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ORIGINAL ARTICLE

Utilization of textile effluent wastewater treatment plant sludge as brick material

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Abstract In the present work, the feasibility of using sludge generated in wastewater treatment plants of textile industry as a partial replacement for clay in the conventional brick manufacturing process is examined. Physico-chemical properties of the sludge and clay were studied. The characteristics of bricks with replacement of sludge (0–50 %) with an increment of 3 % were determined. All the brick samples satisfied the requirements of Indian Standards norms in terms of weight loss on ignition. The bricks with sludge up to 15 % satisfied the prescribed norms for compressive strength and water absorption. Results also showed that the brick weight loss on ignition was mainly attributed to the organic matter content in the sludge being burnt off during the firing process. The characteristics of bricks such as efflorescence, density and weight loss on ignition for bricks with replacement of clayey soil with textile sludge up to 15 % also satisfied the requirements of the Indian Standard. Thus, textile sludge up to 15 % can be effectively added to make brick material.

Keywords Textile sludge · Sludge characteristics · Sludge bricks · Brick characteristics

Introduction

The textile industry is one of the oldest and most widely established industrial sectors in India. The textile units are scattered all over India; out of 21076 units, Tamil Nadu alone has 5285 units [1]. The garment export from Tirupur, Tamil Nadu, India touched US$2500 million in the year 2008–2009 [2]. More than 100000 m^3/day of textile effluent was generated from 800 dyeing, bleaching and textile processing industries situated in Tirupur [3]. The textile chemical sludge is generated in huge quantities after physico-chemical treatment of these effluents in common effluent treatment plants treating textile wastewater [4]. About 200 tonnes/day of textile sludge are generated in Tirupur [5]. This sludge is toxic in nature and disposal of this sludge in an environmentally safe manner is very important. Sludge disposal via landfill treatment, incineration, etc., will cause extra high operational costs to textile wastewater treatment. 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 [5].

Recycling of sludge is an alternative method to avoid the problem posed by the excessive sludge production from textile industries. Balasubramanian et al. [5] replaced 30 % of cement using textile sludge in flooring tiles, solid and pavement blocks, and bricks. Kaçan and Kütahyalı [6] used this sludge as a source for the activated carbon and removed strontium from aqueous solution effectively. Due to the high nutrient content, Rosa et al. [7] used this sludge as a fertilizer in soil. This recycling of sludge converts waste into useful materials and eliminates problems associated with sludge disposal. Therefore, sludge recycling is considered to be a better alternative than land disposal in the environmental point of view.

Large demand has been placed on the building material industry especially in the last decade owing to the increasing population, causing a chronic shortage of building materials, thus, the civil engineers have been

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challenged to convert the industrial wastes to useful building and construction materials [8]. The increase in the popularity for using environmentally friendly, low-cost and lightweight construction materials in the building industry has brought about the need to investigate how this can be achieved by benefiting the environment as well as maintaining the material requirements affirmed in the standards [9]. Brick is one of the important materials used in construction industries. India is the second largest producer of bricks in the world, next only to China, and has more than 10000 operating units, producing about 140 billion bricks annually [10]. Several waste materials such as cotton and limestone powder wastes [8], paper mill waste [11], waste marble powder [12], waste tea [13], limestone dust and wood sawdust [9], textile effluent sludge [14], etc., have been utilized partially for the production of bricks by various researchers.

The objective of the present study is to investigate the incorporation of textile sludge in the manufacture of bricks and to examine the influence of textile sludge proportion in raw materials in relation to the brick quality. Characteristic studies of sludge have been carried out. Compressive strength, water absorption, weight loss on ignition, liability to efflorescence and density of bricks have been analyzed for the sludge replaced bricks and compared with control bricks.

Materials and methods

Sludge collection and preparation

The dewatered and open air dried sludge sample was collected from a textile industry, Tirupur, Tamil Nadu. The samples of sludge were dried at a temperature of 105 °C until the net weight was constant. The dried samples were then crushed to reduce the size of large and uneven particles and then directly used as clay substitute.

Characteristics of sludge and clay

The sludge samples were used in the dry form for chemical analysis. The chemical characteristics of the sludge such as pH, density, loss on ignition, volatile matter content, specific gravity and particle size distribution were determined. The pH was determined by taking a sample and distilled water in the ratio of 1:10. The sample was mechanically agitated for 30 min. After agitation, the sample was filtered and the pH was determined [14]. The volatile matter was determined by igniting the sample at 550 ± 50 °C for 3 h. The density was determined using the pycnometer.

Scanning electron microscopy (SEM) investigation of the pure clay sample, textile sludge sample and bricks replaced with 15 % textile sludge were conducted in a HITACHI S-3000H operated at 10 kV. The SEM analysis was done at 500× magnification to examine the morphological characteristics. In addition, the surface functional groups of pure clay sample, textile sludge sample and bricks replaced with 15 % textile sludge were detected by a Fourier transform infrared (FTIR) spectroscope (FTIR-2000, Perkin Elmer) using the KBr pellet method. Spectra were recorded from 4000 to 400 cm^{-1}.

Formation of brick specimen

The raw materials such as clay and textile sludge were dried well at 105 °C in an oven for 24 h. Then the dried textile sludge was mixed with clayey soil and homogeneous mixtures of textile sludge and clay at various proportions were made. Textile sludge concentrations up to 50 % by weight was added into the clayey soil. The various mix ratios of sludge and clayey soil used in the present study are given in Table 1. The samples were made pasty with required amounts of water based on optimum moisture content. Solid bricks having a size of 21 cm length, 10 cm width and 7.5 cm height were moulded using this mixture. A constant pressure was applied to the mixtures during the moulding process to avoid cracking and uneven structure. Control bricks (free from textile sludge) using pure clayey soil was also prepared and kept as a reference for this study. After formation of bricks, the specimens were dried in the open atmosphere for 24 h. The dried specimens were then fired at 1000 °C in a brick kiln. Finally, the bricks were taken out from the kiln and kept in natural conditions for cooling.

Testing of brick specimen

The brick specimens manufactured were tested for compressive strength, water absorption, efflorescence, percentage weight loss and bulk density. The tests were carried out as per IS 3495 (Part 1–2):1992 [15] standards. Compressive strength test was carried out for bricks manufactured at various sludge proportions after 1 and after

Table 1 Amount of sludge and clay added for the formation of bricks

Mix ratio (%)	Amount of textile sludge (g)	Amount of clay (g)
3	150	4850
6	300	4700
9	450	4550
15	750	4250
20	1000	4000
30	1500	3500
50	2500	2500

7 days of immersion in water. Load was applied to bricks in a uniform rate using a universal testing machine. The compressive strength was determined by dividing the maximum load with the applied load area of the brick samples. Water absorption values of bricks were determined from weight differences between the dried bricks and water-saturated samples. The weight loss on ignition was monitored by comparing the weights before and after igniting the bricks.

Results and discussion

Characteristics of sludge and clay

The physico-chemical properties of the sludge and clay were determined in a dried condition. The physico-chemical properties of the textile sludge and clay are given in Table 2. Since the specific gravity of sludge is similar to that of the clayey soil, it can be used as a partial replacement of clay in brick manufacturing but, the volatile content of the textile sludge is higher than that of the clayey soil. This indicates that textile sludge contains more amounts of organic matter than that of clayey soil. The particle size distribution of the sludge is shown in Fig. 1. Effective sizes of the textile sludge were obtained as: $D_{10} = 0.016$ mm, $D_{30} = 0.038$ mm and $D_{60} = 0.22$ mm. The uniformity coefficient (U) and coefficient of curvature (C_c) of textile sludge were calculated from Eqs. (1) and (2), respectively. The values of U and C_c were obtained as 13.75 and 0.41, respectively. Since the C_c value of sludge is <1, it can be considered as poorly graded soil.

$$U = \frac{D_{60}}{D_{10}} \tag{1}$$

$$C_c = \frac{D_{30}^2}{D_{10} D_{60}}. \tag{2}$$

FTIR analysis

The FTIR spectroscopy analysis was carried out for the pure clayey soil sample, textile sludge and brick containing 15 % textile sludge. The bands were observed in the range, 4000–400 cm^{-1}. The results for FTIR analysis is shown in Fig. 2. The FTIR studies help in the identification of the various forms of minerals present in the clay. In the IR studies of clay, the Si–O stretching vibrations were observed in the range 771.62, 542.75 and 463.38 cm^{-1} showing the presence of quartz [16]. A strong band in the range 3920.61, 3787.18 and 3440.97 cm^{-1} indicates the possibility of the hydroxyl linkage [17]. However, a broad band 1617.61 cm^{-1} in the spectrum of clay suggests the possibility of water of hydration. The vibrations observed at 1027 cm^{-1} indicate the possibility of the presence of hematite [17, 18]. In IR studies of textile sludge, the O–H stretching vibrations were observed in the range 3787 cm^{-1} [18]. A band at the range of 2900 cm^{-1} shows the presence of C–H bonds [19]. Thus, the results of IR are quite helpful in the identification of the various forms of minerals present in clay and sludge. Most of the bands

Table 2 Characteristics of textile sludge and clay

Characteristics	Textile sludge	Clay
pH	7.14	7.95
Particle density (g/cm^3)	0.824	1.495
Volatile matter content (%)	9.52	3.36
Specific gravity	2.21	2.46
Moisture content (%)	3.34	1.85

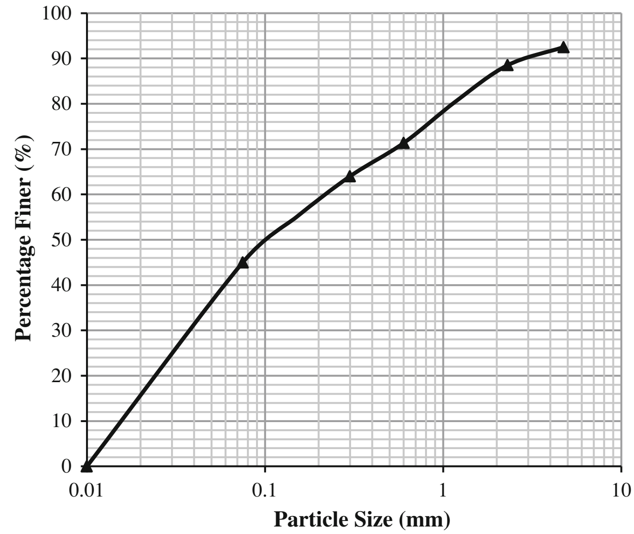

Fig. 1 Particle size distribution of textile sludge

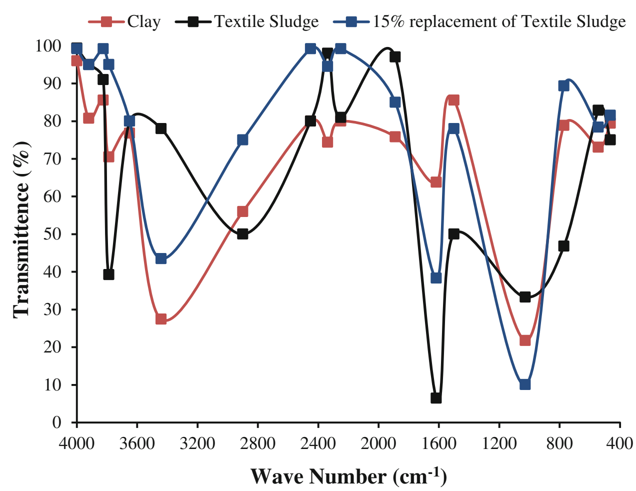

Fig. 2 FTIR for pure clay, textile sludge and brick replaced with 15 % textile sludge

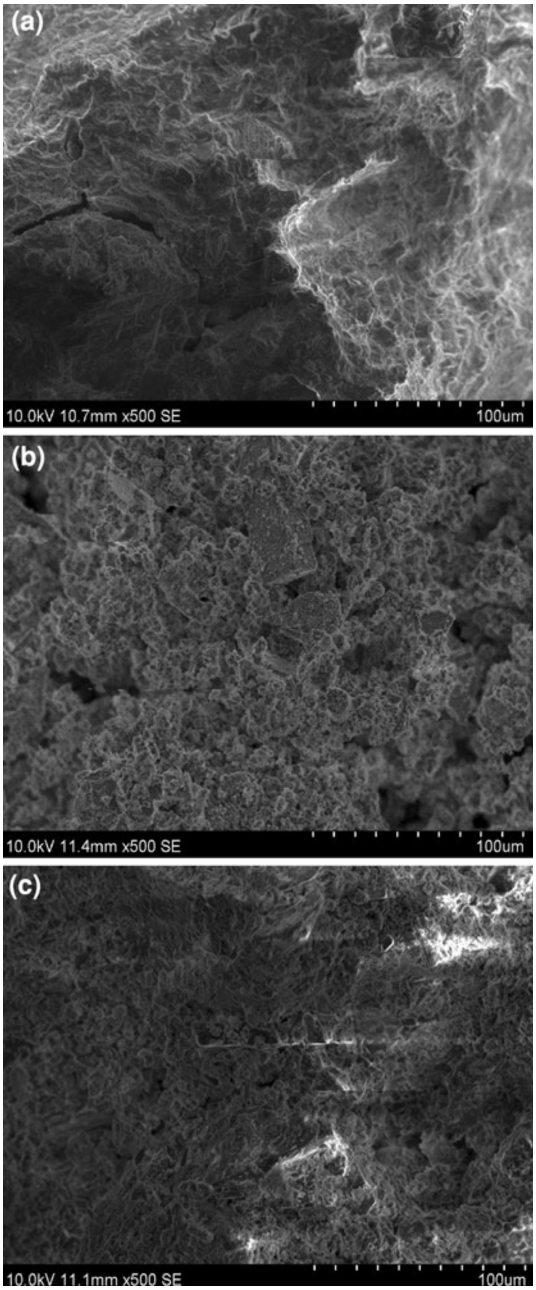

Fig. 3 Scanning electron microscope images of **a** pure clay soil sample, **b** textile sludge sample and **c** specimen replaced with 15 % textile sludge

observed in clayey soil and textile sludge were also observed in brick containing 15 % sludge. This indicates that no reaction occurred between sludge and clayey soil, even at higher temperatures.

SEM analysis

The SEM analysis was carried out for the pure clayey soil sample, textile sludge and bricks replaced with 15 % textile sludge. The SEM images are shown in Fig. 3. From

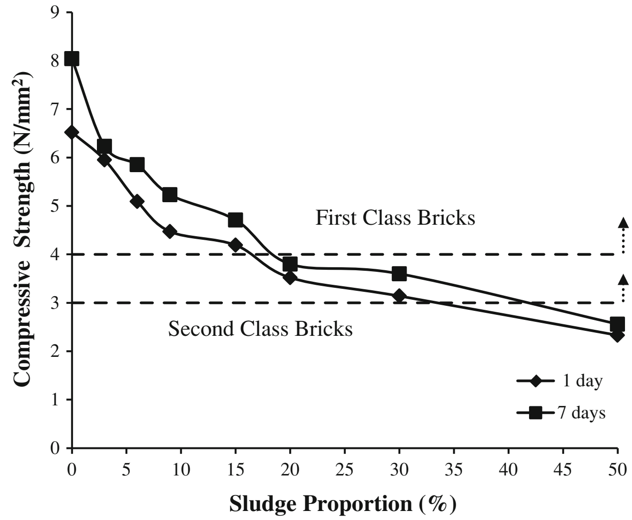

Fig. 4 Compressive strength after 1 and 7 days immersion in water

Fig. 3a, it can be observed that the clayey soil consists of granular material, whereas there are materials of different shapes, sizes, as well as fibrous ones, in the textile sludge samples (Fig. 3b). The image of bricks with 15 % sludge (Fig. 3c) indicates that it is a mixture of granular as well as fibrous materials. The pure clayey soil contains a more compact structure than that of the textile sludge, but the sludge obtained from the textile industry contains more voids. The clayey soil particles were arranged in a random manner. The size of the textile sludge particles seemed to be higher than that of the clay particles.

Compressive strength of brick

The compressive strength test is the most important test for the engineering quality of building materials. The variation in compressive strength of both pure clay bricks and bricks replaced with sludge after 1 and 7 days is shown in Fig. 4. The compressive strength of bricks after 7 days immersion in water was greater than that of the bricks immersed in water for 1 day. Water immersion has proved to be an important step to increase the strength of bricks. The compressive strength of brick decreased with an increase in the replacement level of textile sludge. The compressive strength of brick was found to be 8 and 2.5 N/mm^2, for reference and brick containing 50 % textile sludge even after 7 days of immersion. This decrease in strength with increase in sludge concentration is due to the increase in pore volume of bricks. Since the sludge contains more organic matter than clayey soil, thermal treatment of moulded bricks at 1000 °C causes volatilization of these organic matters and results in increase in pore volume. This increase in pore volume will decrease the compressive strength. According to Indian Standards, first quality bricks should have strength higher than 4 N/mm^2. Similarly, second quality bricks should have compressive strength greater than 3 N/mm^2. Therefore, the maximum amount of waste sludge that can be added lies in the range of 3–15 % corresponding to the compressive strength between 5.62 and 4.19 N/mm^2 for textile sludge bricks. The mix up to 15 % satisfied the requirements of first class bricks as per the Indian Standards. The sludge mix ratio of 20 and 30 % satisfied the requirements of second class bricks.

Water absorption of brick

Water absorption is a key factor affecting the durability of brick. More durability of the brick and resistance to the natural environment is expected, when lesser water infiltrates into the brick [20, 21]. Thus, the internal structure of the brick must be intensive enough to avoid the intrusion of water [22]. The determination of water absorption was done using the procedures as described in IS 3495 (Part 1–2):1992 [15]. The percentage of water absorbed for bricks with different proportions of sludge is shown in Fig. 5. From Fig. 5, it is observed that the water absorption of the bricks increased with increased sludge addition. When the mixture contains higher amount of sludge, the adhesiveness of the mixture decreases but the internal pore size of the brick increases [11]. The SEM images also indicated that bricks replaced with textile sludge had more pore spaces compared to that of the pure clayey soil sample. As a result, the quantity of absorbed water increased. When the mixture contains <15 % sludge, the percentage of water absorbed in the brick is <15 % and it satisfies the requirements of first class bricks as per the Indian Standard. With 20 and 30 % sludge in replacement of clay, the brick produced in this condition meets the 2nd class brick water absorption criteria.

Weight loss on ignition

The brick weight loss on ignition is not only attributed to the organic matter content in the clay, but it also depends on the inorganic substance in both clay and sludge being burnt off during the firing process [21]. The weight loss of bricks on ignition for different sludge proportions is shown in Fig. 6. Increasing the sludge proportion and temperature resulted in increase in brick weight loss on ignition. Visual observation showed that an uneven surface was found in the sludge-brick. It is speculated that the formation of this unwanted surface was mainly due to the organic component burnt off during the firing process [23]. For a control brick, the loss of weight after firing is mainly attributed to the organic matter content present in the clay. Furthermore, the brick weight loss on ignition also depends on the inorganic substances in both clay and sludge being burnt off during the firing process. The weight loss criterion for a normal clay brick is 15 % [24]. The produced bricks all meet the requirements of the first class bricks as per the Indian Standard.

Liability to efflorescence

The liability to efflorescence shall be reported as ‘nil’, ‘slight’, ‘moderate’, ‘heavy’ or ‘serious’ in accordance with the following definitions [15]; Nil - When there is no perceptible deposit of efflorescence. Slight—when not more than 10 % of the exposed area of the brick is covered with a thin deposit of salt. Moderate—when there is a heavier deposit than under ‘slight’ and covering up to 50 % of the exposed area of the brick surface but unaccompanied by powdering or flaking of the surface. Heavy—when there is a heavy deposit of salts covering 50 % or more of the exposed area of the brick surface but unaccompanied by

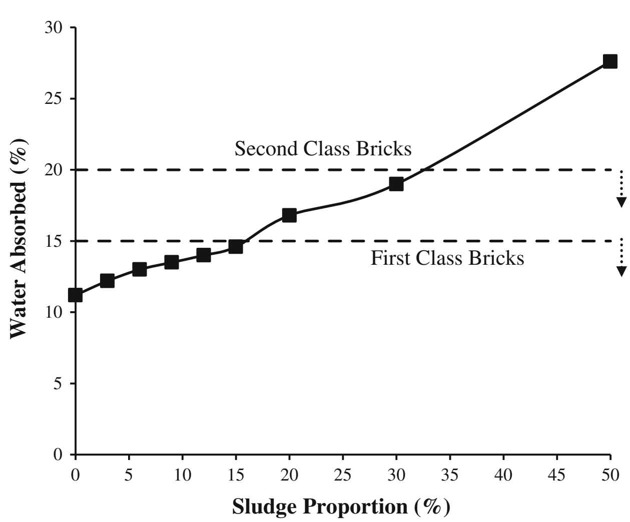

Fig. 5 Water absorption of brick

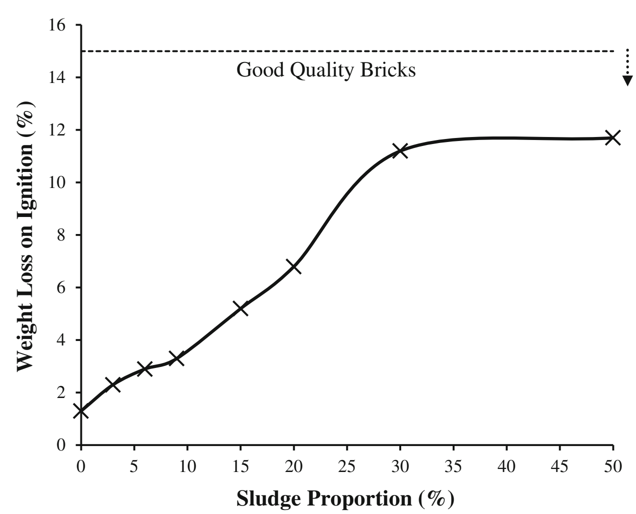

Fig. 6 Weight loss on ignition

Fig. 7 Liability of efflorescence on the brick

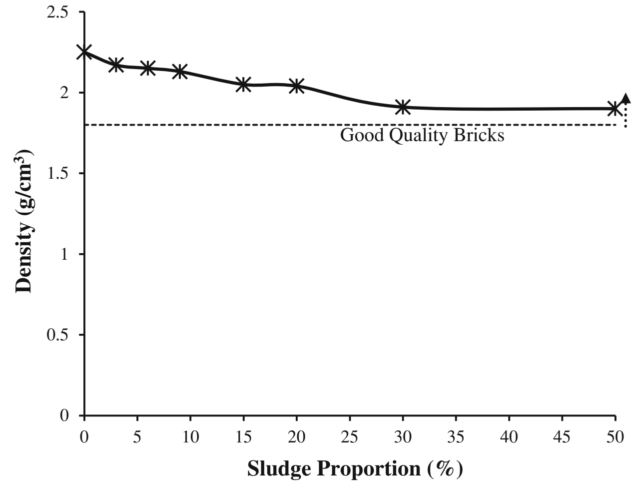

Fig. 8 Effect of sludge addition on bulk density

Table 3 Effect of sludge addition on efflorescence

Sludge proportion (%)	Liability to efflorescence
0	Nil
3	Nil
6	Nil
9	Nil
12	Nil
15	Slight
20	Slight
30	Slight

powdering or flaking of the surface. Serious—when there is a heavy deposit of salts accompanied by powdering and/or flaking of the exposed surfaces.

The liability of efflorescence on the bricks is shown in Fig. 7. The results for the formation of efflorescence on the bricks are given in Table 3. From Table 3, it was observed that the bricks up to 15 % did not have any liability to efflorescence when compared to the bricks with 20, 30 and 50 % sludge. It indicated that the bricks with replacement up to 15 % textile sludge can be exposed to various climatic conditions because there is no formation of white patches on the brick after the experiments. No change in the aesthetic appearance of the brick was also observed during the experiment.

Density of bricks

The density for control bricks and bricks made from different proportions of sludge is shown in Fig. 8. The bricks made with clay normally have a bulk density of 1.8–2.5 g/cm^3 [25]. The density of the bricks was inversely proportional to the quantity of sludge added in the mixture (Fig. 8). This finding is closely related to the quantity of water absorbed as demonstrated in Fig. 6. When the mixture absorbs more water, the brick exhibits a larger pore size, resulting in a lower density [24]. The results showed that the bulk density for all the bricks up to 50 % replacement of clayey soil with textile sludge were all above 1.8 g/cm^3. All the bricks had bulk density of a good quality brick.

Conclusions

This study demonstrated that textile sludge can be used as a replacement material for clayey soil in the manufacturing of bricks. The strength of bricks decreased with increase in sludge concentration. From the compressive strength study, the maximum amount of sludge that can be added in bricks was found to be 15 % for first quality bricks and 30 % for second quality bricks. Water adsorption results also indicated the same. All the bricks made with proportion (0–50 % sludge) were found to satisfy the norms of weight loss and bulk density properties of good quality bricks. The bricks with sludge proportions up to 15 % did not have any effect of efflorescence. This study indicates that the replacement of clay with sludge has positive effects on the environment via recycling of waste.

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