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Research Article

Experimental Evaluation of Strength Improvement in Class F Pond Ash through Cement Stabilization and Jute Fiber Reinforcement

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Keywords

XRF,
UCS,
Pond ash,
Additives,
Compressive strength.

Abstract

The main aim of this research is to study the strength improvement in pond ash by adding different materials like sand, cement, jute fiber. The study also seeks to determine the appropriate proportion for use of pond ash as an engineering material. The research aims were achieved through a series of laboratory experiments. X-ray fluorescence (XRF) was used to identify the pond ash, which was found to be Class F according to AASHTO M295. Pond ash of class F has less cementitious properties, therefore 1%, 2%, 3% and 4% cement had been added with 78.5%, 79.5%, 80.5%, and 81.5% of pond ash, respectively. Furthermore, these pond ash mixtures were also mixed with 0.5% jute fibers of size 12 mm (mixing percentage of sandy soil was added to these mixing ratios was 20%,18%,16% and14%). The results showed a significant variation in the engineering properties after adding admixtures to pond ash. The results showed a significant variation in the engineering properties after adding admixtures to pond ash. The MDD of the mix was decreased from 1.63 to 1.575 gm/cc through the set of proportions, whereas the OMC was increased from 15% to 17.4%. The unconfined compressive (UC) strength of raw pond ash increased significantly with the addition of jute fiber, cement and sand as also with prolongation in curing period. The strength was increased from 113 kN/m² on the 1st day up to 943.82 kN/m² at 28 days, indicating the positive effect of curing time and material optimization on the strength. Mixes of 3% and 4% cement with pond ash have much higher compressive strength at 7, 14 and 28 days curing making them suitable for subgrade, subbase or embankment, but the mixes of cement (1-2%) are suitable for non-immersed condition.

1. Introduction

A waste product from a thermal power plant, pond ash consists of varying percentages of bottom ash and fly ash depending on when it was deposited. The evil of this kind of rubbish is that it has been damped. For saving the costs of a project, although pond ash has low shear strength and bearing capacity, it can be improved and used as a construction material [1]. BTPP, which is the country's first-ever coal-based power plant will cater to the power requirement of Bangladesh. In the process of generating 250 MW power, 300 metric ton/day of pond ash is generated by burning 2,400 t coal at BTPP [2]. Coal ash from thermal power plants is released to the coal ash pond located adjacent to the BTTP. The ash pond water is released into the Tilai River through a recharge culvert [3]. Several authors mowed to investigate the alternative use of pond ash in geotechnical structures (instead of occupying earth). Reinforced pond ash Pradhan and Pothal (2024) [4] proposed that raw pond ash materials can be an alternative construction material used in geotechnical engineering sector is simply referred as reinforced pond ash. Index and engineering properties of the waste material need to be determined before any engineered use. In the recent daily practice, pond ash (PA) — a coal-fired thermal plant waste, is also considered to be re-compacted and reused for geo-technical purposes because it has both ecological and economic profits if a somewhat indication of its low density and strength are bettered properly. Early work by Bera et al. (2009) [5] found that the shear strength (normal stress ~ 103% in normal loadings) of pond ash reinforced with three layers becomes high. Similarly, Sreedhar et al. (2011) [6] reported that CBR properties of fiber and fabric reinforced pond ash is higher than unreinforced PA which shows the superior CBR properties of fabric reinforcement over fiber reinforcement. Yadav et al. (2018) [7] reported that when cement-stabilized clayey soil is partially replaced with pond ash in conjunction with polypropylene (PP) fibers, the strength increases but the stiffness decreases and postpeak strength deterioration becomes slower. Laboratory experiments of Kumer & Kanaujia (1999) [8] in silty sand–pond ash blends reinforced with randomly distributed polyester fibers also affirmed the role played by reinforcing fiber to improve the load-bearing capacity. Newer works on both physical (natural fibers / synthetic fibers / gasohshitics) and chemical or hybrid stabilization (lime, cement, GGBS and geopolymerizing agents etc.) of pond ash -or- pond ash blended mixtures have been conducted to make pond ash meet the requirement for subgrade / sub-base / foundation etc. For instance: Kumar & Sharma (2018) [9] When PA was combined with cement dust and PP fiber, better geotechnical soil properties were shown. The fibre with the cementitious binder led to improvement in compaction and strength, indicating a possible application as subbase. Malik et al. (2021) [10] investigated the application of PP fibers (from plastic waste bags) combined with pond ash in highway embankments. The fibre isovalerate content and the aspect ratio of the fiber were altered; at a given fibre content and aspect ratio (e.g., 1.5% PP fiber at AR = 100), PA-fiber blends displayed up to a 46% improvement in CBR over neat PA, as well as an increase in cohesion and friction angle as measured by direct shear testing. Pradhan & Pothal (2025) [11] offered coir woven geotextile as a replacement to synthetic fibers. In the present study, various types of coir geosynthetic (C1, C2 and C3) was placed in pond ash subgrade under several depth, width and different reinforcement layers by adopting triaxial test and model-footing test. Compressive bearing capacity and strength have improved significantly with coir multi layers reinforcement and hence, natural fiber geosynthetics can be environmentally feasible for the construction of sustainable subgrade. Kedar & Patel (2025) [12] used combined stabilization, lime and GGBS to stabilize PA, and tested UCS, M_r as well as microstructure. It was found that the blends derived with sewage sludge and waste glass meet engineering properties suitable for use as subbase

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in flexible pavement layer and provide a sustainable waste application path. Varma and Singh (2025) [13] further investigated the geopolymer activation of PA (with different binder contents) – which is thewithout-binder or low-cement-demand approach, an enhancement in strength and durability was achieved. This implies that geopolymer-stabilised pond ash could be a potential low CO_2 footprint alternative for road base/subbase or other geotechnical end uses. Vilasini & Thangasamy (2025) [14] gave 120-day long-term curing results for both lime and cement, indicating that compaction dry density, and UCS significantly improved due to the addition of both materials; the optimum dosage could be known (e.g., 6% cement or 8% lime) which gives highest strength increase. This contributes to the assessment of durability and time-evolution of strength in treated PA that had generally been absent from previous short-term studies. The analogous combination of pond ash and a geosynthetic (natural/synthetic) for subgrade improvement has been reported by Modak & Ali (2025) [15]. These authors pointed out the role which PA— a material with low density and pozzolanic potential — assisted by geosynthetic tensile reinforcement, could play in terms of increase in strength under loading level, decrease in settlement, although long term field studies were few. While many researches dealt with physic-chemical and technical properties of the reinforced pond ash, very few focused on the material characterization. The objective of the present study was to study the role of jute fiber, cement and soil on pond ash to improve its engineering behaviour. Four pond ash blends were prepared for laboratory study to find out the optimum percentage.

2. Materials and methods

2.1. Used materials

2.1.1. Pond ash

BTPP is situated in Parbatipur Upazila of District Dinajpur. The pond ash was collected from the dumping site of BTPP (Figure 1a-b). One of coal ash's byproducts is pond ash. These ashes are disposed of in two ash ponds next to the BTPP together with water.

2.1.2. Jute fiber

The jute utilized in this investigation as reinforcement was collected from the Jute Seed Production and Research Center, Nashipur, Dinajpur (Figure 1c). This study used 12 mm cropped jute fiber as fiber reinforcement. The fibre had a tensile strength of 202 MPa, diameter of 14 µm, and water absorption rate of 13.5%.

2.1.3. Cement

The Portland Composite Cement (PCC) used in this research work was collected from the local market (Figure 1f).

2.1.4. Soil sample

The soil sample was obtained from a bridge site of Chadganj, which is in Dinajpur (Figure 1d-e).

(a) (b) (c)

(d) (e) (f)

Figure 1. Collection of used materials (a) Pond ash site, (b) pond ash, (c) Jute fiber, (d) soil collection site, (e) soil sample and (f) Cement

2.2. Methodology

2.2.1. Index properties

A few laboratory investigations were conducted to determine the geotechnical properties of soil and pond ash samples collected. Laboratory tests include grain size analysis, Atterberg limit, and the specific gravity (Gs). For size analysis, ASTM D-422 [16] (for finer particles hydrometer analysis and for courser particles sieve analysis) was used. The Gs of the materials used was determined by making use of a pycnometer according to ASTM D 854-00 [17]. The Atterberg limit was determined according to the ASTM D 4318 [18] test standard.

2.2.2. Chemical properties

A Rigaku ZSX Primus wavelength dispersive X-Ray fluorescence spectrometer was used in the chemical test at the Institute of Mining, Mineralogy, and Metallurgy (IMMM), Joypurhat, to identify the different components of the pond ash (Figure 2).

2.2.3. Engineering properties

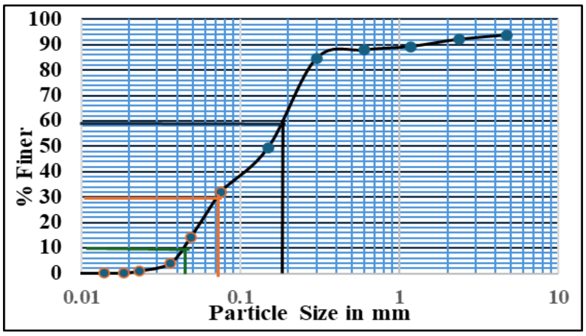
The correlations between density and moisture content were determined using compaction test according to ASTM D 1557 [19]. The MDD and OMC were obtained from the dry density-moisture content relation through the modified Proctor test. The strength from UCS was computed following ASTM D 2166 [20].

Figure 2. XRF testing

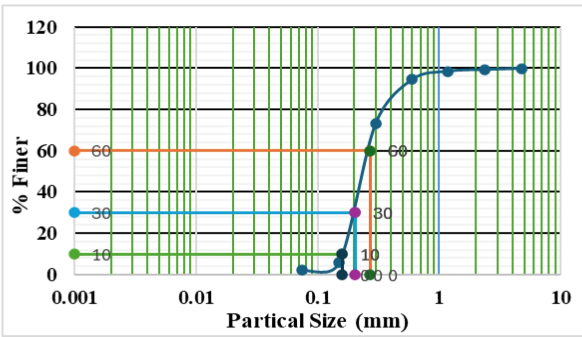
3. Result and discussions

3.1. Index properties

The sp. Gravity (Gs) of ash was observed as 2.40. Typically, the Gs of pond ash is between 1.9-2.6 depending on its type. For instance, Sharma et al. (2020) [21] has provided a specific gravity value for the pond ash as 2.30. The Gs of the soil sample was 2.68, in contrast. The grain size distribution of the coarse grained soil was conducted by sieve analysis while for fine grained soil sample, it was determined using hydrometer method. Figures 3(a) and 3(b) shows the particle size distribution curve for pond ash and soil samples, respectively.



(a)



(b)

Figure 3. Particle size distribution curve for (a) pond ash and (b) soil sample

The percentages of sand and gravel are 97.66% and 0.24%, respectively, as depicted in Figure 3(b) according to USCS soil classification. It was discovered that 2.11% of the pond ash passed through a 75 µm sieve. The curvature coefficient (Cc) is 0.96 and the uniformity coefficient (Cu) is 1.70. The Atterberg limit test indicates that neither the soil sample nor the pond ash exhibits plasticity.

3.2. Chemical properties

The chemical test was carried out at the IMMM in Joypurhat. Table 1 displays the chemical analysis of the pond ash utilized in this study.

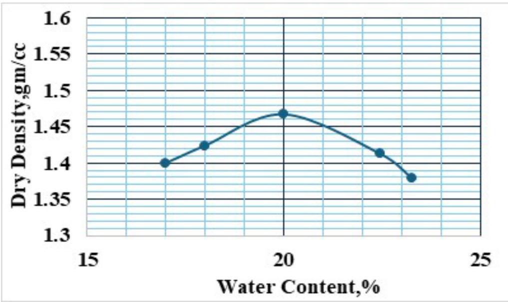
Table 1. Result of chemical analysis

Component	amount (%wt.)	Component	amount (%wt.)
Na_2O	0.0755	Cr_2O_3	0.4499
MgO	0.3987	MnO	0.2690
Al_2O_3	19.918	Fe_2O_3	19.212
SiO_2	54.779	NiO	0.0185
P_2O_5	0.3558	CuO	0.0201
SO_3	0.1017	ZnO	0.0124
Cl	0.0147	Rb_2O	0.0094
K_2O	0.8509	SrO	0.0727
CaO	0.9246	ZrO_2	0.1579
TiO_2	2.3497	Nb_2O_5	0.0099

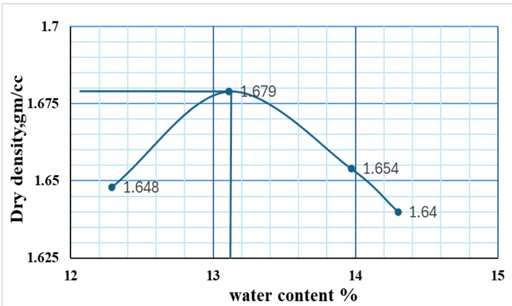
In the United States, pond ash is classified into two groups: Class F pond ash, which has a composition of less than 18% CaO, and Class C pond ash, which has a composition of more than 18% CaO. It is classified as Class F if the total of silica (SiO_2), alumina (AlO_3), and iron oxide (FeO_3) is more than 70%. The total for the Class C type is 50% to 70%. Class F is the classification for the pond ash utilized in this study, as the total of SiO_2, AlO_3, and FeO_3 is 93.9%.

3.3. Compaction properties

Pond ash was tested for modified proctor and maximum dry density (MDD) compaction, to obtain its optimum moisture content. The test result is shown in Fig. 4 (a). The MDD is obtained at 20% moisture content (Figure 4(a)). Hence 20% is optimum moisture content, and MDD is 1.466 gm/ccupportInitialize The optimum compaction is observed when pond ash has 20% moisture level. The MDD and OMC values of pond ash sample are found within the safe limits for highway embankement construction as recommended in IRC: SP:58-2001, whose range specified as follows: 0.9–1.6 g/cm³ (MDD) and 18.0–38 % (OMC). The variation or dry density for different moisture contents is shown in Figure 4(b).



(a)



(b)

Figure 4. Water content and dry density relationship for (a) pond ash and (b) soil sample

The MDD is achieved with a moisture content of 13.11%, as shown in Figure 4(b). Therefore, 13.11% moisture content is ideal, and 1.679 gm/cc is the maximum dry density. Sand typically has a compaction potential of moderate to good, as shown by this rating. The outcome demonstrates that when moisture content is kept at about 13.1%, the sand may be compacted to a good density.

3.4. Compaction test for pond ash mixed with soil, cement and jute fiber

Once the samples were obtained, a few mixture proportions were generated to work out the most suitable percentage. Sample numbering is indicated and reported in Table 2. Modified proctor tests were conducted on MIX 1-MIX 4 to determine the MDD and OMC. Individual results of each blend are shown in Table 3. Based on the results of tests above, the introduction of pond ash results in a reduction in its maximum dry density and an increase in OMC. It is primarily based on the reason that pond ash has a lesser specific gravity than special soil, leading to low density of formed mix.

Table 2. Sample designation

Sample Label	Sample mixing ratio
Mix-1	1% cement, 0.5% jute, 20% soil and 78.5% pond ash mix
Mix-2	2% cement, 0.5% jute, 18% soil and 79.5% pond ash mix
Mix-3	3% cement, 0.5% jute, 16% soil and 80.5% pond ash mix
Mix-4	4% cement, 0.5% jute, 14% soil and 81.5% pond ash mix

Table 3. MDD and OMC for different mixes

Sample Label	Sample Mixing Ratio				MDD (gm/cc)	OMC (%)
	Cement %	Jute %	Soil Sample %	Pond Ash %		
Mix-1	1	0.5	20	78.5	1.63	15
Mix-2	2	0.5	18	79.5	1.609	15.31
Mix-3	3	0.5	16	80.5	1.594	17.30
Mix-4	4	0.5	14	81.5	1.575	17.40

3.5. UCS Test for designed sample

The remold sample was prepared in the laboratory from Mix 1 to Mix 4 for UCS testing of the prepepared samples. Sample size was 30 mm in diameter and 70 mm in height. The prepared samples were placed in buckets with 2 cm thick of water at the bottom, wrapped in plastic and cured. The buckets were sealed with a closed lid to maintain consistent humidity levels (Figure 5). The curing period was carriedout at a constant temperature and humidity of the laboratory, where the bucket was covered and stored. The temperature was kept at approximately 23°C during the curing process. The sample was removed from the bucket once it has been cured for 1, 7, 14, and 28 days.

Figure 5. Curing process of UCS sample

Figure 6 shows a visual representation of the UCS test findings for the four curing periods. The findings show that while the amount of pond ash rises, the cement addition boosts the sample's unconfined strength. As the curing time grew, so did the strength. the highest strength attained after 28 days of curing at 4% cement content. the minimal strength obtained after one day of curing at 1% cement content. The unconfined compressive (UC) strength of four mix types after 1 day curing is shown in Fig. 6a. MIX 1 had a strength of 72.7 kN/m², MIX 2 had a slightly higher strength which is equal to 79 kN/m². The strength of MIX 3 and MIX 4 were much higher, 96 kN/m², and 113 kN/m² respectively. The data shows that the early-age strength in UC increases progressively from MIX 1 to MIX 4, this means that the composition of MIX 3 and MIX 4 provides a remarkable improvement on early curing strength compared to those of MIX 1 and MIX 2.

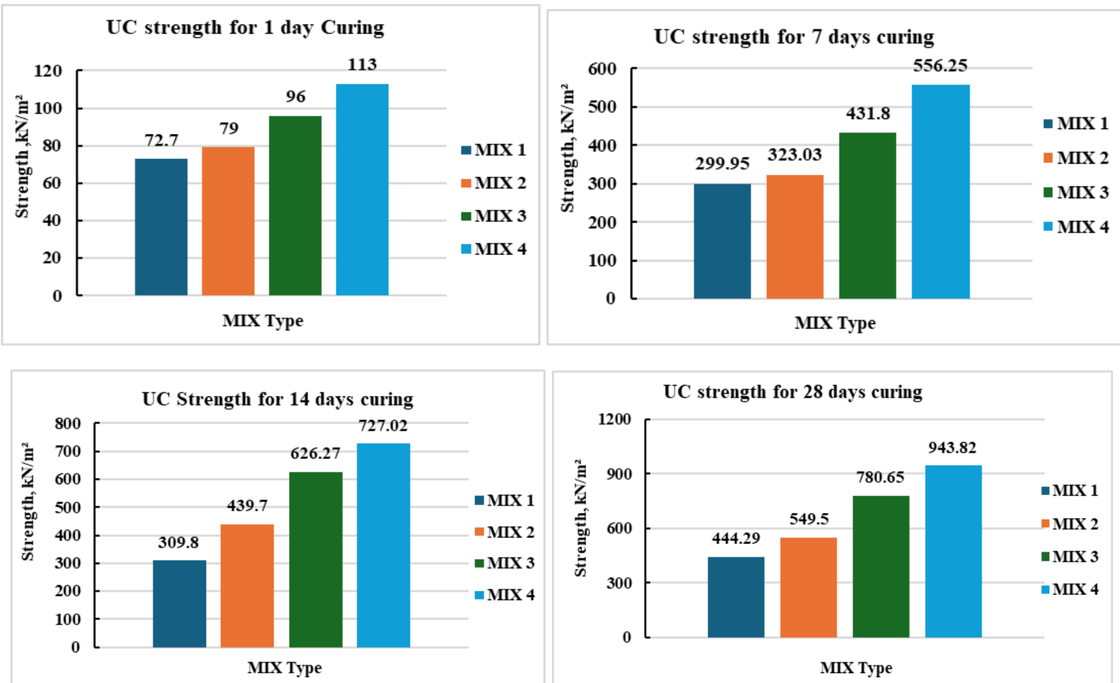


Figure 6. UC strength variation for (a) 1 (b) 7 (c) 14, and (d) 28 days of curing

Strength after 7 and 14 days of curing are compared for unconfined (UC), and differences in four soil - cement mixes performance levels observed. Mix 1 and Mix 2 had lower strengths of 299.95 kN/m² and 323.03 kN/m², respectively after 7 days however Mix 3 and Mix 4 gained higher strength values of about (431.8 kNm/²) and (556.25 kNm/²). At 14 days, Mixes 1 and Mix 2 had achieved barely acceptable strengths categorized as an average of 309.8 kN/m² and 449.7 kN/m² of samples' strength development respectively. Mix 3 and Mix 4, however, continued to increase significantly in strength up to 626.27 kN/m² and 727.02 kN/m² respectively. Considering that Mix 4 resulted in the best property for the both curing times), it is noteworthy to mention that, of all mixtures developed in this study, Mix 3 presented the highest relative increase overtime, almost reaching to values as good as those obtained with Mix 4 within 14 days. These trends highlight the importance of mix design to early-age and final strength development under continued curing. The UC-strength (in kN/m²) of four soil-cement gradations in comparison with percentage by mass, are presented as a bar chart in Figure 6(d) after curing for 28 days. As the results indicate, there is an obvious large variance in performance between the mixes. Mix 1 and Mix 2 exhibited lowest strengths (444.29 kN/m² and 549.5 kN/m²). Much better improvements can be seen with Mix 3 that had strength of 780.65 kN/m². The highest performance was achieved by Mix 4 that resulted in a compressive strength of 943.82 kN/m², almost doubling the value obtained on the mixture with base mix and more than two times its values compared to the base mixes which possessed the greatest compressive strengths. This evolution stresses the key of the mix composition effects on the mechanical behaviour of treated material.

4. Conclusion

The current research work focuses on the analysis of physicochemical, index and engineering properties of fresh pond ash, pond ash mixed with soil sample, cement and jute fiber. Here are the main conclusions:

- The Gs of pond ash was 2.40. The pond ash has 32.123% finer particles with; gavel particles accounting for 6.11% sand particles of 61.76%.
- The pond ash used in this investigation was classified as F-type due to having its compositions such as SiO_2, Al_2O_3 and Fe_2O_3. The compaction test results, the MDD and OMC were 1.466 gm/cc and 20%, respectively.
- The MDD, OMC, and unconfined compressive strength of four mixture samples were tested when they were produced by random proportion. Out of four mixes, Mix 1 gives maximum MDD and minimum percentage of OMC, which are 1.63 gm/cc and 15.0%. Increasing the percentage of pond ash in the mix, the OMC increases and the MDD decreases.
- The strength increased by 1% of cement, between 72.7 kN/m^2 and 299.95 kN/m^2, 309.8 kN/m^2 and 444.3 kN/m^2 after aging it up to curing age (1st day, 7th day,14th day & 28rd days) respectively. It had maximum value of 943.82 kN/m^2 when curing duration is 28 days and with a use of only 4% cement.
- The experimental results are highly effective in the context of sustainable reuse of pond ash from BTPP, enhanced environmental properties and imperishable behaviour of recycled materials are addressed. The high strength values, which are much higher than those of the control at 7, 14, and 28 days, indicate that pond ash can be used for structural applications by improving existing cementitious products with just a 3% or 4% addition of cement and jute fiber. The result is a significant achievement for low-cost geotechnical projects.
- The maximum curing period in this study is 28 days; therefore, the long-term performance is not evaluated. The durability elements, such as wet–dry cycling, chemical resistance, and the environmental effects (e.g., leachability), were outside the scope of this study. Further, the results are obtained only from laboratory experiments, and on-site multiphase flow experiments also need to be carried out for verification.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest.

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