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Investigating calcined filter backwash solids as supplementary cementitious material for recycling in construction practices

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HIGHLIGHTS

- Filter backwash solids (FBS) are selectively investigated for potential utilization.
- Sieve analysis, XRF, SEM, XRD, TG-DTA etc. techniques are used for characterization.
- FBS is calcined at 800 °C and investigated as supplementary cementitious material.
- Calcined FBS is found suitable for partially replacing cement in construction.
- Recycling of FBS in construction would provide sustainable disposal option.

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ABSTRACT

Backwashing of filter beds in the water treatment plant produces a large volume of spent filter backwash water containing finer solid particles as waste/residue. In this study, solids present in the spent filter backwash water have been collected, processed, and calcined at 800 °C to prepare calcined filter backwash solids (CFBS) and investigated for its potential utilization as supplementary cementitious material in construction industry. Up to 20% replacement of 43 grade ordinary Portland cement, the cement-CFBS mixture complies the Indian standard specification required for construction. The study concludes that WTS obtained from filtration units in the form of CFBS is one of the best sustainable and beneficial reuse options.

1. Introduction

Water treatment plants (WTPs) generate a large volume of waste or residue known as Water treatment sludge (WTS) or Water treatment residuals (WTR), during the treatment of raw water for municipal supplies. Raw water often carries contaminants such as clay minerals, sandy and loamy particles, organic matter, microorganisms, and other impurities from the discharge of urban and industrial effluents and other human activities, depending on the source (surface water or groundwater). Contaminant particles are agglomerated during the coagulation-flocculation process using chemical coagulants and further removed from the liquid phase by sedimentation and filtration processes. Larger discrete as well as flocculent particles get removed in the clarifier or sedimentation tank and are drawn as clarifier sludge. Suspended finer particles manage to escape from the clarifier/sedimentation tank, are collected on the rapid sand filters. Exhausted filter beds are cleaned through the batch process of backwashing. The residuals generated during the backwashing process are called spent filter backwash water (SFBW) that contain fine solid particles. The clarifier sludge plus SFBW form the WTS. The volume of WTS discarded as waste depends on the quality of raw water and the characteristics of operational units involved in its treatment. Typically, a WTP produces about 100,000 ton of WTS per year and globally, it is estimated that at present daily production of WTS exceeds 10,000 ton [1,2].

Disposal of such a large volume of WTS in an environment-friendly manner remains a challenging task for scientist and engineers under strict environmental legislation. In India and other developing countries, WTS from most of the WTPs is discharged directly into nearby river, stream, or drainage basin, causing significant damage to the environment. It leads to the accumulation of aluminium and iron (commonly used as coagulants during

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coagulation process) and other heavy metals (present as impurities) in the receiving water bodies thus, adversely affecting the water quality and aquatic microorganisms [3,4]. Therefore, WTS requires special attention for safe and sustainable disposal. Several disposal alternatives including constructive utilization for beneficial reuses have been identified and investigated globally to provide sustainable and economical sludge management. Nair and Ahammed [5], Guan et al. [6], Keeley et al. [7] and Xu et al. [8] have reported the feasibility of coagulant recovery from WTS and further reuse in wastewater treatment or directly using WTS as a coagulant in wastewater treatment. WTS could be utilized as a potential adsorbent for contaminants and heavy metals removal from aqueous solution [9,10], and as a substitute to constructed wetland media, in place of traditionally used soil, sand, and gravel for better removal of nutrients from wastewater [11,12]. WTS also increases the dewaterability and settleability of sewage sludge when used as co-conditioning and dewatering agent during sewage sludge treatment [13]. WTS is also found to have its application as civil engineering materials such as substitute to raw materials in manufacturing cement [14,15] and light weight aggregate [16], in making brick and ceramic products [17–19], as a substitute to cementitious material and sand in preparing concrete and mortar mix [20,21]. Land-based applications in agricultural practice and in reducing excess nutrients from laden soil and runoffs could be simple and economical option for sustainable disposal of WTS [22,23].

Typically, physicochemical characteristics of WTS will govern the selection of reuse option [2]. Hence, knowledge of WTS characteristics is necessary prior to reuse or recycle WTS, ensuring safety and sustainability. Waste/residue produced from different treatment units too, vary in their physicochemical nature. A separate study on waste/residue generated from different units would show the horizon of new research and many more beneficial reuse options in view of protecting the environment and enhancing sustainability. Filtration is an important unit of the water treatment scheme and generates large volume of SFBW containing fine solid particles unlike relatively coarser particles settled in the clarifier/sedimentation tank. Earlier studies have reported the physicochemical characteristics of WTS collectively obtained after the clariflocculation and filtration of the raw water. Therefore, in this study, investigation has been focused selectively on the filter backwash solids (FBS) i.e. solids present in the SFBW for exploring better opportunity of utilizing the waste/residue from the WTP. The study aimed at characterization of FBS, calcination of FBS to enhance the pozzolanic properties and investigating the calcined filter backwash solids (CFBS) as supplementary cementitious material. Results have been assessed for evaluating the feasibility of recycling CFBS in construction industry for incorporation in unblended cement mortar and concrete and in lime-pozzolana mixture, and for manufacture of Portland pozzolana cement.

2. Materials and method

2.1. Collection of FBS

In the present work SFBW is collected from a 120 MLD WTP at Ghaziabad, India. The WTP is treating the Ganga river water and uses polyaluminium chloride (PACl) as coagulant for removing suspended and colloidal impurities imparting turbidity to the raw water. Discrete and flocculant particles settle in the clariflocculator tank and the over-flowing clear water is distributed over the rapid sand filter beds for removing the finer particles, escaped from the clariflocculator tank. These particles are continuously retained by the filter media and when the filter beds get exhausted, backwashing is done in a batch operation to remove the solids retained on the filter beds. SFBW is collected during backwashing and solids present in the SFBW are allowed to settle down. The settled solids are dewatered, and sun dried to obtain solid cakes (Fig. 1), which are grinded to finely powdered FBS and then analyzed for various physicochemical characteristics.

2.2. Characterization of FBS

FBS is characterized by physical parameters such as particle size distribution, pH, moisture content, volatile matter, and loss on ignition. Chemical composition, surface morphology and thermal behavior of FBS are also studied. Particle size distribution in the FBS is measured by sieve analysis and hydrometer method. Particle size distribution curve is shown in Fig. 2. The pH of FBS is determined according to Indian Standard Method of Test for Soils: Determination of pH Value [24]. Volatile matter content and loss on ignition are determined by heating FBS in muffle furnace and following the Standard Methods for the Examination of Water and Wastewater [25]. Major chemical compounds present in the FBS are analyzed by energy dispersive X-ray fluorescence spectroscopy (ED-XRF) whereas trace elements are determined by wavelength dispersive X-ray fluorescence spectroscopy (WD-XRF). FBS morphology is studied under scanning electron microscopy, SEM, using a Jeol model JSM 6510 LV. The FBS minerals are examined with Rigaku X-ray diffractometer, (copper radiation, K-beta filter, 0.05° step, 40 kV, 30 mA) and scanned for 2θ ranging from 10° to 85° to obtain an X-ray Diffraction (XRD) pattern. The crystalline phases are identified using International Center for Diffraction Data database (JCPDS–ICDD). The thermal behavior of the sludge is studied by thermogravimetric (TG) and differential thermal analyses (DTA) using SDT Q600 TA instrument. Samples are heated at the rate of 10 °C/min to a maximum temperature of 1000 °C under a flow of nitrogen (100 mL/min).

2.3. Calcination of FBS

The FBS is passed through 90 μm IS sieve to segregate the fine FBS having fineness comparable with that of cement as per IS 4031 (Part 1) [26], calcined at 800 °C for 1 h then cooled to room temperature to obtain CFBS. Specific surface area of CFBS is determined by low temperature N_2 adsorption-desorption isotherms at 77 K using surface area and pore size analyzer (Micromeritics Gemini V) and Brunauer, Emmett, and Teller (BET) method.

2.4. Testing of pozzolanic activity

The pozzolanic activity of CFBS is determined according to Chapelle's test [27]. It is a direct method to assess the pozzolanic activity by measuring the $Ca(OH)_2$ consumed by the CFBS. In this study, 1 g of CFBS and 2 g of CaO are mixed in 100 mL of CO_2 free distilled water and this solution is heated at 80 °C for 8 days. The free available portlandite is determined by acid titration using 0.1 N HCl and phenolphthalein indicator.

2.5. Preparation and testing of mortar specimens

Ordinary Portland Cement (OPC) 43 Grade conforming to IS 8112 [28] and standard sand conforming to IS 650 [29] is used in this study. OPC is replaced by calcined FBS in the varying percentages of 0, 10, 15, 20 and 25. Standard consistency of cement and cement-CFBS mixture is determined according to IS 4031 (Part 4) [30], whereas initial and final setting time is measured following the procedure mentioned in IS 4031 (Part 5) [31]. Hydration of cement and cement-CFBS mixture is measured using isothermal calorimetry according to ASTM C1679-08 [32]. As the hydration of cement is an exothermic reaction, the heat released can be used to determine the rate of reaction and for this, the isothermal calorimeter which measures the heat flow, was set at a temperature of 27 °C. Cement and cement-CFBS pastes are prepared with water to cement ratio determined in the standard consistency test and 30 g of the paste is placed in sample holder which is subsequently kept inside the calorimeter. The heat released on hydration reaction is recorded at every 1 min. The test is carried out for 3 days, as at later age the heat released is not so prominent. The baseline error is reduced, by subtracting the measured heat value with a reference sample of sand and water kept in the calorimeter. The heat measured is plotted against time.

Five mortar mixes are prepared and designated as MM_0 (control mix) without CFBS and MM_{10}, MM_{15}, MM_{20}, and MM_{25} having 10, 15, 20 and 25 percent CFBS respectively. Table 1 summarizes the mortar mixture proportion. Mortar cubes of 70.6 mm are casted following the procedure mentioned in IS 4031 (Part 6) [33], 12 cubes of each designated mix are casted and tested for compressive strength, water absorption and permeable voids in triplicate. The compressive strength of the mortar cubes is determined at 3, 7, and 28 days by applying a compressive load steadily and uniformly at a rate of 35 N/mm^2/min using an automatic compression testing machine. Total water absorption and permeable voids of the mortar cubes at 28 days are determined as per ASTM C642-06 [34]. Mortar cubes having maximum compressive strength at 28 days are broken and small fragments from the center are taken out for micro structure analysis through SEM and XRD techniques.