% (2.5 mm) and 82.3% (5 mm) and a low expansion ratio of 0.62% which satisfies the subgrade requirement. However, further studies are should be conducted for other soil types and with other additives.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper

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