Development of Sustainable Brick Using Textile Effluent Treatment Plant Sludge

Uday Singh Patil, S. P. Raut, and Mangesh V. Madurwar

Abstract A huge quantity of textile effluent treatment plant (TETP) sludge is generated from 21,076 units in India. Significant environmental impacts occur due to the landfilling of TETP sludge, such as land and water pollution. Thus, effective management of this sludge is important, which otherwise adds to the ever-escalating cost of disposal. With the rapid industrialization and urbanization, there is also an increased demand for construction materials to fulfill the shortage of housing in India (i.e., 18.78 million in urban and 43.9 million in rural). Brick is one of those significant construction materials, whose production is found to increase by 30% from 2000 to 2020 which consequently leads to an increase in carbon footprints. The present study, therefore, focuses on the effective utilization of TETP sludge to develop cost-effective, environmentally friendly bricks, which serve as an alternate solution for solid waste management, conservation of natural resources, and earning carbon credits. Sludge incorporated bricks were prepared with varying compositions of cement (6–24%), sludge (50–70%), and quarry dust (25%). Bricks are tested as per the Bureau of Indian Standards (BIS). The TETP sludge is characterized using X-ray fluorescence (XRF) and the properties of bricks were evaluated by conducting various tests such as compressive strength, water absorption, and density. Obtained results were also compared with commercially available fly ash bricks and clay bricks. The maximum strength of 4.2 N/mm^2 was observed for the combination of 24% cement, 51% sludge, and 25% quarry dust, which exceeds the value of 4 N/mm^2 for grade D, load-bearing units of IS: 2185(part1)—1979 and found to be greater than 3.5 N/mm^2 that meets the criteria of IS: 1077–1979 for bricks in load-bearing units. When textile sludge is used in the range of 50–57%, the water absorption value of bricks was found to be less than 20%, thus meeting the requirement of BIS. The resultant unit weight of the brick is also found to be lesser than the conventional bricks. Thus, it can be said that TETP sludge has the potential to develop sustainable

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bricks that meet the requirements of BIS, similar to the other sustainable materials, viz., concrete, mortar, etc., developed using other industrial wastes.

Keywords Sustainable brick · Material characterization · Physicomechanical properties · Sustainable construction material · Textile effluent treatment plant sludge

1 Introduction

In India, due to rapid growth, a huge amount of industrial waste is produced annually and gets accumulated, which is difficult to handle without proper management [1–10].

A substantial portion of the land is utilized for dumping these industrial wastes, thus causing soil and water pollution [11]. Therefore, effective management of this sludge is important which otherwise adds to the ever-escalating cost of disposal. Rapid urbanization has also increased the demand for building materials in urban and rural areas thereby exponentially rising the demand for new, economically viable building materials. As per the report on development alternatives [12] and technical group on an estimation of the urban /rural housing shortage [13], there will be a large demand for building materials to minimize housing shortages, i.e., 18.78 million housing shortages in urban areas with an approximate rural housing shortage of 43.9 million. It is seen that 90% of this scarcity applies to society's economically weaker and lower income classes, which is a cause of concern. The high construction costs cannot be afforded by an economically weaker segment, thus there is a need to increase the production of sustainable materials to satisfy these requirements. Consequently, an increase in output contributes to an increase in CO_2 emissions. It is observed that in India, about 22% of total CO_2 emissions are produced annually by the construction industry, of which 80% are mainly from industrial processes, involving the manufacture of steel, cement, bricks, and lime. One of the world's leading textile industries is the Indian textile industry. Approximately 21,076 textile units are distributed in India [14]. During the processing of textiles, a significant amount of water is used by the textile industry. As a result, an enormous amount of wastewater is produced, which needs to be properly handled before it is disposed of safely. In the effluent treatment plant units, this industrial wastewater is treated and a large amount of sludge is produced during the treatment process. This sludge is then disposed of for landfilling, resulting in pollution of the environment. The present study, therefore, focuses on the effective utilization of TETP sludge to develop cost-effective, environmentally friendly bricks that serve as an alternate solution for solid waste management, conservation of natural resources, and earning carbon credits.

2 Methodology for the Development of Sustainable Construction Material

2.1 Collection of Raw Materials

2.1.1 Collection and Preparation of Sludge Sample

Dewatered and open-air dried textile sludge sample was collected from the Morarjee textile industry located in MIDC Butibori, Nagpur (Figs. 1 and 2). The sludge obtained from the industry was in semi-solid form, therefore it was sun-dried until

Fig. 1 Image of dry textile effluent sludge

Fig. 2 TETP sludge before pulverization

the sludge is completely dried. The dried samples were then ground and pulverized to convert them into fine powder. This material was then sieved through 300 μ for the proper bonding between cement and sludge. The percentage of various size particles in the textile effluent sludge sample is determined using sieve analysis. The coefficient of curvature and uniformity coefficient is also calculated.

2.1.2 Collection of Cement and Quarry Dust

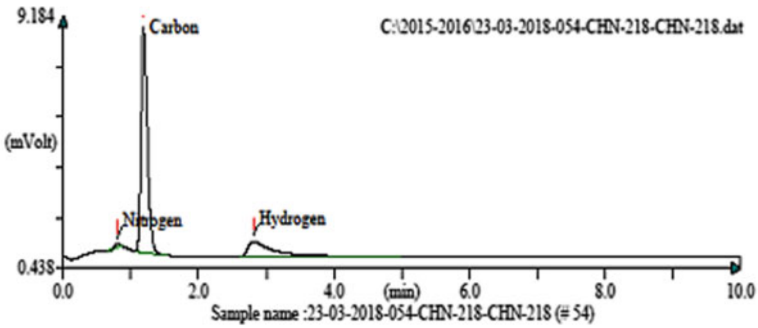
Similarly, other raw materials such as cement and quarry dust are collected. The cement used is the Ordinary Portland Cement (OPC) of Grade 53 confirming to BIS, IS:12269 [15]. The consistency limit of cement and cement with different percentages of sludge is determined using standard Vicat apparatus IS: 4031-4 [16]. Initial and final setting time tests were also performed using the Vicats apparatus. A density bottle test is performed to measure the specific gravity of the cement and sludge IS: 4031-11 [16]. Quarry dust is a by-product, released from the cutting and crushing process of stone and was collected from Gupta Industries located at MIDC Buti Bori, Nagpur.

2.2 Chemical Characterization of Textile Effluent Treatment Plant Sludge

The sludge is characterized (Tables 2 and 3) for various physicochemical parameters using an X-ray fluorescence test (Fig. 3). The USEPA and toxicity characteristic leaching procedure (TCLP) (Table 4) tests were performed on developed bricks. The leaching test was carried out at ANACON Laboratories Pvt. Ltd., Butibori MIDC, to check the feasibility of textile sludge for the development of sustainable bricks.

2.3 Manufacture of Brick Specimens

Sludge integrated bricks with different cement and sludge compositions (6–30 % wt.) were prepared (Fig. 4) with a constant proportion of quarry dust (Table 1) in a mould of 230 × 150 × 1000 mm. The required quantities of raw materials were calculated for various combinations of cement, sludge with quarry dust, and then hand-mixed with a required quantity of water until a homogenous mixture is obtained. The material is then poured into the mould in three layers and immediately after the casting, each layer is tamped 25 times to expel the entrapped air present in it. (Fig. 5) After forming, the bricks were sun-dried for about 15 days. The compressive strength of bricks is evaluated as per IS 3495- 1, Cl.4.1.4. Three [17] samples were subjected to a compressive strength test in the Universal Testing Machine after 28 days of curing.



Peak Number (#)	Retention Time (min)	Area (.1*uV*sec)	Element %	Component N
1	0.800	7458	0.145	Nitrogen
2	1.192	507613	4.020	Carbon
3	2.808	140962	0.504	Hydrogen
		656033	4.668	

Fig. 3 Chemical characterization of TETP Sludge

Fig. 4 Formation of brick specimens

Table 1 Specimen ID with proportions

S. No.	Proportions	ID
1	6% cement+69% sludge+25% quarry dust	6C94S25Q
2	9% cement+66% sludge+25% quarry dust	9C66S25Q
3	12% cement+63% sludge+25% quarry dust	12C63S25Q
4	15% cement + 60% sludge+25% quarry dust	15C60S25Q
5	18% cement+57% sludge+25% quarry dust	18C57S25Q
6	21% cement + 54% sludge + 25% quarry dust	21C54S25Q
7	24% cement+51% sludge+25% quarry dust	24C51S25Q

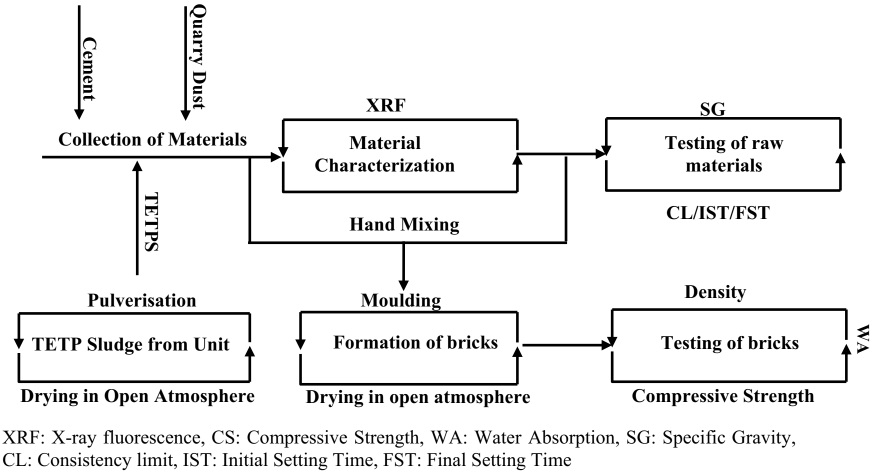


Fig. 5 Flowchart for development of sustainable bricks [19]

The average result of these specimens is taken as the brick's compressive strength. For the comparison of strength, different samples of commercially available bricks such as clay brick and fly ash brick have been taken. To obtain water absorption values, three samples of bricks were selected. The bricks are weighed in dry condition and immersed in water for 24 h. After 24 h, the brick is properly wiped and the weight is taken in wet condition. For the calculation of the percentage of water absorption, IS 3495- 2, Cl.4.1.4 [18] is referred.

3 Results and Discussion

3.1 Chemical Characterization of Textile Effluent Treatment Plant Sludge

From Table 2, the specific gravity of sludge obtained is 2.4. Total volatile solids of about 31.85% are found, which will result in an increase in ash content during incineration, hence it is not recommended as a technique for sludge disposal. During the treatment process of textile wastewater, the addition of excess lime makes the concentration of calcium oxide as 108.22 mg/l, which is considered one of the chief components of the sludge and affects the pH content. The pH of sludge is found to be 9.13, which shows its alkaline nature. The presence of various oxides (Table 3) shows its potential to develop a sustainable construction material. The present study is also focused on the concentration of heavy metals such as Cu, Ni, Cd, Pb, Zn, Co, and Cr in TETP sludge, which is commonly found in the textile effluent due to the usage of dyes and other chemicals. The presence of metals in TETP sludge is of concern

Table 2 Characterization of textile effluent treatment plant sludge waste

S. No.	Property	Values
1	Water content (%)	28.72
2	Specific gravity	2.4
3	pH	9.13
4	Average particle size	–
5	Cadmium(mg/kg)	3.96
6	Copper (mg/kg)	57.48
7	Total chromium(mg/kg)	2.98
8	Zinc (mg/kg)	91.6
9	Nickel (mg/kg)	0.68
10	Lead (mg/kg)	12.1
11	Ferrous (mg/kg)	180.5
12	Sulphates (mg/l)	116
13	Sulphides (mg/l)	BDLa
14	Calcium (mg/l)	108.22
15	Magnesium (mg/l)	154.30
16	Chlorides (mg/l)	5445
17	Total hardness as $CaCO_3$(mg/l)	905
18	Total volatile solids	31.85%

Table 3 Chemical composition of textile effluent treatment plant sludge waste (% By Mass)

S. No	Composition	Sludge (%)
1	SiO_2	14.85
2	Al_2O_3	2.87
3	Fe_2O_3	–
4	CaO	21.04
5	MgO	9.53
6	K_2O	–
7	Na_2O	–
8	SO_3	–
9	SO_4	1.55
10	TiO_4	1.12
11	LOI	–

because of its toxicity to aquatic and mammalian species. The possible sources of metals are incoming fibre, water, dyes, and chemical impurities. Some dyes include metals as an integral part of the dye molecule. The concentrations of heavy metals are compared with the CPCB guideline (Table 4) and found that the concentrations of all heavy metals, including chromium species, are within the regulatory limits

Table 4 TCLP test result on TETP sludge

S. No.	Composition	Test method	Limits as per CPCB guideline	Test result (mg/l)
1	Arsenic	USEPA test method	Max. 5	absent
2	Barium		Max.100	0.13
3	Cadmium		Max.1	absent
4	Chromium		Max.5	absent
5	Lead		Max.5	absent
6	Manganese		Max.10	0.07
7	Mercury		Max.0.2	absent
8	Selenium		Max.1	absent
9	Silver		Max.5	absent
10	Ammonia	TCLP	Max.50	10.15
11	Cyanide		Max.20	0.02
12	Nitrate		Max.1000	8.51

indicating that the sludge is non-hazardous. Hence, this sludge can be explored for the possibility of reuse and recycling using some suitable technology rather than disposing of it in a landfill. It is also observed that the results of the characterization of TETP sludge vary from industry to industry and depend on the type of chemical used during the processing of textiles.

3.2 *Physical Tests on Raw Materials*

The physical properties of the cement and quarry dust are shown in Table 5. The specific gravity of cement obtained is 3.15 and that of quarry dust is 2.64. Results

Table 5 Physical test results of cement and quarry dust

S. No.	Tests conducted	Test results	
		Cement	Quarry dust
1	Specific gravity	3.15	2.64
2	Density	1440 kg/m^3	1650 kg/m^3
3	Water absorption	–	10.6
4	Standard consistency	30%	–
5	Initial setting time	80 min	Not less than 30 min
6	Final Setting time	125 min	Not more than 600 min

Fig. 6 Sieve analysis of TETP sludge

of grain size analysis of dried textile sludge are shown in Figs. 7 and 8. The particle size distribution of the sludge sample (Fig. 6) shows that the maximum percentage of sludge particles was retained on a 0.075 mm sieve. The curve shows that the sample of textile sludge consists of materials of all sizes. Effective sizes of the textile sludge before pulverization were obtained as D10 = 0.019 mm, D30 = 0.14 mm and D60 = 0.4 mm. Whereas, after pulverization, it is D10 = 0.014 mm, D30 = 0.13 mm and D60 = 0.3 mm. The values of uniformity coefficient Cu and coefficient of curvature Cc were 21.045 and 2.57, respectively. Whereas, after pulverization, the values of Cu and Cc obtained are 21.42 and 4.02, respectively.

3.3 Physico-Mechanical Tests on Brick

3.3.1 Density of Sustainable Bricks

The clay bricks normally have a bulk density of 1.8–2.0 g/cm^3. It is found that the dry density of the TETP sludge is lower, so the resulting unit weight of the material would get reduced when used as building materials. In the current research, similar findings have been found. From Fig. 9, it can be seen that with the increase in the cement and corresponding decrease in the textile sludge, the density of bricks increases.

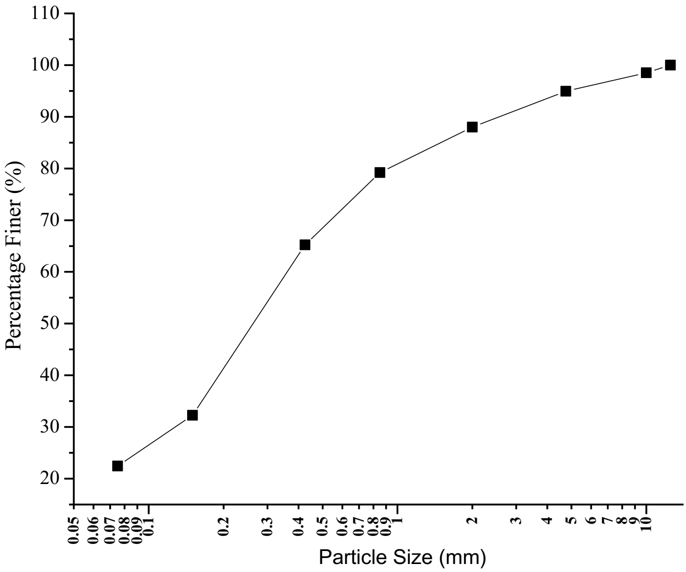


Fig. 7 Grain size analysis before pulverizing

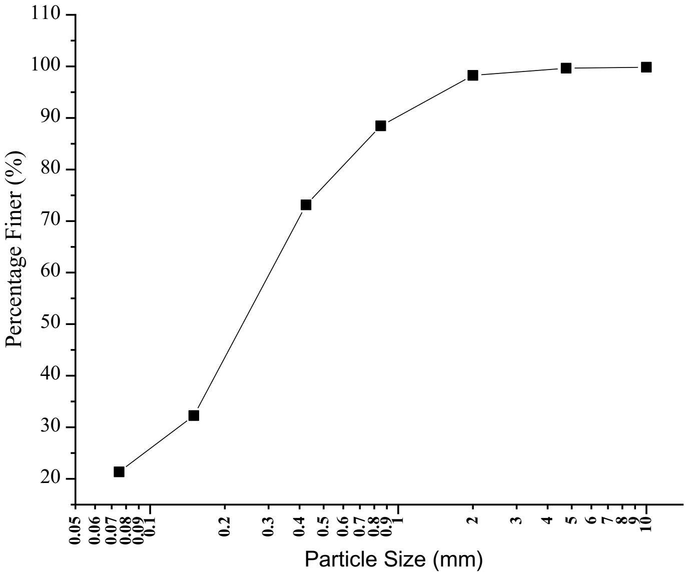


Fig. 8 Grain size analysis after pulverizing

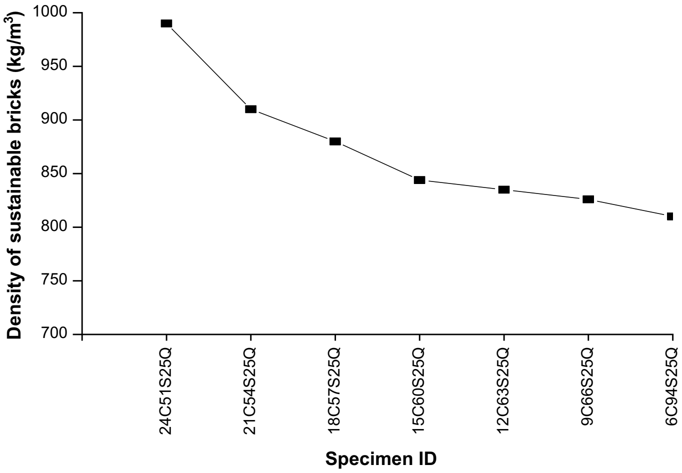


Fig. 9 Density of sustainable bricks

3.3.2 Compressive Strength of Sustainable Bricks

Figures 10 and 11 demonstrate the results of the average compressive strength of bricks. It is observed from Fig. 10 that, when TETP sludge is used as a partial substitute for cement, the compressive strength of the bricks decreases as the percentage

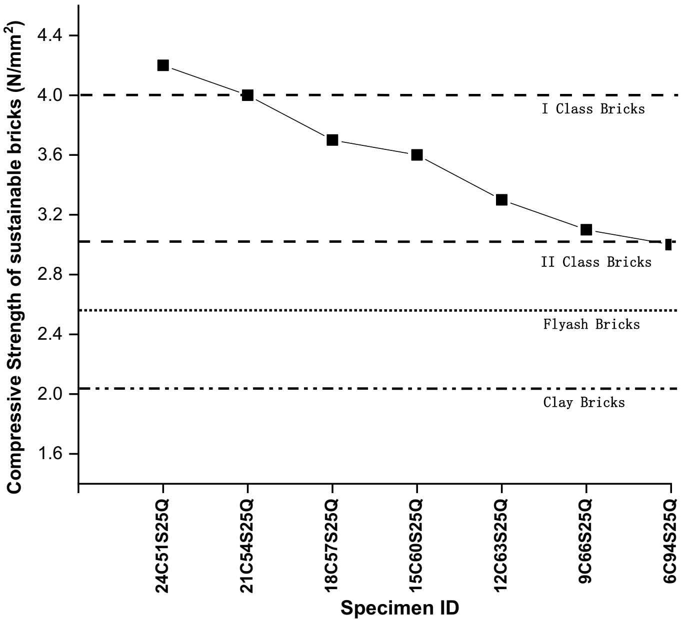


Fig. 10 Compressive strength of sustainable bricks

Fig. 11 Compressive strength test on third sample of the brick

of textile sludge increases. There is a maximum decrease of 29%, this reduction in strength might be due to fineness in particles of textile sludge compared to cement particles. The sludge is hydroscopic in nature [20], which increases the volume of the sample, so the demand for the water increases to preserve workability during mixing, thereby affecting the water–cement ratio. This may cause a reduction in the strength of bricks. The existence of chloride (Table 2) in the TETP sludge often reduces the quality of construction materials [21]. The obtained strength was found to meet the specifications of non-structural materials or components [22], as stated in various standards. The maximum strength of 4.2 N/mm^2 was observed for the combination of 24% cement, 51% sludge, and 25% quarry dust, which is greater than 4 N/mm^2 for grade D, load-bearing units of IS: 2185-1 [23], hence meets the criteria of required minimum strength, and found to be greater than 3.5 N/mm^2 as specified in IS: 1077 [24] for bricks in load-bearing units. The results also indicate that the compressive strength for the sludge incorporated brick is higher than that of the commercially available fly ash brick (2.5 N/mm^2) and clay brick (2.02 N/mm^2).

3.3.3 Water Absorption of Sustainable Bricks

From Fig. 12, it is observed that with the increase in the quantity of TETP sludge the value of water absorption increases. A maximum increase of 93% is observed. With an increase in the content of TETP sludge in the bricks, the porosity increases consequently the water absorption value increases [22]. Also, the presence of higher voids in the microstructure of sludge bricks subsequently increases the consumption of water [14]. With an optimum usage of TETP sludge of around 50%, the sustainable bricks showed promising results, i.e., compressive strength of 4.2 N/mm^2 with a corresponding water absorption value of 16%. This value is found to be less than the water absorption value of commercially available fly ash bricks, i.e., 18.43% and clay bricks, i.e., 27.11%.

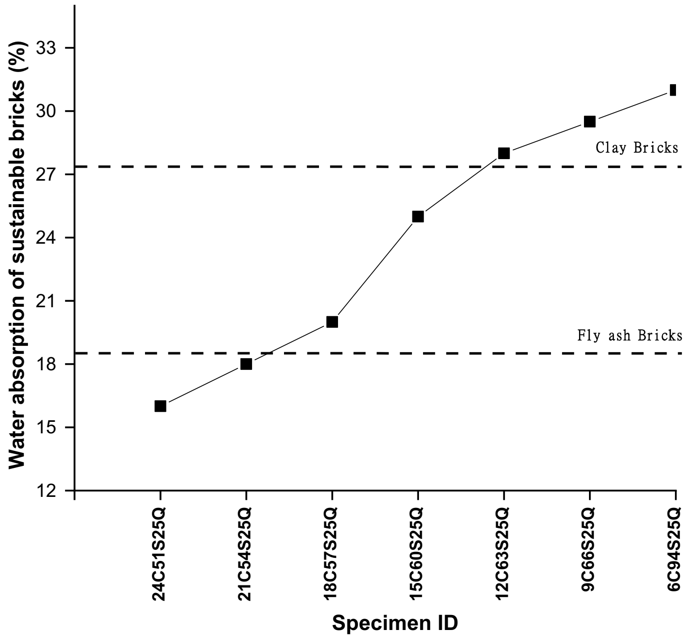


Fig. 12 Water absorption value of the brick

4 Conclusions

The disposal of textile effluent treatment plant sludge has a detrimental effect on the environment. Thus, its effective utilization in the production of the bricks is carried out, which proves to be a good alternative solution to such problems. Thus following conclusions have been drawn based on the detailed experimental investigation:

1. The presence of calcium and magnesium in sludge suggests its potential as a partial substitute for the development of sustainable building materials.
2. The heavy metals are found to be within regulatory limits and can therefore be used directly as a raw material without producing any harmful effects.
3. Developed bricks showed the maximum strength of 4.2 N/mm^2 for the combination of 24% cement, 51% sludge, and 25% quarry dust, which exceed the value of 4 N/mm^2 for grade D, load-bearing units of IS: 2185(part1)–1979 [23] and found to be greater than 3.5 N/mm^2 that meets the criteria of IS: 1077–1979 [24] for bricks in load-bearing units.
4. The textile sludge incorporated bricks were found to have strength greater than conventional fly ash and clay bricks.
5. When textile sludge is used in the range of 50–57%, the water absorption value of bricks was found to be less than 20%, thus meeting the requirement according to standards.

6. The bricks made with textile effluent sludge showed a lesser density compared to the other conventional bricks thus the resultant unit weight of the brick is lesser.
7. The optimum range of 51% of sludge for the manufacture of sustainable bricks in combination with quarry dust and cement is recommended.
8. The present study concludes that the utilization of TETP sludge for the production of sustainable bricks provides promising results of physico-mechanical properties when compared with commercially available bricks.

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