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Reuse of textile effluent treatment plant sludge in building materials

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Abstract

This study examines the potential reuse of textile effluent treatment plant (ETP) sludge in building materials. The physico-chemical and engineering properties of a composite textile sludge sample from the southern part of India have been studied. The tests were conducted as per Bureau of Indian Standards (BIS) specification codes to evaluate the suitability of the sludge for structural and non-structural application by partial replacement of up to 30% of cement. The cement–sludge samples failed to meet the required strength for structural applications. The strength and other properties met the Bureau of Indian Standards for non-structural materials such as flooring tiles, solid and pavement blocks, and bricks. Results generally meet most ASTM standards for non-structural materials, except that the sludge-amended bricks do not meet the Grade NW brick standard. It is concluded 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. Detailed leachability and economic feasibility studies need to be carried out as the next step of research.

1. Introduction

The textile industry is one of the oldest and largest sectors in India. At present it is amongst the top foreign exchange earning industries for India (Naik, 2001). The textile units are scattered all over India; out of 21,076 units, Tamilnadu alone has 5285 units (Bal, 1999). The textile industry involves processing or converting raw material into finished cloth employing various operations. It consumes large quantities of water and produces polluting waste effluents (Karthikeyan and Venkatamohan, 1999).

Tirupur (11.7° North latitude and 77.5° East longitude), in the Coimbatore district of Tamilnadu state, India, is well known for its hosiery and knitwear industries and its annual exports of these items are worth over US$ 550 million (Thomson et al., 1999). According to records of the Tamilnadu state pollution control board (TNPCB), there are 830 units engaged in textile industry processes in Tirupur. These industries have established eight common effluent treatment plants (CETPs) and several Effluent Treatment Plants (ETPs) for treatment of their liquid effluents, and sludge is generated during the treatment process as a result of chemical coagulation (by addition of aluminum/iron/magnesium salts and lime), flocculation and liquid/solid separation.

About 200 tonnes/day of textile sludge are generated in Tirupur. Although some of the sludge is disposed in an engineered landfill, much of the sludge is openly dumped, which leads to soil, surface water and groundwater contamination. The inorganic salts and toxic met-

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als in the sludge pose a threat to residents (Thomson et al., 1999; Palanivelu and Rajakumar, 2001). There is a growing need to find alternative solutions for textile sludge management. The textile ETP sludge has a high calcium and magnesium content, which comes mainly from coagulating chemicals (magnesium salts and lime) used in ETP. The presence of high calcium and magnesium indicates the potential use of this sludge as partial replacement of.

It is estimated that demand in the form of building materials would be on the order of US$ 1333 million per year in India (Anon., 2002). In India, nearly 250 million tonnes of industrial wastes are generated annually (Laul, 2002). Other industrial wastes have been used in building materials as partial replacement of cement, as replacement of clay in bricks, or for use in flooring tiles and walling materials (Sharma and Laxmi, 2002). Singh (2002) investigated the use of beneficiated phospho-gypsum (a byproduct of gypsum) in the manufacture of building materials like semi-hydrated plasters and plaster products, fibrous gypsum plaster boards, gypsum blocks, slotted paving and gypsum tiles. The paving tiles of 300 × 300 × 20 mm size had properties meeting Bureau of Indian Standards (BIS): 1237–1980.

Fly ash has been found suitable for Portland pozzolona cement (IS: 1489–1976), readymade fly ash concrete building units (building blocks, flooring and roofing units), sintered light-weight aggregates, lime fly ash cellular concrete and Portland cement clinker, oil well cement, masonry cement, clay- fly ash and fly ash lime bricks. Fly ash-sand-lime bricks or calcium silicate bricks are new methods for using fly ash and suitable where good quality clay is not in abundance. These bricks have a wet compressive strength of 10–15 N/mm^2, water absorption of 15–20% and bulk density of 1500–1600 kg/m^3 (Singh, 2002).

Saxena et al. (2002) reported the use of copper tailings up to 50% in replacement of clay in the manufacture of bricks and found properties on a par with standard bricks meeting the relevant BIS. Sengupta et al. (2002) reported that the bricks prepared in commercial plants using petroleum ETP sludge met all the requirements as described in the Indian standard.

In this investigation, dry textile sludge was used for partial replacement of cement and composite clay soil. The physico-chemical and engineering properties of Textile ETP sludge (dry) were analyzed. This sludge contains heavy metals and inorganic salts. The excessive leaching out of heavy metals can have a toxic effect on ground water and soil. The inorganic salts may cause corrosion in steel of reinforced cement concrete (RCC) structures. The use of textile sludge in cement can result in reduction in strength, and so the investigation considered both structural and non-structural building components. The sludge was used in cement concrete flooring tiles (BIS, IS: 1237:1980), pavement blocks, hollow blocks (BIS, IS: 2185:1980), and solid blocks (BIS, IS: 2185:1980) with 10%, 20% and 30% replacement of cement from the mix. Common burnt clay building bricks (BIS, IS: 1077–1976) were also made by partial replacement of composite clay soil with the textile sludge (up to 30%). Various tests were conducted for the developed building materials as per BIS specification codes.

1.1. Materials

The textile sludge was obtained from the Veerapandi CETP, Tirupur town, Coimbatore district, Tamilnadu State, India. The sludge was collected from the sludge drying beds and landfilling areas by random sampling method. The sludge had a roughly 30% moisture content. The sludge was dried in a hot air oven for 24 h at 100 °C. After drying, the sludge was ground manually in a dry clean steel tray with the use of trowel. The study used the ground sludge that passed a 212-micron sieve and was retained on a 90-micron sieve.

The fine sludge that passed the 90-micron sieve was discarded in this study. There were handling problems with this material because of its small size and low density. Its retention in a pile was not possible in a dry state (unlike cement) because it was blown away by small air movement. This sludge is finer than cement and has a lower specific gravity than cement. It occupies more volume and requires more water during mixing and that ultimately reduces the strength of building materials.

Ordinary Portland cement (43-grade) confirming to BIS, IS: 12269 was used. The 43-grade means the average compressive strength of cement is 43 N/mm^2 after 28 d of curing; this cement is normally used for non-structural building purposes. Mortar cube steel moulds of 70.6 × 70.6 × 70.6 mm size were used to find the compressive strength of cement and cement with various percentages of Textile ETP sludge at different curing days.

River sand passing through an IS: 1.18 mm sieve was used for making building materials. Cement concrete flooring tiles (IS: 1237–1980) of size 300 × 300 × 25 mm, Hollow blocks (IS: 2185 Part I – 1974) of size 400 × 150 × 200 mm, Solid blocks (IS: 2185 Part I – 1974) of size 400 × 150 × 200 mm, Pavements blocks of combined hexagon shape of 39,000 mm^2 and Common burnt clay building bricks (IS: 1077–1976) of size 190 × 90 × 90 mm were made by using sludge up to 30% and other materials like cement, dolomite powder, stone quarry dust, stone chips of 6 mm, sand and composite clay soil (for bricks).

1.2. Methodology

A Standard Vicat apparatus was used to determine the consistency limit (BIS, IS: 4031(part 4) – 1980) of cement and cement with various percentages of sludge.

The specific gravity (IS: 4031(part 11) – 1980) of the cement and sludge was determined using a density bottle of 50 ml capacity. Chemical properties of the sludge used in the work were analyzed in the Tamilnadu Pollution Control Board Laboratory, Tirupur town, as per standard methods (APHA, 1998). For heavy metal analysis, 5 g of dried sludge was pretreated by nitric acid–perchloric acid digestion as prescribed in section 3030 H and further metal analysis was done by flame atomic absorption spectroscopy by the method prescribed in section 3111 A of APHA (1998), respectively. The inorganic soluble salts (expressed in mg/l) were analyzed by making 1:5 sludge to water extract. For this, 20 g of dried sludge was weighed in a 250 ml conical flask and 100 ml distilled water added to it and shaken at 200 rpm in an orbital shaker for 30 min. Then, the sludge–water suspension was filtered through a whatman no.1 filter paper, and the clear filtrate was subjected to chemical analysis as per APHA (1998). The volatile solids fraction of the sludge was determined by standard methods (APHA, 1998).

Mortar cubes of size 70.6 × 70.6 × 70.6 mm were cast to find out the compressive strength of cement with various percentages of sludge, for 3, 7, and 28 days of curing. The water to cement ratio was kept at 0.45–0.75 for cement and with various percentages of sludge, and the cement to sand ratio kept at 1:3. Mortar cubes were made with 5–20% sludge added as partial replacement of cement. Three cement–sludge mortar cubes samples were made for each sludge percentage.

All of the building materials were manufactured according to BIS. The mix proportions are given in Table 1.

The compressive strength was found in a Compression Testing Machine as per BIS specifications. For various percentages of sludge, three samples were made and subjected to a compressive strength test after the required curing period, and the average strengths were obtained.

Wet transverse strength (BIS, IS: 1237–1979) for cement concrete flooring tiles was found in a Universal Testing Machine.

Resistance to wear for cement concrete flooring tiles was determined as per the procedure of appendix F of BIS (IS: 1237–1979). The amount of wear was determined from the difference in thickness readings obtained by the measuring instrument (dial gauge) before and after the abrasion of the specimen. The value obtained was checked with the average loss in thickness of the specimen obtained by the following formula:

$$T = (W_1 - W_2)V_1/(W_{1x}A) \tag{1}$$

where T, average loss in thickness in mm; W_1, initial mass of the specimen in g; W_2, final mass of the abraded specimen in g; V_1, initial volume of the specimen in mm^3; A, surface area of the specimen in mm^2.

The calculated values are reported in this study. The discrepancies found with observed values were within ±0.2 mm.

Table 1
Mix proportions for tests of building materials using textile ETP sludge

Building material type	% of cement/clay substituted with sludge	Cement	Water/cement ratio	Sludge	Dolomite powder	Sand	Quarry dust	Stone chips of 6 mm	Stone aggregate of 40 mm	Composite clay soil
Cement concrete flooring tiles	10%	0.9	0.37	0.1	1.5	3	–	–	–	–
	20%	0.8	0.41	0.2	1.5	3	–	–	–	–
	30%	0.7	0.47	0.3	1.5	3	–	–	–	–
	Commercial	1	0.33	0	1.5	3	–	–	–	–
Hollow blocks	10%	0.9	0.47	0.1	–	2	5	7	–	–
	20%	0.8	0.53	0.2	–	2	5	7	–	–
	30%	0.7	0.61	0.3	–	2	5	7	–	–
	Commercial	1	0.43	0	–	2	5	7	–	–
Solid blocks	10%	0.9	0.50	0.1	–	2	5	7	1	–
	20%	0.8	0.56	0.2	–	2	5	7	1	–
	30%	0.7	0.64	0.3	–	2	5	7	1	–
	Commercial	1	0.47	0	–	2	5	7	1	–
Pavement blocks	10%	0.9	0.39	0.1	–	0.5	1.5	3	–	–
	20%	0.8	0.44	0.2	–	0.5	1.5	3	–	–
	30%	0.7	0.50	0.3	–	0.5	1.5	3	–	–
	Commercial	1	0.35	0	–	0.5	1.5	3	–	–
Common burnt clay building bricks	10%	–	–	0.1	–	–	–	–	–	0.9
	20%	–	–	0.2	–	–	–	–	–	0.8
	30%	–	–	0.3	–	–	–	–	–	0.7
	Commercial	–	–	0	–	–	–	–	–	1

Note: water/cement ratio influenced by the moisture content & quantity of the quarry dust used and moisture content of the sand used.

Block density and moisture movement were measured for the hollow and solid blocks as per BIS, IS: 2185(Part-1) – 1979.

The water absorption capacity of the building material was determined as follows: three samples from each of the building materials were selected and immersed in water for 24 h, then taken out and wiped dry; each unit was weighed immediately after saturation and wiped; the samples were oven-dried for a period of 24 h, cooled to room temperature and re-weighed.

Efflorescence of bricks was observed by immersing bricks samples in water for 24 h, and then removing them and allowing them to dry in shade. Presence of white or gray deposits on the surface of bricks was looked for as an indication of the presence of soluble salts in bricks (BIS, IS: 3495 (part3): 1976).

2. Results and discussion

2.1. Characterization of textile ETP sludge

The physico-chemical properties of the textile sludge are shown in Table 2. The specific gravity (Bureau of Indian Standard, 1980; BIS, IS: 4031(part11): 1980) of the cement used in this experimental work is 3.07, and of the sludge it is 2.4. The volatile solids of around 32% of sludge results in a very high ash content as a result of incineration and hence it is not recommended as a sludge disposal technique.

The consistency limit (IS: 4031(part 4): Bureau of Indian Standard, 1990) of the cement used in this experimental work was found to be 31%. The consistency limits of the cement with various percentage of sludge (dry) (Fig. 1) indicate that the consistency limit of sludge–cement mixtures was increasing with increasing percentages of sludge. In addition, the water to cement ratio was increasing from 0.45 to 0.7 at 35% substitution of sludge for cement. As per BIS, IS 456:2000, a low water–cement ratio is an important factor in the durability of concrete.

Table 2
Characterization of textile ETP sludge

Sl. No.	Property	Value
1	Water content	28.72%
2	Specific gravity	2.4
3	pH	9.13
4	Cadmium	3.96 mg/kg
5	Copper	57.48 mg/kg
6	Total chromium	2.98 mg/kg
7	Zinc	91.60 mg/kg
8	Nickel	0.68 mg/kg
9	Lead	12.1 mg/kg
10	Ferrous (Fe++)	180.5 mg/kg
11	Sulphates	1167 mg/1
12	Sulphides	BDL mg/1[a]
13	Calcium	108.22 mg/1
14	Magnesium	154.30 mg/1
16	Chlorides	5445 mg/1
17	Total hardness as $CaCo_3$	905 mg/1
18	Total volatile solids	31.85%

Parameters expressed in mg/l are from 1:5 sludge to water extracted.
[a] BDL, below detectable limit.

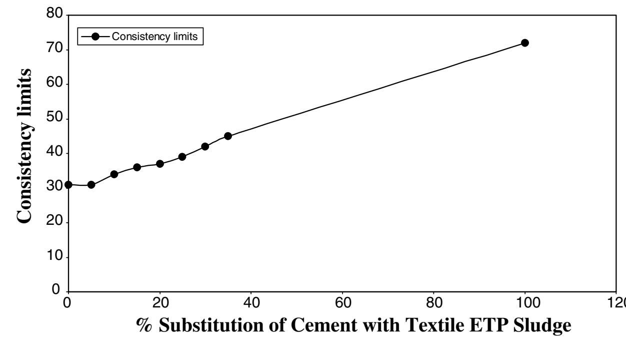

Fig. 1. Consistency limits for mixtures of cement and textile ETP sludge.

The presence of an organic fraction in the sludge delays the setting time and this delay is proportional to the organic fraction contained in the sludge. Accordingly, there was a delay (more delay in 30% sludge) in the setting process of building components.

2.2. Compressive strength and structural applications

The results of the average compressive strength analysis are shown in Fig. 2. The individual compressive strength of the samples vary to a maximum of 4% from the average values and this variation may be as a result of ineffectiveness of compaction and mixing. The results indicate that the compressive strength for the mortar cubes is gradually decreasing with increasing percentage of sludge in cement. The 5% sludge sample has a compressive strength near the compressive strength for the sample with cement alone. For samples with greater than 5% sludge, the compressive strength gradually decreases compared to the use of cement alone. Swamy et al. (2000) reported on the potential use of municipal wastewater sludge as a cementing material and found that when the sludge ash proportion increases, the com-

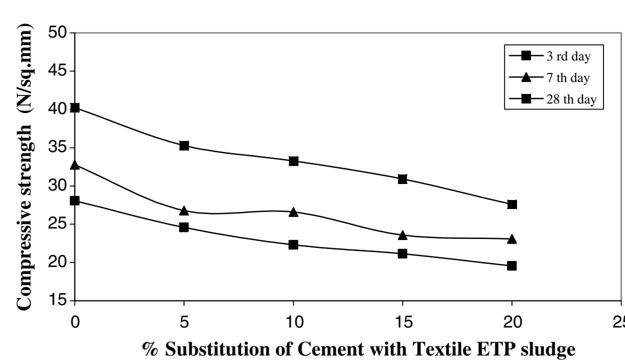

Fig. 2. Compressive strength for mixtures of cement and textile ETP sludge.

pressive strength showed a decline of the same trend as the present study. Hence, the partial use of textile sludge does not provide the compressive strength required for construction work and structural applications.

2.3. Properties of non-structural building materials

The properties of the non-structural building material made of textile ETP sludge utilized as partial replacement of cement and partial replacement of clay (in bricks) are shown in Table 3 and the results are discussed below.

2.4. Cement concrete flooring tiles

The wet transverse strength, water absorption and resistance to wear tests conducted for the cement concrete flooring tiles indicate that the tiles with up to 30% sludge as replacement of cement can meet the BIS specification code IS: 1237–1980. In particular,

1. The wet transverse strength of cement concrete flooring tiles is more than the minimum of 3 N/mm^2 in IS: 1237–1980 (BIS, 1980).
2. The water absorption percentage of tiles is less than the maximum of 10% in IS: 1237–1980 (BIS, 1980).
3. The wear resistance of tiles is less than 3.5 mm on average and less than 4 mm for individual samples, which are the specified limits for general purpose use in IS: 1237–1980 (BIS, 1980).

The relevant British standard (BS, 1955) has no specifications for strength properties; however, the size, shape, finish and color of flooring tiles were as per British standards.

2.5. Hollow blocks

The hollow blocks with up to 20% sludge substituted for cement met the BIS specification for load-bearing units, and the 30% blocks met the BIS specification for non-load-bearing units. In particular, the results show:

1. The block density of hollow blocks with 10%, 20% and 30% use of textile ETP sludge is higher than the minimum 1500 kg/m^3 required by IS: 2185(part1) – 1979. The hollow blocks are classified as 'medium weight' categories as per ASTM (C90–75) standards.
2. Regarding the compressive strength, the 10% and 20% sludge blocks attained Indian Standard Grade B, where the average compressive strength should not be less than 3 N/mm^2 (IS: 2185(part1) – 1979). The 30% sludge blocks attained Grade C where the average compressive strength should not be less than 1.5 N/mm^2 (IS: 2185(part1) – 1979). However, none of the hollow blocks met the compressive strength required for hollow load-bearing units as per ASTM (C90–75) standards.
3. Water absorption of all blocks is less than the 10% prescribed by IS: 2185(part1) – 1979.

Table 3
Properties of the building materials using textile ETP sludge

Building material type	% of sludge	Compressive strength in N/mm^2	Wet transverse strength in N/mm^2	Water absorption in %	Block density in kg/m^3	Moisture movement in %	Wear resistance in mm	Efflorescence
Cement concrete flooring tiles	10%	–	4.00 ± 0.35	3.69 ± 0.27	–	–	2.40 ± 0.10	–
	20%	–	3.70 ± 0.1	4.10 ± 0.31	–	–	2.50 ± 0.11	–
	30%	–	3.47 ± 0.31	5.24 ± 0.16	–	–	2.55 ± 0.08	–
	Commercial	–	4.47 ± 0.23	3.46 ± 0.16	–	–	2.08 ± 0.05	–
Hollow blocks	10%	3.30 ± 0.19	–	6.40 ± 0.08	1819 ± 53	<0.09	–	–
	20%	3.05 ± 0.08	–	7.60 ± 0.36	1805 ± 32	<0.09	–	–
	30%	2.17 ± 0.19	–	8.50 ± 0.15	1770 ± 55	<0.09	–	–
	Commercial	3.43 ± 0.00	–	6.42 ± 0.14	1861 ± 52	<0.09	–	–
Solid blocks	10%	4.27 ± 0.25	–	6.30 ± 0.45	2493 ± 24	<0.09	–	–
	20%	4.02 ± 0.07	–	7.50 ± 0.35	2507 ± 32	<0.09	–	–
	30%	3.74 ± 0.09	–	8.30 ± 0.35	2444 ± 52	<0.09	–	–
	Commercial	4.52 ± 0.13	–	6.66 ± 0.29	2493 ± 12	<0.09	–	–
Pavement blocks	10%	39.74 ± 1.12	–	3.86 ± 0.18	–	–	–	–
	20%	33.11 ± 0.98	–	4.14 ± 0.25	–	–	–	–
	30%	29.4 ± 1.07	–	4.29 ± 0.21	–	–	–	–
	Commercial	41.11 ± 0.39	–	3.57 ± 0.24	–	–	–	–
Common burnt clay building bricks	10%	3.81 ± 0.0	–	8.25 ± 0.47	–	–	–	Nil
	20%	3.10 ± 0.24	–	15.1 ± 0.24	–	–	–	Nil
	30%	2.48 ± 0.12	–	16.4 ± 0.21	–	–	–	Nil
	Commercial	4.29 ± 0.24	–	6.75 ± 0.36	–	–	–	Nil

All properties are expressed as mean ± standard deviation and three numbers of samples were tested in each case.

4. Moisture movement of all blocks is less than the 0.09% prescribed in IS: 2185(part1) – 1979.

2.6. Solid blocks

The results obtained indicate that solid blocks with up to 30% of sludge utilized as a substitute for cement meet the BIS specification code IS: 2185(part1) 1979. In particular:

1. The block density of solid blocks with 10%, 20% and 30% sludge are more than the 1800 kg/m^3 prescribed in the IS 2185(part1) – 1979. The solid blocks are classified as 'normal weight' as per ASTM (C129–75) standards (ASTM standards, 1981).
2. The compressive strength of each block with 10% and 20% sludge meets the minimum average compressive strength of 4 N/mm^2 for grade D, load-bearing units as per IS: 2185(part1) – 1979. The 30% sludge blocks have an average compressive strength of 3.74 N/mm^2. All solids blocks meet the compressive strength requirements for non-load-bearing units as per ASTM (C129–75) standards.
3. Water absorption of all blocks is less than the 10% stated in the IS codes.
4. Moisture movement of each blocks up to 30% sludge is less than 0.09% as prescribed in IS: 2185(part1) – 1979.

The solid blocks satisfy ASTM (C129–75) standard specifications for non-load-bearing concrete masonry units.

2.7. Pavement blocks

The compressive strength test results indicate that the pavement blocks of 10%, and 20% sludge as a substitute for cement provide more than 80% of the strength of commercial blocks with no sludge. The 30% sludge samples provide more than 70% of the strength of commercial blocks. Water absorption of each block tested is less than 10%, meeting BIS requirements.

2.8. Common burnt clay building bricks

The results indicate lower compressive strength for sludge-amended bricks than for commercial bricks with no sludge, which could be a cause of concern. In particular, the results show:

1. The compressive strength of 10% bricks provide more than the minimum 3.5 N/mm^2 compressive strength for bricks in load-bearing units as per IS: 1077–1979. The 20% and 30% sludge bricks provide a compressive strength less than prescribed in IS: 1077–1979. The bricks samples tested are not meeting the minimum compressive strength requirements for 'Grade NW' bricks as per ASTM (C62–80). It should be mentioned that the minimum compressive strength requirement as per the ASTM standard for commercial bricks is 2.9 times the value in the Indian standard (BIS, 1979), and the ASTM standard is seen as too strict in India.
2. Water absorption of all bricks with 10%, 20% and 30% sludge is less than the 20% required by the IS.
3. Efflorescence of all bricks with 10%, 20% and 30% sludge was nil. As per BIS specifications, efflorescence should not be more than 'slight' for bricks used in construction purposes.
4. The shrinkage during drying of the bricks was affected by more than 20% addition of sludge to the clay. The bricks with more than 20% clay had minor cracks that led to more water absorption compared to bricks that did not have sludge in them.

3. Conclusions

From this study, it is possible to conclude that the use of Textile ETP sludge up to a maximum of 30% substitution for cement may be possible in the manufacture of non-structural building materials. The use of Textile ETP sludge in these applications could serve as an alternative solution to disposal. However, the addition of sludge to the cement delays the setting process of the building components. Detailed leachability and economic feasibility studies need to be carried out as the next step of research.

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