

## PHYSICOCHEMICAL AND MINERALOGICAL ASSESSMENT OF BARAPUKURIA THERMAL POWER PLANT (BTPP) POND ASH

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### ABSTRACT

The purpose of this study was to investigate the physical, chemical and mineralogical properties of pond ash. Its physical properties were determined by laboratory tests such as: specific gravity, grain size distribution and Atterberg limits. The specific gravity is found to be lower (2.44) than soil (2.6-2.7) and a non-plastic to low plastic, predominated by silt size fraction (75.36%). It is therefore confirming the lightness property which makes it as a fill material for pond ash. Chemical property and mineralogical analyses were performed by using X-ray fluorescence (XRF), X-ray diffraction (XRD), scanning electron microscopy (SEM), respectively. Based on XRF, The major oxide compositions of BTPP pond ash were found to be  $SiO_2 = 48.34\%$ ,  $Al_2O_3 = 32.26\%$ ,  $Fe_2O_3 = 11.53\%$ , and  $CaO = 1.15\%$ . The purity of  $SiO_2$ ,  $Al_2O_3$  and  $Fe_2O_3$  is approximated as 92.13%, which exceed the minimum requirement of being not less than 70% for Class F fly ash specified by ASTM C618. It is also farmed as a Class F fly ash due to the presence of CaO lower than 18% criteria. The XRD analysis indicated that some mineral phase such as quartz ( $SiO_2$ ), mullite ( $Al_6Si_2O_{13}$ ) and hematite ( $Fe_2O_3$ ), non-reactive at the ambient temperature, were found to be typical of cementitious materials. In the final analysis, these results show that pond ash can be satisfactorily utilized in geotechnical applications such as subbase fills, embankment materials and land reclamation work because of its favourable physico-chemical and mineralogical properties.

**Keywords:** Physicochemical; BTPP; XRF; XRD

## 1. INTRODUCTION

Pond ash, a solid waste byproduct of coal-based thermal power plants, poses a huge disposal problem due to the need for large tracts of land for its disposal worldwide. The application of pond ash in civil engineering works such as structural fill, embankment construction, road subgrade and slope stabilisation has also attracted more attention due to the growing demand for sustainable construction materials. The potential of green concrete for waste minimisation and environment protection makes it one of the key issues in developing sustainable engineering solutions (Gupta et al., 2021). In Bangladesh, such thermal power plants are operating at Barapukuria with a capacity of 250 MW. Barapukuria Coal Fired Thermal Power Plant (BTTP) is located in the Hamidpur union of Parbatipur Upazila, Dinajpur district (Figure 1). To meet the power demand of the country, Bangladesh Power Development Board (BPDB) commissioned 2 x 125 MW coal-based PPs under BPDB at Barapukuria, Dinajpur, in June. Following much delay, mishaps and high operating expenses were arranged by a specialised Turkish Company. Howladar & Islam (2016) have added that the BTTP has largely contributed to the Bangladeshi economy. Recently, some waste products have been suggested to save energy and natural resources used for the preparation of construction material.

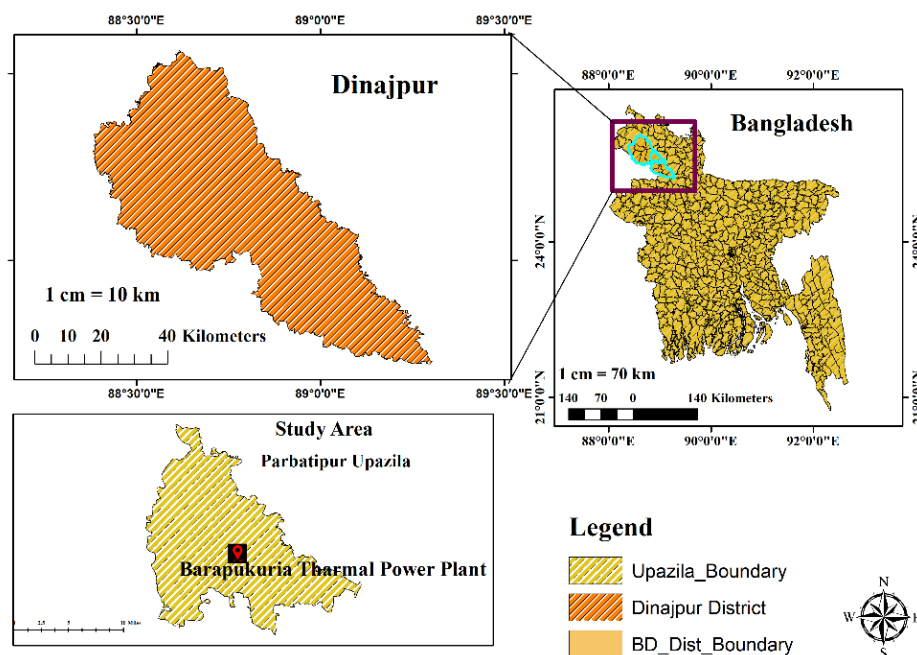


Figure 1: The location map of BTTP, Dinajpur

Fly ash contains numerous mineral components like silica, alumina, iron oxides, carbon, etc. The characteristics of the fly ash mainly depend on the coal types and the burning method in the power plant (Noaman et al., 2022). Fly ash is sluiced to an ash pond in a slurry form after mixing with water and allowed to remain under water till it becomes 'pond ash.' Pond ash includes fly ash as well as bottom ash, which is conveyed to an artificial containment such as a pond; all of this is plausibly considered to be the solid waste produced by a coal-burning power plant. These materials are of great interest due to their physiochemical and mechanical properties (Mohanty & Patra, 2015). Environment, natural resources, and energy Several studies have been conducted on the potential for recycling industrial by-products as environmentally sound construction materials with a view to preserve both natural resources and energy. Among these, pond ash has shown promising facts about being a substitute construction material, like in stabilization with optimal additives (Randhawa & Chauhan, 2021). Influence of diverse nature pond ash The diversity of pond ash, as reported in previous research results with the various relevant properties, directly affects its geotechnical characteristics (Teli & Sachan, 2024). Mineralogical constituents (silica & alumina) in pond ash are pozzolanic in nature, which increases their stability and strength when they stabilize with stabilization agents such as lime, cement, or ground

granulated blast furnace slag (Pradhip et al., 2021). It is this kind of environmental and pond ash property variation that needs to be investigated thoroughly in order to improve the performance of admixture as well as reduce its disadvantages (Singh et al., 2024). In addition, the environmental benefits of pond ash are waste utilization and a decrease in CO<sub>2</sub> generation so this is a way out for green-averse construction (Kedar & Patel, 2025). Moghal et al. (2020) studied the possibility of incorporating fly ash for sustainable use in civil engineering through stabilization with lime or gypsum. Pond ash's pozzolanic character contributes to increased resistance from environmental impacts, including moisture penetration and chemical attack, for embankment and subgrade (Ghosh & Roy, 2022). The goals of the project are to identify Physical, chemical, and mineralogical properties of pond ash collected from BTTP and, toward that end, to ensure the best possible utilization of pond ash in order to facilitate efficient reuse for the discharged pond ash, thus preventing disposal problems while at the same time causing no environmental problems. The burning of coal in the Barapukuria Thermal Power Plant (BTTP) at 1400–1500°C with ≈20% air is used. The coal is ground up into a fine powder and then burned in the boiler, producing steam to drive turbines that generate electricity. Finer fly ash is trapped by electrostatic precipitators (ESPs), while coarser bottom ash is collected at the bottom of a furnace following combustion. Once collected, the fly ash is mixed with water to form a slurry and transferred to an ash pond and kept under water to produce pond ash. This process requires a high amount of water and handling to prevent the environment from being contaminated with heavy metal and other toxic substances (Howladar & Islam, 2016). The overall process of fly and bottom ash generation is illustrated in Figure 2.

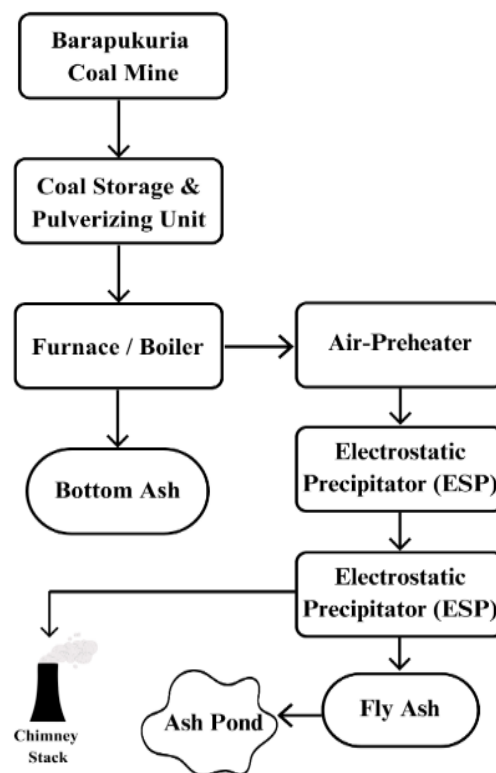


Figure 2: The process of ash generation in the BTTP, Dinajpur

## 2. MATERIALS AND METHODS

The pond ash samples of the BTTP were collected from an original ash pond. The samples were sieved, air-dried, and made laboratory-ready for physical, chemical, and mineralogical analyses. Grain size analysis was performed according to ASTM D422 and density by the pycnometer method (ASTM

D854). The Atterberg limits were determined using the ASTM D4318 to determine the consistency and plasticity behavior. Chemical composition was analyzed by XRF as per ASTM C618. The mineralogical consideration of material was found out from XRD, in accordance with ASTM E975 and the surface morphology and microstructural connection of pond ash particles is studied by SEM. The research process flowchart is shown in Figure 3.

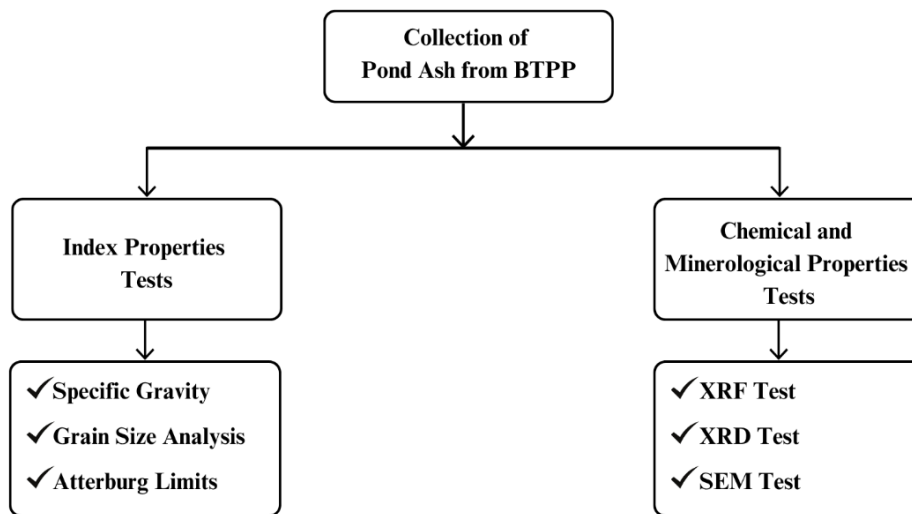


Figure 3: Flow chart of research methodology

To guarantee accuracy and reproducibility of results, all tests were conducted in a typical laboratory setting.

## 2.1 Collection of Pond Ash

The BTTP is located in Dinajpur District at the junction of Hamidpur and Parbatipur Upazila. Pond ash is a coal ash byproduct, fly ash and bottom ash are mixed with water and deposited in ash ponds near the BTTP (Figure 4). The BTTP disposal site was the source of the pond ash. The study region lies between latitudes 25°33'57" - 25°33'24" N and longitudes 88°56'71" - 88°56'43" E.



Figure 4: Pond ash disposal site of BTTP

## 2.2 Laboratory Tests

To determine physical and chemical characteristics, of the pond ash, laboratory tests were performed. Specific gravity, grain size analysis, and Atterberg limits tests were among the physical analyses; XRF, XRD, and SEM tests were among the chemical analyses. In accordance with the applicable ASTM standard procedures, all tests were conducted on raw pond ash samples (Table 1).

Table 1: Standard test method to determine the physical, chemical and engineering properties

Tests Name	Standard Test Method
Specific gravity	ASTM D 854
Grain size distribution	ASTM D 422
Atterberg limit tests	ASTM D 4318
XRF test	ASTM C618
XRD test	ASTM E975
SEM test	ASTM E766

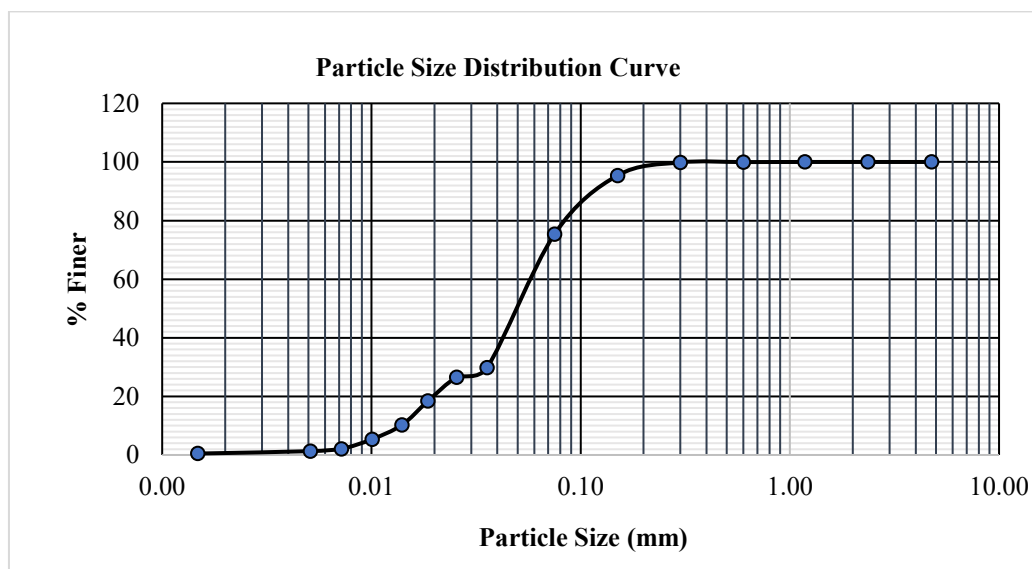
### 3. RESULTS AND DISCUSSION

#### 3.1 Specific Gravity

The specific gravity of the sample specimen of pond ash was 2.44. It may be noted that pond ash is relatively light (almost half in dry density compared to those of natural soils and aggregates), as indicated by its specific gravity value of 2.44, which falls within the common range (2.1–2.6 measured). This characteristic results in a reduced load in uses (slope stabilization, embankment fills). This result is consistent with several studies; for example, pond ash from Panki and Panipat (India) exhibited low specific gravity values ranging from 2.21 to 2.338 (Mohanty & Patra, 2015), suggesting that the value of specific gravity in general was lower than those found in native soils or aggregates. This feature enables it to be used for purposes like decreasing overall weight, such as in slope stabilization and embankment fill.

#### 3.2 Grain Size Analysis

The grain size distribution for a coarse-grain sample is determined through the use of sieve analysis, and that for a fine-grain soil sample requires hydrometer analysis. The distribution curve is shown in Figure 5. The effective particle sizes are shown in Table 2.



The PSD curve of pond ash showed that it is a fine-grained material with 0% gravel, 24.64 % sand and 75.36% silt and clay constituents. The effective sizes mean  $D_{10} = 0.0137$  mm,  $D_{30} = 0.0358$  mm and  $D_{60} = 0.0617$  mm. The uniformity coefficient ( $C_u = 4.47$ ) and curvature coefficient ( $C_c = 1.509$ ) further suggest that the particle size is quite extensive. Given that the fly ash from the pond is in the form of fine particles, these parameters only show gradation behavior and cannot be used to classify pond ash as well graded using the Unified Soil Classification System. The sharp rise of the PSD curve already shows how fine it is, and the absence of gravel shows how non-coarse it is. These values indicate that the pond ash likely forms a fine-grained material and it probably comprises clayey and silty silts (Das & Sobhan, 2018).

### 3.3 Liquid Limit and Plastic Limit

Atterberg's limit tests carried out on the samples of pond ash indicate that the pond ash is non-plastic (NP), as neither the Liquid Limit (LL) nor the Plastic Limit (PL) could be obtained using ordinary procedures. This is due to the high percentage of silt fraction and an approximate amount of clay in pond ash, which does not allow sufficient cohesive and plastic properties to be developed for these indices. This finding is in accordance with previous studies that have also found pond ash to be non-plastic in nature due to low clay mineral content and the absence of many cohesive particles (Pandian, 2004; Kumar & Sharma, 2014).

### 3.4 XRF

Decoding the element composition of pond ash, a byproduct of burning coal in thermal power plants, is frequently done using X-ray fluorescence (XRF) analysis. Figure 6 shows the chemical composition in percentage of BTPP pond ash.

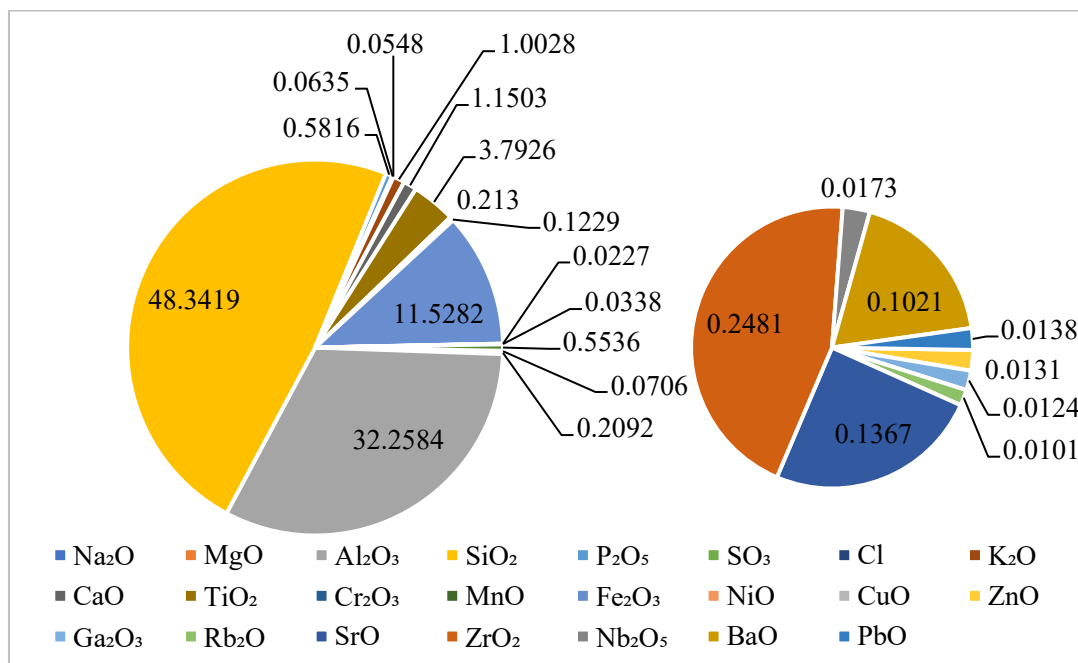


Figure 6: Proportional distribution of pond ash components

With this non-destructive method, the existence and concentration of main oxides such as SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, CaO and precious metals can be obtained. As the chemical properties of pond ash have strong correlation to its physical and engineering characteristics, XRF analysis is crucial for determining whether it is suitable for use in environmental impact assessments, geotechnical applications, and construction. The XRF results (Figure 6) reveal that the XRF assessment of the pond ash sample contains three primary oxides: SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and Fe<sub>2</sub>O<sub>3</sub> at 48.3419%, 32.2584%, and 11.5282%,

respectively. However, CaO content is relatively low being only in a proportion of about 1.1503%. According to ASTM C618, the total of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and Fe<sub>2</sub>O<sub>3</sub> is more than 70%. The obtained results verify that the pond ash is Class F, which is pozzolanic in nature and can be identified by a high concentration of silica, alumina, and iron oxides with a low concentration of calcium. While this ash doesn't bond particularly well, it can react with lime or other activators to form a cement-like compound that extends its application for construction and soil stabilization. It is consistent with the previous investigation study of Suthar and Aggarwal 2016 who observed that pond ash samples with combined oxide (SiO<sub>2</sub> + Al<sub>2</sub>O<sub>3</sub> + Fe<sub>2</sub>O<sub>3</sub>) over 70% also lie into the category Class F of ASTM C618. So XRF analysis provides a strong reason to use pond ash as chemically sustainable for geotechnical and construction purposes.

### 3.5 XRD

The XRD pattern of the pond ash sample is shown in Figure 7. The diffraction peaks were analyzed to determine the crystalline phases present, using Origin data analysis and graphing software with reference to the International Centre for Diffraction Data (ICDD) database.

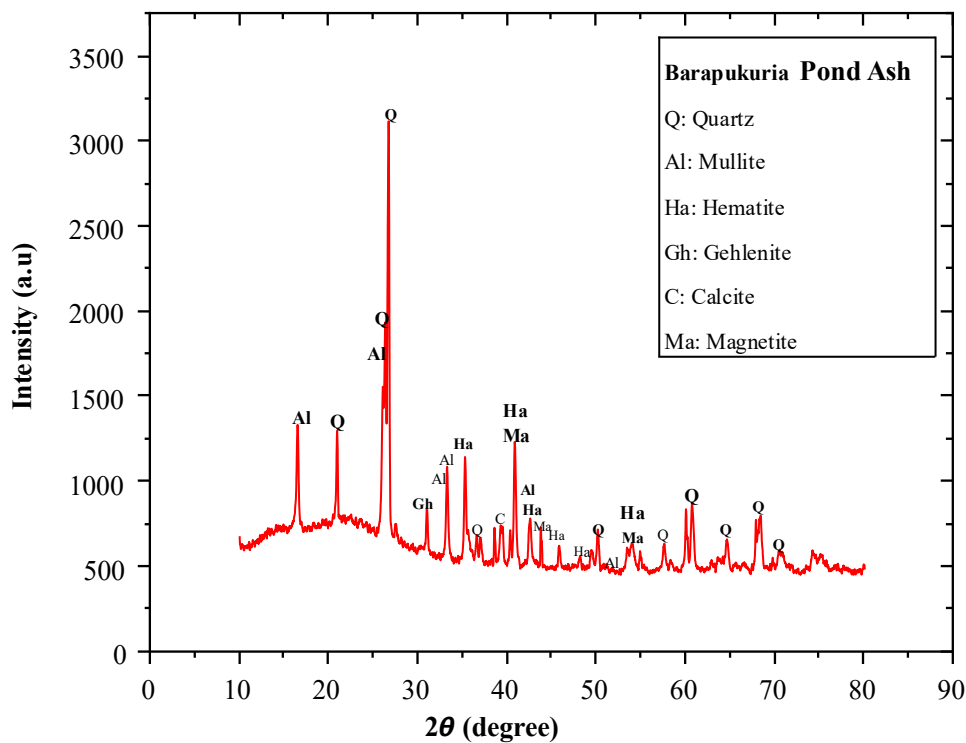


Figure 7: XRD diffractogram for Barapukuria Pond Ash

Figure 7 revealed that the sample mainly consisted of quartz (SiO<sub>2</sub>), mullite (3Al<sub>2</sub>O<sub>3</sub>·2SiO<sub>2</sub>), and hematite (Fe<sub>2</sub>O<sub>3</sub>) with small amounts of magnetite (Fe<sub>3</sub>O<sub>4</sub>), gehlenite (Ca<sub>2</sub>Al<sub>3</sub>SiO<sub>7</sub>), and calcite (CaCO<sub>3</sub>). These minerals were identified by their characteristic intensity and peak positions. The diffraction patterns of the sample prepared for the XRD study were analyzed using Origin software. The mineralogy in the present study is consistent with the results of previous work with fly ash and pond ash, which found a similar suite of minerals (e.g., Winburn et al., 2000; Pradhip et al., 2023). The principal mineralogical phases observed in the pond ash samples are quartz (SiO<sub>2</sub>) and mullite (3Al<sub>2</sub>O<sub>3</sub>·2SiO<sub>2</sub>) along with negligible amounts of hematite (Fe<sub>2</sub>O<sub>3</sub>) and magnetite (Fe<sub>3</sub>O<sub>4</sub>). And calcite (CaCO<sub>3</sub>). at room temperature these crystalline minerals will largely be non-reactive, and the high concentration of these materials decreases the overall reactivity of the material, which behaves as if it were inert (a-Suthar & Aggarwal, 2016). Nevertheless, the calcite in pond ash may help improve cementitiousness when lime or other alkaline activators are included through pozzolanic reaction or similar mineralogical reactions (Kalinkin et al., 2020).

### 3.6 SEM

Scanning electron microscopy (SEM) of pond ash provides information on surface morphology, structure and sometimes chemistry of the ash particles at micro and nanometre scale. SEM images of microstructural characteristics are shown in Figures 8(a-d).

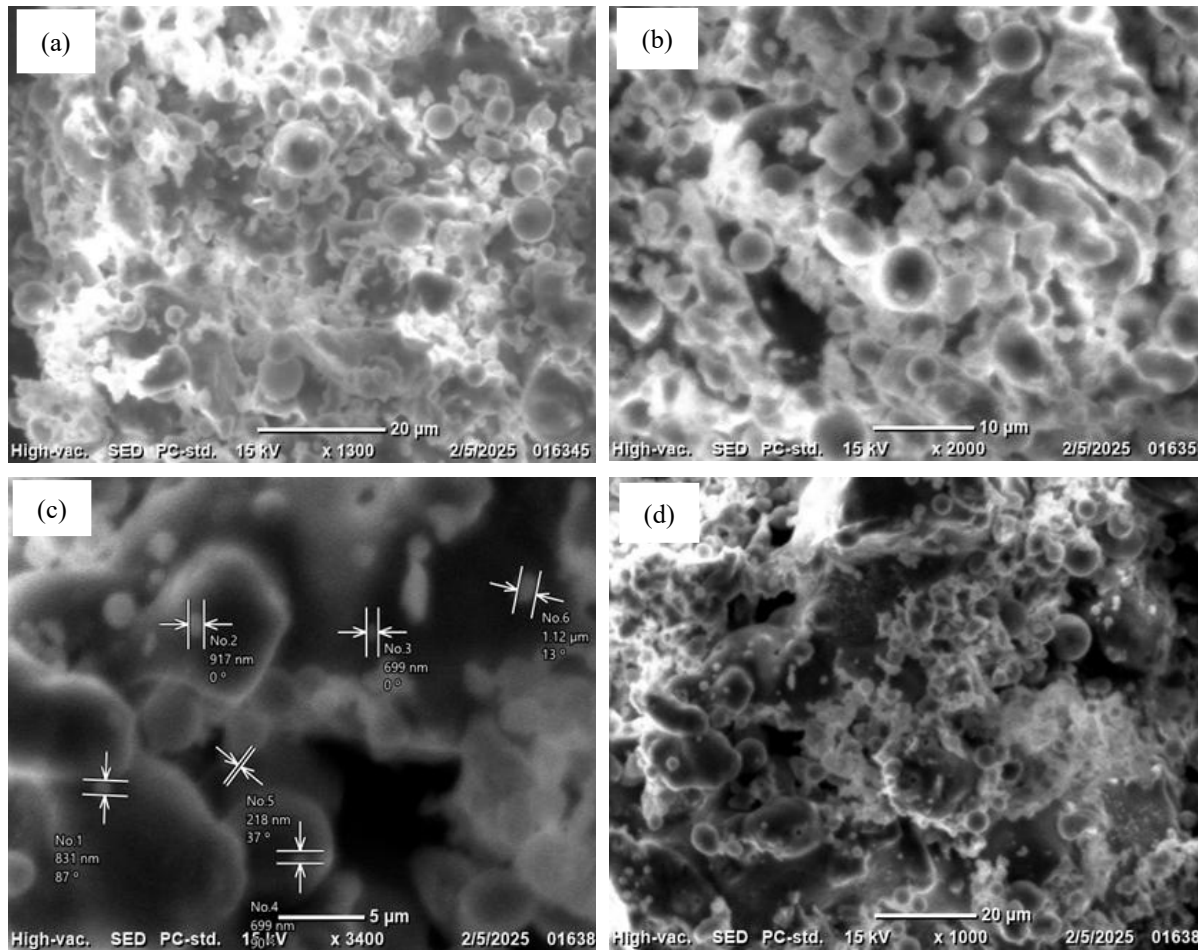


Figure 8: Scanning electron micrographs of BTTP Pond Ash (a) 20 µm, (b) 10 µm, (c) 5 µm, and (d) 20 µm of x1000

The results (microstructure) from, SEM of the present work are in good agreement with those reported in the literature. For example, Gupta et al. (2020) found similar microstructural characteristics of pond ash, such as fine porous surfaces and irregular shapes, which impacted its geotechnical capabilities. The spherical shape of the ecospheres indicates localized areas of low shear strength that promote particle mobilization. Clustered and porous materials, along with those that particles while having partially fractured and have moderate surface roughness, would be more compressible and less dense. This means that stabilization (like lime) might be a good idea for structural purposes. Walker & Pavía (2017) found that micro-voids and rough textures improve bonding with lime, improving pozzolanic reactions and increasing long-term strength. Vilasini et al. (2025) investigated the bonding capability of lime-stabilized pond ash in the presence of micro-voids and rough surfaces. SEM pictures of pond ash reveal microparticles sized between 2 and 20 µm, suggesting a large surface area and favorable circumstances for pozzolanic interaction with lime. Mineral microparticles, improve inter-particle adhesion which increased strength growth over time. Particles larger than 20 µm may reduce compaction uniformity, resulting in lower load-bearing capacity and stability. Thus, microstructure analysis is critical in regulating the geotechnical behavior of pond ash in stabilized soil applications (Kishor et al., 2024).

### 4. CONCLUSIONS

The Pond ash considered in this study is a fine-grained, light gray, nonplastic material with a specific gravity of 2.44. The granulometric analysis suggests that the material is composed predominantly of silt and clay-sized particles (75.36%) without (gravel) fragments but including a little sand portion (24.64%). The pond ash can be grouped into ML (inorganic, non-plastic silt). Chemical analysis shows that the content of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and Fe<sub>2</sub>O<sub>3</sub> is more than 70%, which qualifies it as ASTM C618 Class F ash with pozzolanic properties and low calcium content. Major crystal phases of mineralogy XRD were quartz, mullite, and hematite, with some calcite, magnetite, and gehlenite. Presence of these minerals indicates the formation of aluminosilicate structures that can help in charge neutrality when they react with lime or any other alkali to form secondary cementitious compounds. It was found out from an SEM study that the surface of irregular, porous, rough-textured particles (with sizes ranging between 2 and 20 μm) enhances surface area, allowing good contact with the stabilizing agent so as to obtain better bonding and mechanical strength of soil fly ash mixes. These physico-chemical and microstructural properties imply that Barapukuria pond ash may be utilized as geotechnical and construction material, including slope stabilizing, embankment fills, subgrade or subbase layering, and land reclamation projects by offering an environment-friendly substitute to natural resources.

#### **ACKNOWLEDGEMENTS**

This manuscript appreciates the facilities provided by the Department of Civil Engineering, Hajee Mohammad Danesh Science and Technology University (HSTU). The research was funded by The Institute of Research and Training (IRT), HSTU. Reference No.: HSTU/IRT/4697(64).

#### **DECLARATION OF USE OF AI**

The authors confirmed that no AI tools or technology were used in the preparation of this paper.

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