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RESEARCH ARTICLE - CHEMICAL ENGINEERING

Textile Effluent Treatment Plant Sludge: Characterization and Utilization in Building Materials

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Abstract The main objective of this study is to characterize and find a potential use of textile effluent treatment plant (ETP) sludge produced in Bangladesh. Textile ETP sludge collected from the local textile industries have been characterized in the laboratory. The physicochemical and engineering properties of the sludge have been studied. Collected ETP sludge has been processed to get cement-like fine powder that has been used for partial replacement of Portland cement/sand in the composition of the mortar and concrete specimens. Different mechanical (compressive and flexural strength), physical (water absorption) and morphological (porosity) properties of the test specimens have been evaluated. The test result shows that the addition of sludge in the mortar and concrete composition as a substitution of Portland cement or sand decreases the compressive strength and flexural strength, and increases the water absorption and porosity of the mortar and concrete specimens. Leaching study, conducted for the sludge-based mortar and concrete specimens following tank leaching test procedure, reveals that the concentration of leached metals is quite low than the limits specified by the Department of Environment in Bangladesh. These results amply demonstrate that textile ETP sludge can be utilized for making non-structural building components where lower strength is justified.

Keywords Textile ETP sludge · Compressive strength · Leachability · Mortar · Concrete

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1 Introduction

Textile is the most important sector in the developing countries like Bangladesh, India, Srilanka, Pakistan. It is one of the major foreign exchange earning industries for Bangladesh. The garment sector now accounts for about 77 % of the country's foreign exchange earnings and 50 % of its industrial work force [1]. The textile industry consumes large quantities of water and produces polluting waste effluents [2]. Generally, textile mills produce mixed wastewater in large quantities up to 600 m^3/kg fabric that are characterized by high organic load, up to COD of 1000 mg/L [3]. Huge quantities of inorganic, biological and organic mixed sludge are generated from the effluent treatment plants (ETP) during the treatment process of textile wastewater. In Bangladesh, textile industries generate 2.82 million m^3 wastewater per day, which results in the generation of solid sludge 1.14 kg/m^3 of wastewater. Generation of textile ETP sludge increases from 0.113 million tons in 2007 to 36 million tons in 2012 [4]. This huge amount of abandoned textile ETP sludge is not only thrown away without any commercial return but also it leads to environmental pollution. In addition, large quantity of sludge is openly dumped, which leads to soil, surface water and groundwater contamination. Eventually, these wastes cause alteration of the physical, chemical, and biological properties of aquatic environment that is harmful to public health, livestock, wildlife, fish, and other biodiversity [2]. The impurities of inorganic salts and toxic metals in the textile sludge pose a threat to the environment and residents. Therefore, it is crucial to find an effective and sustainable solution for the management of textile sludge.

The use of ETP sludge in construction materials could serve as an alternative solution to disposal and reduce pollution. Few attempts have been made to incorporate ETP sludge in the building materials. Balasubramanian et al. [5] have reported suitability of textile ETP sludge as partial replacement of cement in structural and non-structural building materials. It is found that the use of textile sludge in partial replacement of cement results in reduction of strength of the materials. It is finally recommended that the substitution of textile ETP sludge for cement, up to a maximum of 30 %, may be possible in the manufacturing of non-structural building materials. Sengupta et al. [6] have used petroleum ETP sludge for the preparation of bricks commercially, which meets the requirements as described in the Indian standard. Garg et al. [7] suggested that the use of automobile sludge up to maximum substitution of 35 % for Portland cement may be possible in making non-structural building component.

It is generally recognized that one of the most important environmental risks associated with the use of ETP sludge for construction purposes is the potential release and subsequent migration of contaminants from the material into ground. The contaminants, which are released upon contact with water and transported by water, are called leachate and may pose a risk to the groundwater, surface water and soil. Therefore, it is necessary to determine the content of toxic substances in these sludge-based building materials and to estimate the risk to the environment as a result of the release of contaminants from the final products. Though little information on use of ETP sludge in building materials [5–7] is found in the literature, various important issues including leachability of the ETP sludge-based building materials still remain largely unexplored.

In addition, to the best of our knowledge, there is no comprehensive study on the characterization and use of textile ETP sludge in Bangladesh. Although few studies reported on characterization and use of ETP sludge in India, treatment of textile wastewater and dosage of chemicals are different. Thus, composition of dye used in the textile industries and dosage of chemicals used in the ETP in Bangladesh vary largely in many cases. Consequently, properties of resultant ETP sludge and subsequent environmental impacts also vary largely with the composition of dye. Thus, it deserves the comprehensive study on characterization and utilization of ETP sludge in Bangladesh.

In this regard, the aim of the present study is to investigate the potentiality of textile ETP sludge in Bangladesh as a partial replacement of Portland cement in construction materials. The ETP sludge is characterized for the physicochemical parameters and heavy metals. Mortar and concrete specimens with various content of sludge are prepared following ASTM standard methods. The effectiveness of specimens is assessed by measuring mechanical (compressive and flexural strength), physical (water sorption) and morphological (porosity) properties. The leachability of the specimens made with textile sludge in water over a time period of 60 days has also been reported.

2 Materials and Methods

2.1 Materials

Portland cement, sand and water are use to prepare mortar specimens. Concrete specimens are composed of Portland cement, sand (as fine aggregate), stone chips (as coarse aggregates) and water. Fine aggregates and coarse aggregates used in the present investigation are collected from the localities 'Sylhet' and 'Madhapara' (Bangladesh), respectively. The cement used in this study is a commercial ASTM type I ordinary Portland cement (Shah Cement Industries Ltd, Mukterpur, Munsigonj, Bangladesh).

The physico-mechanical properties of the aggregates are shown in Table 1, and the particle size distribution curves for the fine and coarse aggregate are presented in Fig. 1a, b, respectively. Figure 1a shows that the size of the fine aggregates is in the range of 0.15–4.75 mm and about 50 % of the fine aggregates are with sizes larger than 0.9 mm. Figure 1b shows that the size of the coarse particles is in the range of 4.75–19 mm and 50 % of the coarse particles are with sizes larger than 7.50 mm.

The chemical composition and some other characteristics (in weight percent) of the Portland cement used in the experiment are as follows: CaO-63.6, SiO_2-20.4, Al_2O_3-5.34, Fe_2O_3-4.0, loss on ignition-1.10, insoluble residue-0.07 and moisture content-0.5. The characteristic properties of the used Portland cement are presented in Table 2. The setting time of Portland cement is determined by Vicat Niddle following ASTM standard method (C 191-82) [8]. The compressive strength, setting time and the fineness of Portland cement are determined by ASTM standard method C109-80 and C 184-83.

The textile ETP sludge has been collected from the sludge drying beds and landfill areas of Textile Composite Ltd, Tangail, Bangladesh, following random sampling method. During collection, the moisture contents of the sludge are observed in the range of 30–75 %. The collected sludge is

Table 1 Physico-mechanical properties of the fine and coarse aggregates

Aggregate types	Specific gravity	Fineness of modulus	Water absorption (%)	Crushing value (%)	Los Angeles abrasion value
Fine aggregate	2.6	2.5	0.9	–	–
Coarse aggregate	2.4	6.9	1.0	16.3	22.5

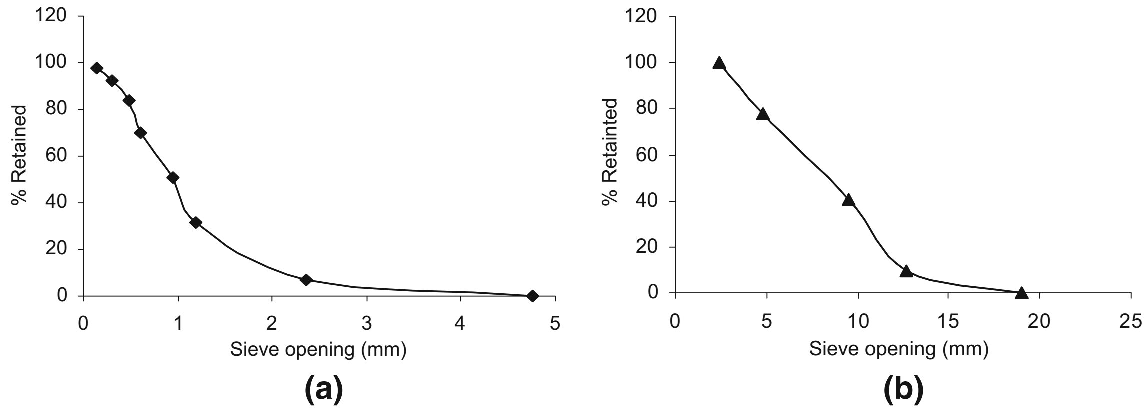

Fig. 1 Particle size distribution curve for **a** fine aggregate and **b** coarse aggregate

Table 2 Properties of the Portland cement used in the experiment

Test performed	Result
1. Fineness test (%)	0.068
2. Setting time (h)	
Initial	2.0
Final	3.0
3. Compressive strength (MPa)	
3 days	15.0
7 days	19.0
28 days	24.0

Table 3 Sieve analysis result of processed ETP sludge powder used in the experiment

Sieve size	Mass retained (%)	Cumulative mass retained (%)
1.18 mm	20.6	20.6
600 μm	32.7	53.3
300 μm	23.7	76.8
150 μm	15.9	92.7
75 μm	5.5	98.2
Pan	1.8	100

dried in two stages: firstly, wet sludge obtained from the plant is dried in drying bed under sunlight; secondly, dried sludge from drying bed is sent in to hot air oven for 24 h at 100 °C. After drying, the sludge has been grounded in a ball mill.

The particle size distribution for the fine sludge is presented in Table 3. Particle sizes of the ground sludge (x) in the range of $0.075 \leq x \leq 1.2$ mm are used in this study. About 50 % of the sludge particles are with sizes $0.75 > x \geq 0.4$ mm.

2.1.1 Sample Preparation and Curing

Mortar and concrete specimens with various content of sludge are prepared following ASTM standard methods. Based on mode of use of sludge in the composition, different types of mortar samples are prepared in the experiment. Sludge is used as a partial replacement of cement/sand in the composition of mortar specimens. Cement-to-sand ratio of 1:3 is maintained for the preparation of mortar specimens. The sludge is used in ratio of 0, 10, 20, 30, 40 and 50 wt% as a partial replacement of cement. Secondly, the sludge is added in the composition of mortar partially replacing sand by 20, 40, 60 and 80 wt%. Components of the mortar are mixed by a method and technique as prescribed by ASTM [8]. The workability of the fresh compositions is determined in terms of flow % following ASTM C 230. Freshly prepared mortar composition is put into desired molds and compacted with a tamping rod with specific diameter as prescribed by the ASTM. Specimens prepared are demolded after 24 h of molding and subsequently are cured in water for 28 days. The dimensions of mortar specimens for different tests are as follows:

$$\text{Compressive strength, water uptake and porosity test:}$$
$$50.8\,\text{mm} \times 50.8\,\text{mm} \times 50.8\,\text{mm}$$
$$\text{Flexuralstrengthtest:}304.8\,\text{mm} \times 25.4\,\text{mm} \times 25.4\,\text{mm}$$

In the concrete compositions, Portland cement/fine aggregate/coarse aggregate ratio is kept constant at 1:2:4. The sand and the sludge together constitute the fine aggregate, and the stone chips are used as the coarse aggregate. The sludge is incorporated with replacing sand by 20, 40, 60, 80 and 100 wt%. The fine and coarse aggregates are mixed using a mixer machine. The properly mixed fresh concrete mixture is placed into a desired mold (The 152.4-mm-cube molds for compressive strength test) and is compacted using table vibrator. Finally, the concrete specimens are separated out of the mold after 24 h and are cured in water for 28 days.

2.2 Methodology

2.2.1 Mechanical Properties

The compressive strength and flexural strength of the mortar specimens are measured according to the ASTM standard test method of C 109 and C 348, respectively [9]. A universal testing machine (TIB/M.C., Capacity 300 ton) is used for the measurement of the compressive and flexural strength of mortar specimens. Compressive strength and flexural strength of concrete specimens are measured according to the standard test method of ASTM C 39 and C 293-2, respectively. Universal testing machine (Tecnotest F 050/TC) is used for the measurement of the compressive strength and flexural strength.

2.2.2 Analytical Techniques

Textile ETP sludge and water in curing tank after curing of mortar prepared with sludge are analyzed using atomic absorption spectrophotometer (AAS). AAS is used to determine Pb, Cr, Cu and Zn content, and AAS with MVU for Hg in the ETP sludge. Biochemical Oxygen demand (BOD) is evaluated using respirometric BOD apparatus with 5-day incubation at 20 °C. Chemical oxygen demand (COD) is determined using COD reactor with certified COD reagent and potentiometric titration with comb. Au-ring electrode (Model: Metrohm, 906 Titrando). Total dissolved solid (TDS) is determined with TDS meter.

2.2.3 Water Absorption and Porosity

For the water absorption kinetics and equilibrium experiment, the 50.8-mm-cube-size mortar samples are dried at 110 °C in an oven and then put in desiccators to cool down to room temperature. The process is repeated until a constant weight, w_0, of the specimen is attained. Then the dried sample is put under water in a beaker at room temperature. At a predetermined interval of time, the samples are taken out and the water adhered to the surface is wiped out by cloth and weighed. Then the sample is returned to the beaker. The equilibrium is reached in 48 h.

The water absorption A_t at a given time t and equilibrium absorption $A\infty$ at $t \rightarrow \infty$ are calculated by the following formulae:

$$A_t = w_t/w_0 - 1 \quad \text{and} \quad A_\infty = w_\infty/w_0 - 1 \qquad (1)$$

where w_t is the weight of the wet sample at time t and $w\infty$ is the weight at equilibrium.

The porosity β of the mortars is calculated based on the equilibrium water absorption data as follows:

$$\beta = 1 - \rho_a/\rho_T \quad \text{with} \quad \rho_a = w_0/V_0 \quad \text{and}$$
$$\rho_T = w_0/[V_0 - (w_\infty - w_0)/\rho_w] \qquad (2)$$

where V_0 is the bulk volume of the sample, w_∞ is the weight of the sample at equilibrium (after 30 h), ρ_w is the density of water, and ρ_a and ρ_T are, respectively, the apparent and the true density of the specimen.

3 Results and Discussion

The mortar and concrete specimens with varying concentration of ETP sludge as partial replacement of Portland cement/sand are characterized by measuring different parameters such as mechanical (compressive, flexural strength), morphological (porosity) and physical (water absorption) properties.

3.1 Characterization of Textile ETP Sludge

Chemical properties of the ETP sludge used in this study are analyzed as per standard methods. The physicochemical properties of the textile sludge are shown in Table 4. The sludge obtained from the plant is acidic in nature; pH of the sludge in wet condition varies in the ranges of 4.5–5. The specific gravity of the sludge used in this study is 2.30, which is less than that of Portland cement (3.10). The sludge contains high volatile solids content of 35.95 %, which indicates high

Table 4 Characterization of textile ETP sludge

Property	Value	Characterization of ETP sludge reported by Balasubramanian et al. [5]
Physical		
pH	4.5–5	9.13
Specific gravity	2.3	2.4
Salinity (mg/L)	0.264	
Total volatile solids (%)	35.95	31.85
Water content (%)	35–75.64	28.72
Chemical		
SiO_2 (%)	12.15	
Al^{+3} (%)	53.14	
Fe_2O_3 (%)	15.65	
CaO (%)	2.5	
SO_4^{-2} (%)	3.0	0.0012
Chromium (Cr) (mg/L)	0.668	2.98
Cadmium (Cd) (mg/L)	0.664	3.96

Fig. 2 Test sample: **a** mortar specimens containing Portland cement, sand and ETP sludge at the ratio of 1:3.76:0.25, **b** mortar and concrete specimens with varying sludge content

organic fraction in the sludge. The presence of organic fraction in the sludge delays the setting time, and this delay is proportional to the organic fraction contained in the sludge.

The salinity of the sludge is found 0.264 mg/L, which is within acceptable range in building materials. The water content in the sludge, obtained from the plant, varies in the ranges of 35–75.5 %, which clearly indicates high water absorption capacity of the sludge. High water absorption capacity is not a desirable property for building materials in durability point of view [10].

On the other hand, the presence of high silica (SiO_2) and calcium oxide (CaO) in the sludge indicates the potential of use of this sludge as partial replacement of Portland cement. However, presence of Cr and Cd are the drawback of the sludge to consider it as building materials. To the contrary, Table 4 shows that the textile sludge reported by Balasubramanian et al. [5] has comparatively less water sorption capacity of 28.7 %, higher pH of 9.13 and higher content of Cr and Cd in the composition. This indicates physico-chemical properties of ETP sludge vary with the dyes and chemicals used in the textile industries, methods and dosage used in the ETP are also crucial which might have significant impact on the mortar properties.

3.2 Test Sample Characterization

Different types of test specimens are prepared for characterization. The dimensions of mortar specimens for compressive strength, water uptake and porosity test are 50.8 mm × 50.8 mm × 50.8 mm. Specimen size for flexural strength test is 304.8 mm × 25.4 mm × 25.4 mm. On the other hand, concrete specimen size for compressive strength test is 152.4 mm cube.

3.2.1 Physical and Morphological Properties

Water absorption capacity and the porosity of the mortar sample are measured as the characteristics of physical properties and mortar morphology, respectively. Water absorption

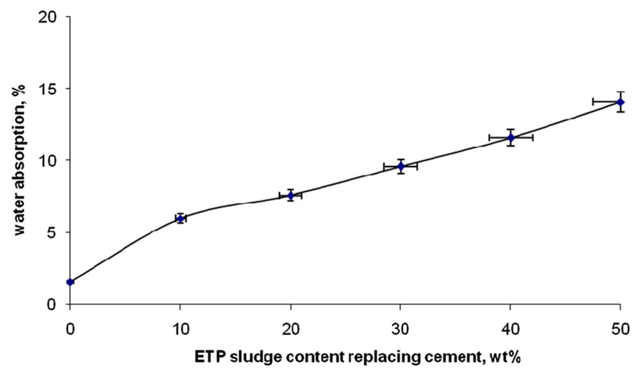

Fig. 3 Effect of sludge content on water absorption of mortar specimen

capacity of the mortar specimens is presented in Fig. 3. The result shows that the water absorption capacity of mortar specimens increases with increasing content of sludge in the composition. The result is expected as the sludge is used as a replacement of sand/cement in the composition of the test specimens, and sludge has higher water absorption capacity (see Table 4).

Porosity, apparent density and true density of different mortar specimens with various content of sludge are shown in Table 5. The result shows that porosity of the mortar specimens increases with increasing content of sludge in the sample and consequently the density decreases.

The morphological property of the sample has been studied by scanning electron microscope (SEM) as shown in Fig. 4a, b. The figures show that the surface structure of the Portland cement sand mortar exhibits homogeneous and dense structure, while the addition of sludge in the composition shows higher heterogeneity of the structure.

3.2.2 Mechanical Properties

The effect of sludge content in the mortar on the average compressive strength is presented in Fig. 5. The result shows that the compressive strength of the mortar gradually decreases with increasing percentage of sludge content. Figure 5 shows

Table 5 Porosity, density and flexural strength of different types of mortar specimens

Types of mortar	Porosity (%)	App. density (gm/cc)	True density (gm/cc)	Flexural strength (MPa)
Portland cement mortar without sludge	7.50	2.19	2.37	10.0
Mortar with 10 wt% sludge replacing cement	7.70	1.98	2.10	4.5
Mortar with 20 wt% sludge replacing cement	10.1	1.87	1.97	4.0
Mortar with 30 wt% sludge replacing cement	13.54	1.83	1.84	3.0
Mortar with 40 wt% sludge replacing cement	15	1.8	1.82	2.5
Mortar with 50 wt% sludge replacing cement	18	1.78	1.8	2.0

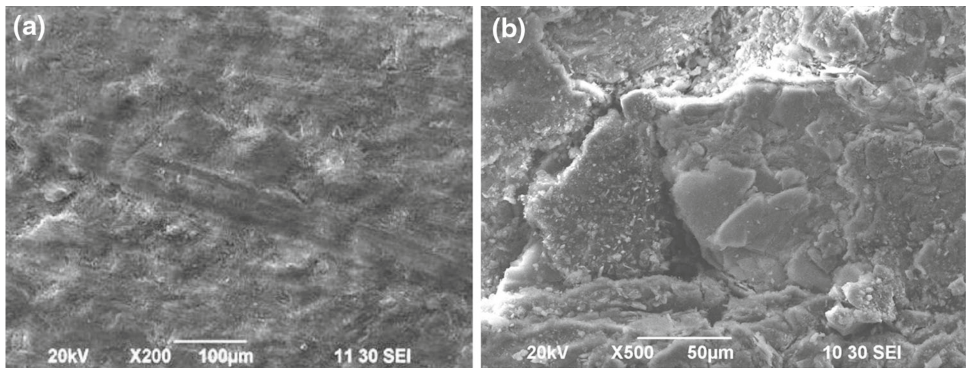

Fig. 4 Scanning electron microscope image: **a** mortar specimens containing Portland cement and sand at the ratio of 1:3, and **b** mortar specimens containing Portland cement, sand and ETP sludge at the ratio of 1:3.51:0.50

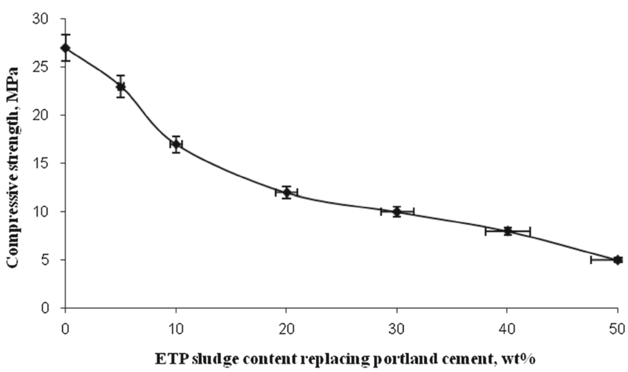

Fig. 5 Effect of ETP sludge content (as partial replacement of Portland cement) on the compressive strength of mortar

that 5 wt% replacement of Portland cement by sludge in the composition of mortar reduces compressive strength of 15 % compared to the mortar made of cement alone. For a sludge content of 10 wt% of portland cement in the mortar, the compressive strength decreases sharply from 27 to 14 MPa. This sharp reduction in strength might be due to higher heterogeneity in the microstructure of the mortar which has been confirmed by SEM images. Thereafter, Fig. 5 shows that reduction rate due to further addition of sludge is reduced down from 1.5 MPa/wt% at 10 wt% replacement of Portland cement by sludge to 0.44 MPa/wt% at 50 wt% replacement, which indicates better homogeneity in the microstructure. Maximum 50 wt% of Portland cement can be replaced by sludge that results in decrease in strength to one-fifth compared to the use of cement alone.

The reduction in strength of sludge-contained mortar indicates lower binding capacity of the sludge compared to that of Portland cement. In fact, the sludge powder used in the experiment is finer than cement and has a lower specific gravity than cement (see Table 4). It occupies more volume and requires higher water cement ratio during mixing to maintain workability and ultimately reduces the strength of building materials. On the other hand, high content of volatile solids in the composition of sludge (see Table 4) and higher water absorption capacity of the sludge lead to decomposition of the sludge after certain compressive strength of the sludge-contained mortar specimens.

The variation of compressive strength with the sludge content as a substitution of fine aggregates in the composition of mortar is shown in Fig. 6. Figure 6 demonstrates that compressive strength of the mortar specimens decreases with increasing content of sludge. 25 wt% replacement of sand by sludge in the mortar composition decreases the compressive strength of 25 %, while 50 % addition of sludge shows 45 % reduction in compressive strength compared to that of the mortar specimen without sludge. The reduction in strength due to addition of sludge can be explained by heterogeneity in the microstructure. Further addition of sludge up to 80 wt% of sand also decreases the compressive strength, but the rate of reduction in strength decreases.

Flexural strength of different mortar specimens with various contents of sludge is shown in Table 5. Flexural strength gradually decreases with the increasing sludge content in the composition of the mortar. The effect of sludge in the

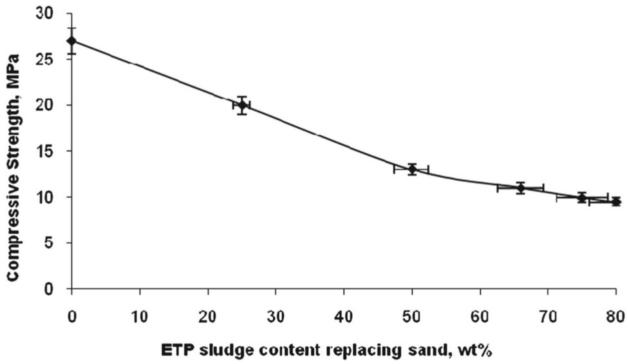

Fig. 6 Effect of ETP sludge content (as partial replacement of sand) on the compressive strength of mortar

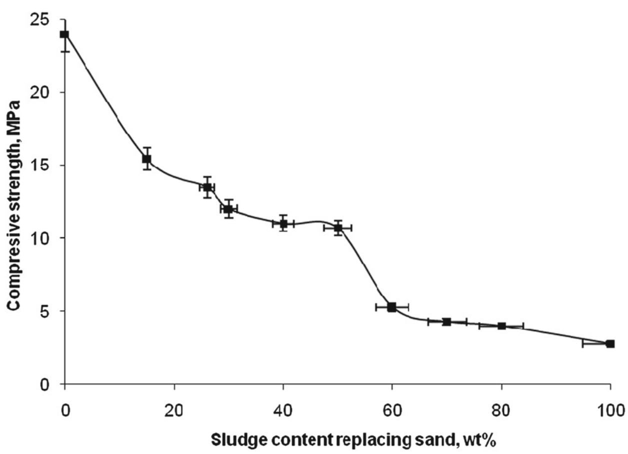

Fig. 7 Effect of ETP sludge content (as partial replacement of cement) on the compressive strength of concrete

reduction of flexural strength can be explained similarly as it influences on compressive strength.

Figures 7 and 8 show the effect of ETP sludge content in the composition of concrete specimen, on the compressive strength of the concrete. Figure 7 shows the decrease in the compressive strength with the substitution of various contents of sand by sludge in the composition of the concrete. The result indicates that 15 wt% replacement of sand by sludge in the composition decreases the compressive strength of concrete specimens from 24 to 15 MPa, which is 37 % less than that of concrete specimen without sludge. It is clearly observed that the 37 % reduction in strength is contributed by the 15 % sludge. Figure 8 also indicates gradually reductions in compressive strength with increasing sludge content in the composition of concrete. The picture of reduction in compressive strength as a function of sludge content is similar. The contribution of sludge to decrease the compressive strength of concrete specimens can be explained similarly as it influences on compressive strength of mortar.

Balasubramanian et al. [5] have also reported reduction in compressive strength with the addition of ETP sludge in the

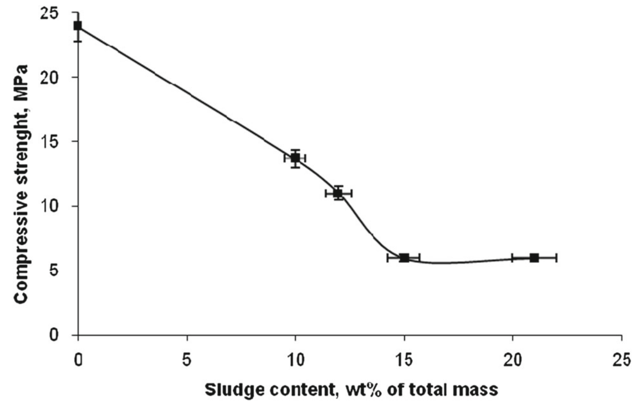

Fig. 8 Dependence of compressive strength on the ETP sludge content in the composition of concrete

composition of building materials, and it is recommended that as much as 30 wt% of Portland cement can be replaced by textile ETP sludge in the preparation of building components. In this study, it is found that the sludge content in the composition of building materials depends on desired properties of the building materials.

3.3 Leaching Test

The leaching test is conducted for 28-day-cured mortar and concrete samples following tank leaching test procedure as reported by Japan Society of Civil Engineers (JSCE) standard leaching test method [11]. This procedure of leaching test is also reported by Sugiyama et al. [12]. Textile ETP sludge-based mortar and concrete specimens are immersed under water at room temperature (30 °C) in a water tank for 60 days. Distilled water is used as the leachant in the water tank, and 5 mL of distilled water is used per 100 mm^2 surface area of the specimens. Leachant refers to a solvent used for the leaching. The leachate has been analyzed analytically at different predetermined intervals of time. Analytical test results are presented in Table 6. The results shows that pH of the water is expectedly increases, which is within the allowable limit set by the Department of Environment (DoE) in Bangladesh [13]. However, pH of the sludge used in preparation of the specimens is only 4.5–5, which clearly indicates acidic in nature. But, in the presence of Portland cement, hydration product of the cement results in neutralization of the acidity of the sludge. Conductivity, on the other hand, increases with time from 1600 ppm at 7 days to 5300 ppm at 60 days. SO_4^{-2} ion content increases from 51 ppm at 7 days to 904 ppm at 60 days, which is a bit unexpected for the environment. Tests for heavy metal contents, BOD and COD are conducted for the leachate obtained after 60 days of immersion of the sludge-based mortar and concrete specimens. As and Cr contents in the leachate are a bit higher than limit specified by the DoE; on the other hand, contents of

Table 6 Leaching test results at different periods

Parameter	Leaching period (days)				DoE standard for inland surface water [13]
	7 days	20 days	35 days	60 days	
pH	7.5	7.5	8.0	8.0	7–9
Conductivity (ppm)	1600	4000	5000	5300	–
SO_4^{-2} (ppm)	51	52	300	904	–
TDS (ppm)	500	1587	2000	2397	2100
Cr (ppm)	–	–	–	0.73	0.50
Cd (ppm)				BDL[a]	0.01
BOD (mg/L)				95.01	50
COD (mg/L)				107.10	200

[a] *BDL* Below detection limit (detection limit for Cd is 0.1 ppm)

Cu, Pb, Hg and Zn in the leachate are quite lower than the limit specified by DoE. BOD and COD found in the test are 95 and 107 mg/L, respectively, which are within the allowable range for surface water [13]. The leachability test result indicates that some of the hazardous elements are still leaching out from the cement matrix, but most of the hazardous elements present in the sludge are confined in the cement matrix.

4 Conclusion

This study demonstrates that ETP sludge can be used as partially replacing fine aggregates in the preparation of building components. But, the addition of sludge in mortar and concrete delays the setting process of cement and reduces compressive and flexural strength of the materials. Inclusion of the sludge in the composition also increases water absorption and porosity of the mortar. Mortar with 25 % replacement of sand by ETP sludge in the composition can exhibit maximum compressive strength of 20 MPa. On the other hand, mortar with 5 % replacement of Portland cement by ETP sludge shows the mechanical properties very close to the properties of mortar made by Portland cement alone. Concrete with 30 wt% substitution of sand by ETP sludge exhibits maximum compressive strength of 12 MPa. The strength and other properties of the sludge-based mortar and concrete found in the experiment, meet the ASTM standards for non-structural materials, which clearly indicates that the textile ETP sludge can be used for making non-structural building components where lower strength is allowed. Leachability study of the sludge-based mortar and concrete indicates that the concentration of leached hazardous elements is quite lower than the limits specified by the Department of Environment in Bangladesh. Utilization of textile ETP sludge is expected to minimize the environmental impact.

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