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Research Article

Reuse Feasibility of Electrocoagulated Metal Hydroxide Sludge of Textile Industry in the Manufacturing of Building Blocks

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During the last decade, the growing load of sludge from textile industries, the top foreign exchange earning sector of Bangladesh, is a common nuisance to environmental system and community health. The present study was aimed to minimize the environmental impact from the disposal of Electrocoagulated Metal Hydroxide Sludge (EMHS) by using it as a partial substitute of clay in the manufacturing of construction material like building blocks (BBs). Different batches of normal and pressurized building blocks (NBBs and PBBs, resp.) were prepared using up to 50% EMHS with clay and then fired at a particular temperature. EMHS proportion in the mixture and firing temperature were two key factors determining the quality of BB. BB did not show any deformation or uneven surfaces at any of the examined firing temperature. At higher firing temperature and EMHS proportion, more weight loss and shrinkage of BB were noticed. Higher compressive strength and lower water adsorption were found at lower EMHS content and higher firing temperature. It was explored that NBB and PBB with 20 and 30% EMHS in clay, respectively, and fired at 1050 °C would be usable for nonloading applications; namely, ornamental bricks, decoration purposes, and fence of garden.

1. Introduction

Degradation of environmental quality due to unrestricted and objectionable discharges of sludge from industrial unit is a common practice in developing countries like Bangladesh where little or no treatment of waste residue is carried out before disposals in landfill site haphazardly or openly. Although textile and dyeing sector is a vital part of economic development, speedy and unplanned progress may result in a wide impact on natural resources and human being living within the close vicinity of the sludge disposal locations [1–3]. Electrocoagulated Metal Hydroxide Sludge (EMHS) produces during the treatment of waste effluent of the industry by electrocoagulation (EC) technique [4], where sacrificial anodes made of aluminum or iron corrode to release active coagulant precursors [5–7]. Coagulant produces insoluble metallic hydroxide flocs which can remove pollutants by surface complexation or electrostatic attraction [8, 9].

Coagulants are in the form of both monomeric hydroxide ions and highly charged polymeric metal hydroxyl species, namely, $Fe(H_2O)_6{}^{3+}$, $Fe(H_2O)_5(OH)^{2+}$, $Fe(H_2O)_4(OH)^{2+}$, $Fe_2(H_2O)_8(OH)^{24+}$, $Fe_2(H_2O)_6(OH)_4{}^{4+}$, and so forth for anodes made of iron [10]. These species neutralize the electrostatic charges on the suspended solids and facilitate agglomeration resulting in separation from the aqueous phase by producing EMHS.

Various steps have been taken by the Government of Bangladesh to monitor the effluent quality of industries. Therefore, the volumes of wastewater treated and the quantities of sludge generated are increasing. Hence, recycle, reuse, and conversion of waste materials into a reusable one is critically important for environmental protection and sustainable development of the society. Sludge contains a wide range of components including organic and inorganic matter; bacteria and viruses; oil and grease; nutrients such as nitrogen and phosphorus; toxic heavy and trace metals [11]. So, sustainable end use of this sludge is a paramount issue. Although the landfills are commonly used for sludge disposal, rapid urbanization has made it increasingly difficult to find suitable landfill sites in Bangladesh.

A potential long-term solution seems to be recycling of the EMHS sustainably and using it for beneficial purposes. Solidification is such a technique that stabilizes and solidifies components of waste materials. The solidified products can be disposed of to a secure landfill site or recycled and reused as construction materials, namely, bricks, concretes, roofing materials, tiles, building blocks (BBs), and so forth if meet the specific requirements [1–3, 12, 13]. Utilization or reuse of EMHS as building materials is a win-win strategy because it converts the waste materials into a useful one and alleviates the disposal problem. The prospective other benefits of using sludge as BB additives include oxidizing organic matter, immobilizing toxic and heavy metals in the fired matrix, destroying any pathogen during the firing process, and reducing the frost damage based on the results of several full or bench scale studies [13–15]. Although there are related works on the sludge of sewage, paper industry, common effluent treatment plant of textile industry, electroplating industry, and oil and petroleum industry to make constructional materials [13–25], no work is on EMHS reuse into such materials. Present study systematically investigates the partial replacement of clay or soil by EMHS in the manufacturing of building materials such as Normal Building Block (NBB) and Pressurized Building Block (PBB). In order to get quality products, the influence of sludge proportion and firing temperature on shrinkage, weight loss, water adsorption, and compressive strength were investigated. Prior such examination basic geoengineering, elemental, thermal, and morphological/microstructural properties of EMHS were also analyzed. The work was ultimately focused if the EMHS will be feasible to reuse as building material in any extent.

2. Materials and Methods

2.1. Samples Collection, Preparation, and Analysis. The wet EMHS samples ($n = 15$) were collected from Adury Knit Composite Ltd., (Geographic Location: 24°02′N latitude and 90°44′E longitude) Narshingdi District, Bangladesh. Brick-making soil or clay samples ($n = 12$) were collected from a local brick field of Savar, Dhaka District, Bangladesh. Both types of samples were separated into plastic containers, levelled with unique code, and tagged and stored at ambient condition prior to analysis. For basic geoengineering properties investigation, EMHS was mixed with brick-making general soil or clay in triplicate at 10, 20, 30, and 40% on wet weight basis. Moreover, 100% soil and EMHS samples were also taken for comparison. Samples were sun-dried and made powder using a grinder of aluminum oxide ball material. Powder samples that passed through 0.853 mm sieve were taken for elemental, thermal, and surface morphological/microstructural analysis and BB making process.

Geoengineering, elemental, thermal, and morphological/microstructural analysis of samples were carried out using British Standard 1377 [26], ARL QUANT'X EDXRF (Thermo Scientific, USA), TG/DTA 6300 (Seiko Instruments Inc, Japan) at a heating range of 30°C ~ 1150°C at 20°C/minute in pure nitrogen gas medium, and Scanning Electron Microscope (HITACHI S-3400N, Japan), respectively. Detailed procedures were discussed elsewhere [1–3].

2.2. Preparation of NBB and PBB. In molding process of NBB, EMHS was mixed with soil up to 50% on weight basis in 10% increment. EMHS-free mixture was also made as a reference. Dry mixing was done first and then 10% aqueous solution of sodium silicate (Na_2SiO_3) was added to make homogeneous paste and bind the materials in the mixture well. Mixtures were then introduced into a series of BB molds of $2'' \times 2'' \times 2''$. Prod was applied with a wooden rod for 32 times in about 16 seconds to ensure the elimination of entrained air. After 24 hours of maturation followed by drying at room temperature, different batches of the molded blocks were fired at 950, 1000, and 1050°C in a muffle furnace (Nabertherm, Germany) for 6 hours maintaining a soaking period of 15 minutes to get the final products. In case of PBB, EMHS was added to soil as the same ratio of NBB. Mixtures were then made into BB of $2'' \times 2'' \times 2''$ at 5 ton pressure using a hydraulic press (Fred S. Carver Inc, Wabash, IN, USA). Such pressure helped to achieve the block with compact shape which was first dried at room temperature followed by firing at 1000 and 1050°C.

2.3. Quality Assessment of NBB and PBB. Fired BB specimen underwent a series of test including weight loss on ignition, shrinkage on ignition, water adsorption, and compressive strength to determine their quality using following equations

$$\begin{aligned} \text{weight loss on ignition} &= \frac{\text{Wa} - \text{Wb}}{\text{Wa}}, \\ \text{firing shrinkage} &= \frac{\text{Va} - \text{Vb}}{\text{Va}}, \qquad (1) \\ \text{water adsorption} &= \frac{\text{Wc} - \text{Wd}}{\text{Wc}}, \end{aligned}$$

where Wa is the weight of BB before firing (gm), Wb is the weight of BB after firing (gm), Va is the volume of BB before firing (cm^3), Vb is the volume of BB after firing (cm^3), Wc is the weight of BB before water submersion (gm), and Wd is the weight of BB after water submersion (gm).

Compressive strength of BB was determined using a hydraulic press (Fred S. Carver Inc, Wabash, IN, USA). The testing blocks were placed in the flat surface of the equipment and then load was applied. When fracture was observed in the blocks that loading pressure was taken and divided by four to get compressive strength in PSI. Then this unit was converted to kg/cm^2, where 1 PSI equivalent to 7.03069×10^{-2} kg/cm^2.

3. Results and Discussion

3.1. Geoengineering, Elemental, Thermal, and Microstructural Properties of EMHS.

Basic geoengineering properties of EMHS and EMHS amended soil were given in Figure 1. All the properties showed an increasing trend when EMHS was added with soil. EMHS contained high specific gravity due to the presence of very high iron content [1]. EMHS was in high plasticity range if considered as soil-like material [1, 27]. Extremely high liquid limit value of EMHS might be due to the high moisture content of EMHS. Craig [28] mentioned that most fine-grained soils existed naturally in the plastic state and the plasticity due to the presence of clay minerals or organic minerals. High plastic limit of EMHS was arrived due to the presence of organic matter from different types of polymers and resins that were used in textile industry. Meanwhile, high linear shrinkage was caused for large moisture content and liquid limit of the EMHS. Shrinkage of soil was caused by the loss of pore water and has enormous damage to structures built on or with clays. Mitchell [29] mentioned that the greater the plasticity is, the greater the shrinkage on drying becomes.

Twenty-two elements were detected by EDXRF in EMHS where Fe was the dominant metal (about 83%). Overall statistics of elemental concentration was given in Table 1. Fe, Mn, Ni, Cu, Zn, and Cd exceeded the permissible limit to apply EMHS as nutrient supplements in agricultural field [30–32]. Cr and Hg content in EMHS also has a great concern due to their toxic effect to soil biota, environment, and human health. Exposure of these metals from the sludge may contaminate and change soil structure and thus becomes harmful for cultivation [32]. EMHS was thermally moderately stable compared to soil due to the moisture content of its porous surface and up to program temperature only 29.3% weight of EMHS was degraded (Figure 2). EMHS sample was unstructured in nature and irregular in shape with uneven edge and porous in body surface (Figure 3). Porosity on surface was observed, filling with a number of small grains of other iron oxides such as maghemite or hematite [33], and formed a complex structure.

3.2. Quality of NBB and PBB.

Initially, BBs were considered unsuitable if they developed cracks during drying and after firing at tested temperature; or if deformation in the shape or size was observed [34]. All BBs of present work were in good shape and size without any deformation at any firing temperature. Weight loss on ignition, shrinkage on ignition,

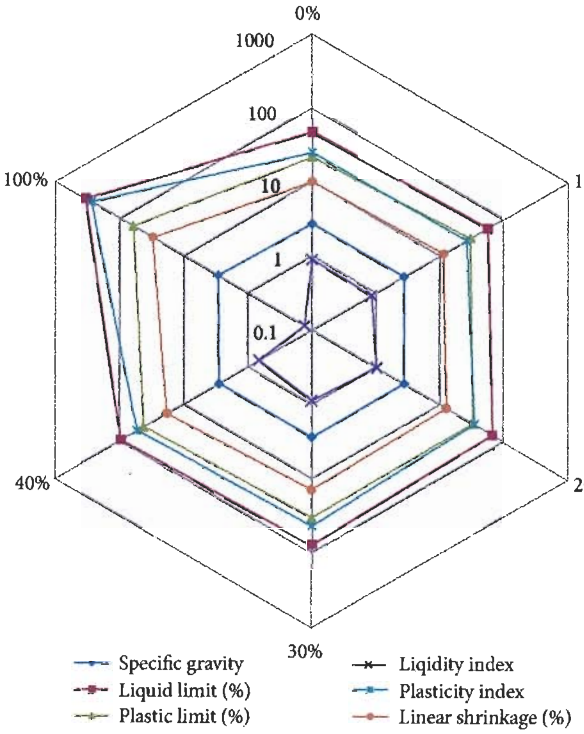


Figure 1: Basic geoengineering properties of EMHS at different mixing ratios with soil.

Table 1: Statistics of elemental concentration (mg/kg) of EMHS.

Element	Mean ± STD	Range
Fe	923.812 ± 16.8	902.6–941.1
Si	51.07 ± 13.9	39.4–68.8
Mg	77.63 ± 63.6	10–157
Ti	0.57 ± 0.08	0.48–0.67
K	1.08 ± 0.4	0.72–1.66
Ca	5.7 ± 0.4	5.3–6.2
Cu	0.5 ± 0.2	0.34–0.78
Ni	0.2 ± 0.05	0.12–0.24
Zn	0.32 ± 0.03	0.28–0.34
Mn	0.76 ± 0.34	0.23–0.98
Zr	0.048 ± 0.03	0.02–0.07
Ba	0.11 ± 0.06	0.05–0.2
Cr	0.130 ± 0.081	0.08–0.250
Cd	0.0145 ± 0.0032	0.01–0.018
V	0.1665 ± 0.112	0.03–0.300
Hg	0.0550 ± 0.010	0.05–0.068
Sr	0.0665 ± 0.015	0.052–0.088
Nb	0.0260 ± 0.007	0.02–0.035
Ga	0.0105 ± 0.0012	0–0.024
Cl	0.00221 ± 0.0009	0.0012–0.0032
Br	0.00957 ± 0.0008	0–0.08
S	0.01197 ± 0.0022	0.001–0.015

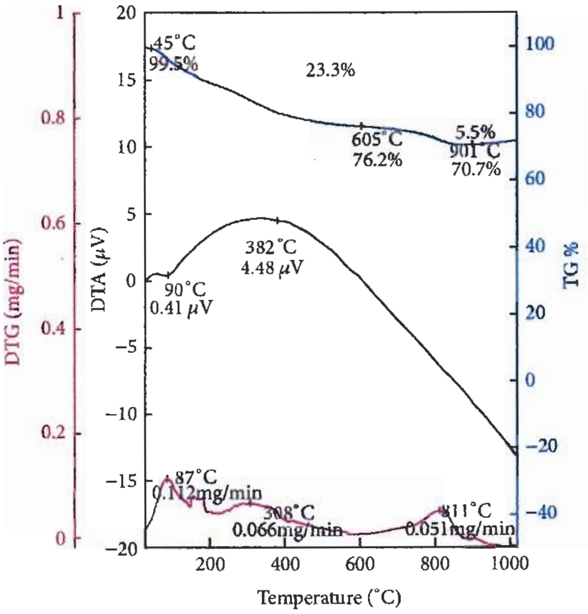


Figure 2: DTG-DTA-TG profile of EMHS.

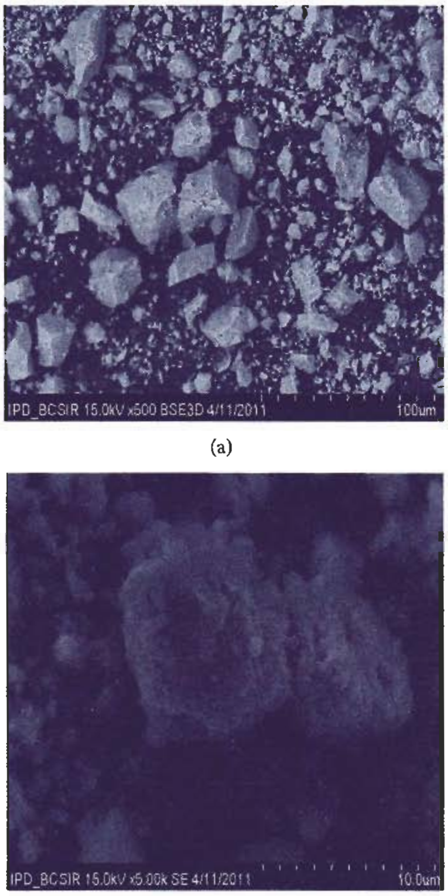
water adsorption, and compressive strength were assessed as the main criteria for quality of fired products.

3.3. *Weight Loss on Ignition of NBB and PBB.*

Higher percentage of EMHS mixed with soil and fired at higher temperature showed more weight loss of NBB and PBB (Figure 4). NBB containing 50% EMHS and fired at 1000 and 1050°C showed weight loss of 20.6 and 21.62%, respectively. Weight loss occurred due to the evaporation of water from products, melting of inorganic substances, and combustion of organic matters during the firing process [13, 14, 34]. A first class brick has a maximum 15% weight loss on ignition [35]. In the present study, NBB containing up to 30% EMHS and fired at 950°C, 20% EMHS fired at 1000°C, and 10% EMHS fired at 1050°C fulfilled the first class criteria. Up to 20% EMHS with soil and fired at all temperature regime, PBB fulfilled the first class standard. There were some small rough textures on the surfaces of BB due to organic matters being burnt off during the firing process. When the firing temperature was higher than 950°C, the carbonate deformed to CO_2 and caused a weight loss of the BB. When the temperature was higher than 1000°C, oxygen was recaptured from the air due to the oxidation of iron and the large weight loss in the blocks was reduced [13, 14]. All BBs were attractive and appeared as light-to-deep red in color. Esthetically, the surface texture was moderate even with the appearance of low small pores, thereby it can be used as fencing and ornamental bricks [36].

3.4. *Shrinkage on Ignition of NBB and PBB.*

A good quality brick exhibits shrinkage below 8% [35]. As swelling of clay is much lower than that of sludge, addition of sludge to the mixture widens the degree of firing shrinkage; as a result the quality of products is downgraded [13]. When firing temperature and percentage of EMHS with soil increased, the shrinkage of the products also increased (Figure 5). Firing shrinkage of PBB increased rapidly up to 7.58 and 15.7% in addition of 50% EMHS in the mixture and fired at 1000 and 1050°C, respectively. Shrinkage on ignition was not only attributed to the organic matter content of the sample, but also depended on the inorganic substances of both clay and sludge being burnt off during the firing process [13, 14]. PBBs with up to 50% EMHS and fired at 1000°C were first class standard. Moreover, NBB with 10% EMHS and fired at 950°C also fulfilled the national criteria of good quality products [12]. A linear relationship between weight loss and shrinkage on the ignition of BB was observed (Figure 6). Due to shrinkage, weight loss of BB occurred and vice versa.



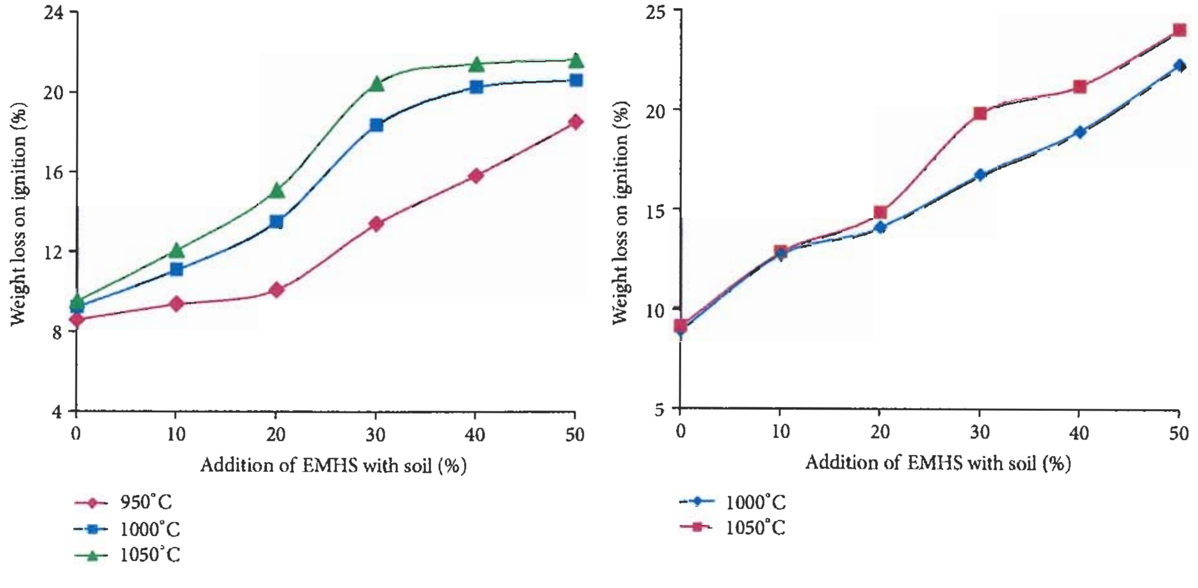
(a)

(b)

Figure 3: SEM micrograph of EMHS at (a) 100 μm and (b) 10 μm.

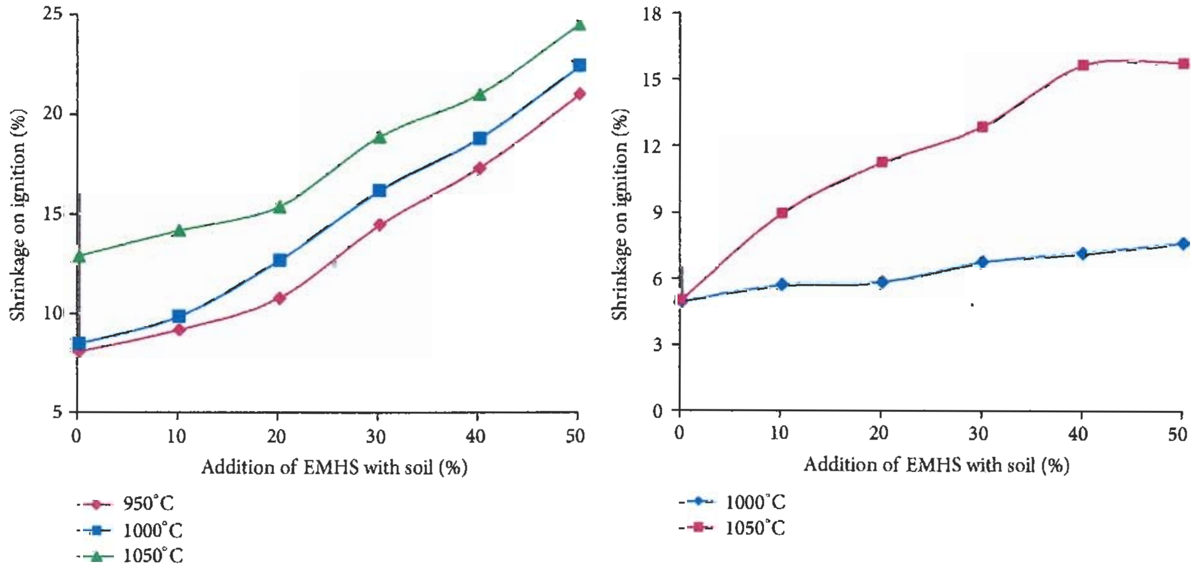
3.5. *Water Adsorption of NBB and PBB.*

Water adsorption is a crucial factor affecting the durability of various types of building materials. The less the water infiltrates into blocks, the more the durability of the blocks and resistance to the natural environment are exposed. The degrees of firmness and compaction of BB, as measured by their water adsorption characteristics, vary considerably depending on the type of clay and methods of production used. Therefore, the internal



(a) (b)

Figure 4: Weight loss on ignition of (a) NBB and (b) PBB at different EMHS percentages and firing temperatures.

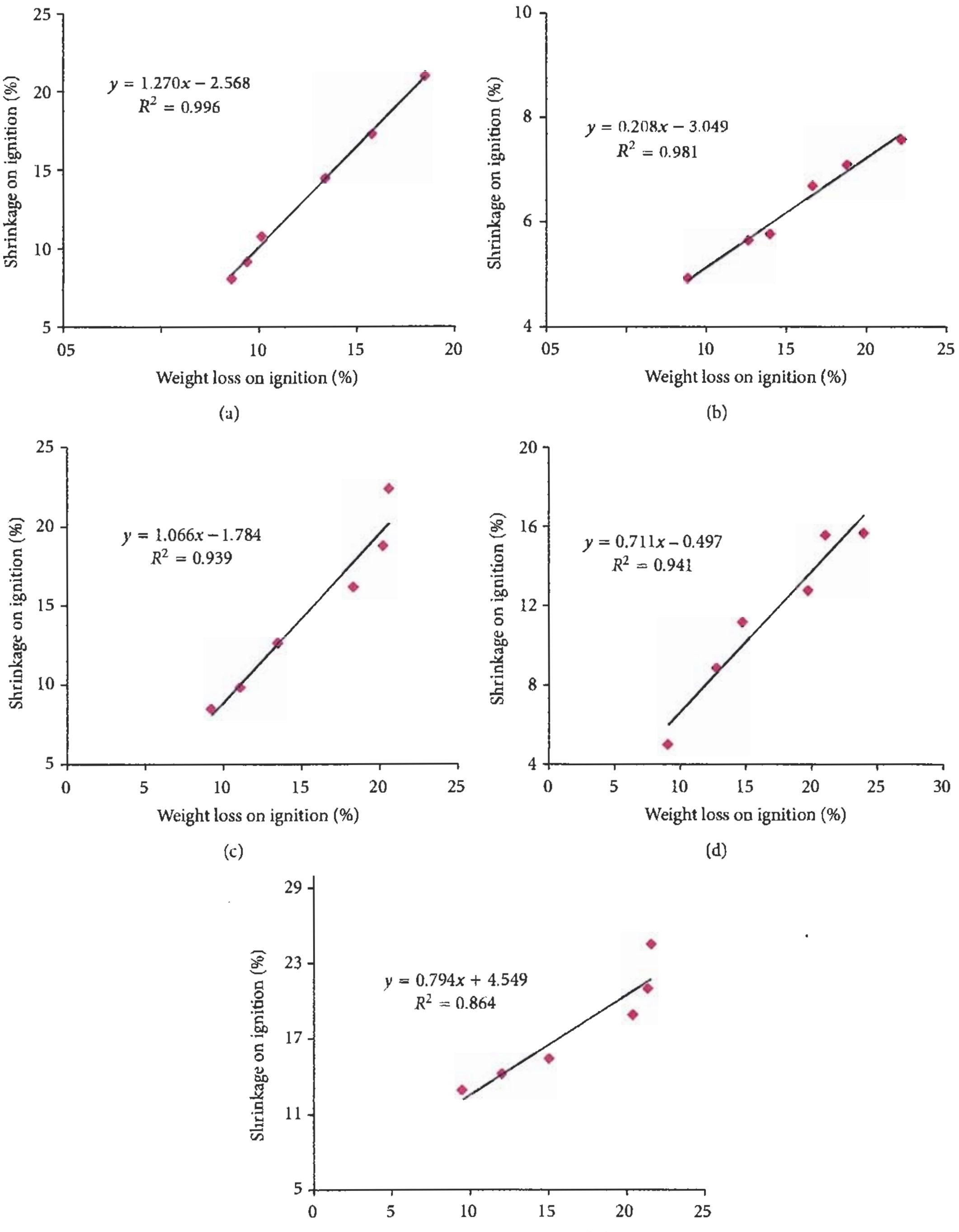


(a) (b)

Figure 5: Shrinkage on ignition of (a) NBB and (b) PBB at different EMHS percentages and firing temperatures.

structure of the BB must be strong enough to avoid the intrusion of much water. Water adsorption of NBB was related to the percentage of EMHS in mixtures (Figure 7). Increasing the firing temperature resulted in a decrease of water adsorption, thereby increasing the weathering resistance.

Water adsorption occurred in two stages. The first stage is characterized by the linear behavior of gains of mass of water with time. This phenomenon related to the larger capillary pores. In the second stage, the gains of mass of water with time followed a nonlinear behavior and the flow of water in materials occurs in the smaller capillary pores [37]. Water adsorption should be within 17% for the first class and 17 to 22% for the second class brick [35]. NBBs with 10% EMHS burnt at 1000–1050°C were in the first class category. NBBs with 10% EMHS fired at 950°C, 20% EMHS fired at 1000°C, and 20–30% EMHS fired at 1050°C fall within the second class



(a)

(b)

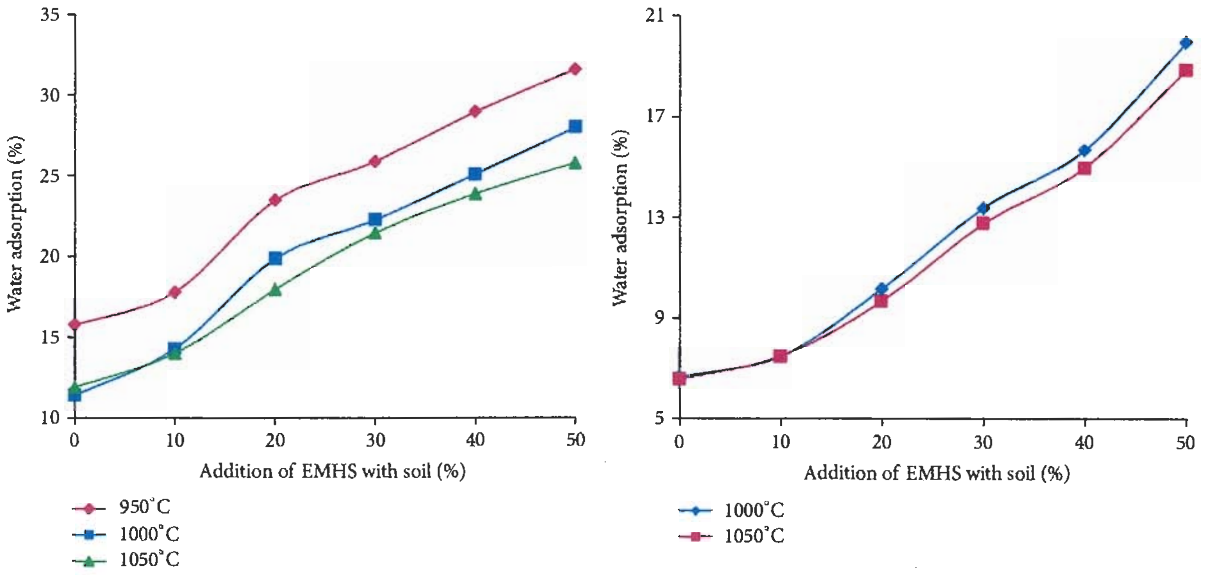
(c)

(d)

(e)

Figure 6: Relationship between weight loss and shrinkage on ignition of NBB at (a) 950°C, (c) 1000°C, and (e) 1050°C and PBB at (b) 1000°C and (d) 1050°C at different EMHS percentages.

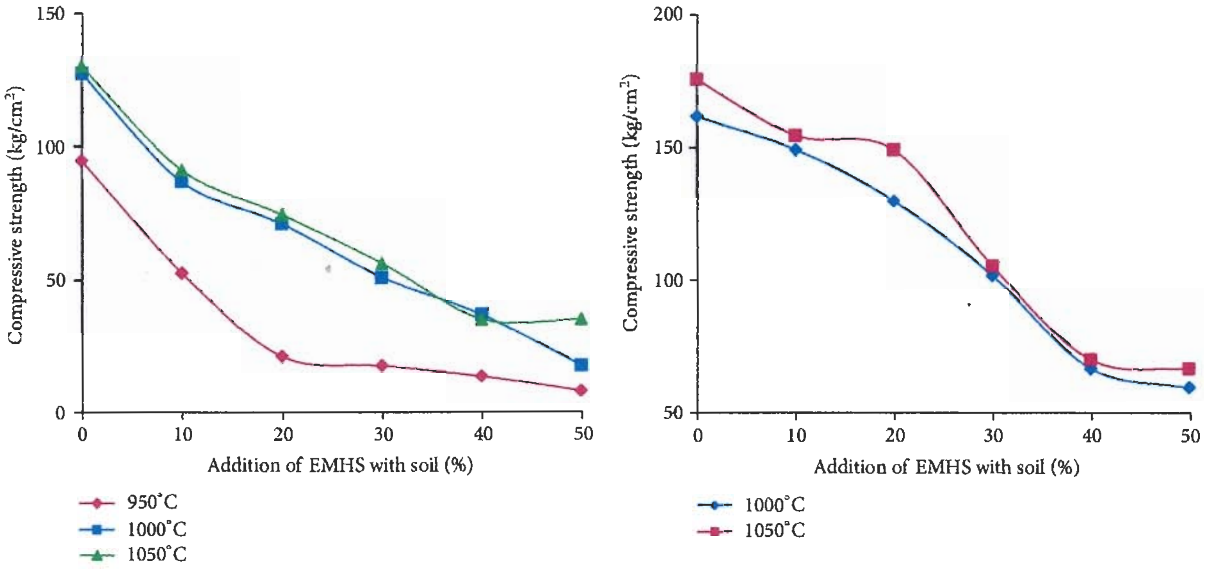
category. PBB fired at 1050°C containing with up to 40% of EMHS in mixture were first class products while 50% EMHS in the mixture was second class. Up to 30% EMHS with soil produced the first class BB at 1000°C (Figure 7). So, PBBs were more reliable than NBB in terms of water adsorption property. BB exhibited general compliance with some criteria for load bearing bricks under class 1 and 2 because there are no specific requirements in these classes [19].



(a)

(b)

Figure 7: Water adsorption of (a) NBB and (b) PBB at different EMHS percentages and firing temperatures.



(a)

(b)

Figure 8: Compressive strength of (a) NBB and (b) PBB at different EMHS percentages and firing temperatures.

3.6. Compressive Strength of NBB and PBB. All construction materials must resist stress and strength of a material indicated its ability to resist forces at failure. It was greatly dependent on the amount of EMHS in the BB and the firing temperature. It decreased with the increase of EMHS in the mixture but increased with the increase of firing temperature in case of NBB and PBB (Figure 8). Compressive strength 150 kg/cm^2 was set for the first class brick/block and 100 kg/cm^2 for the second class [35]. NBB containing only soil and fired at 1000 and 1050°C showed compressive strength of the second class brick. PBB with 10% EMHS and fired at 1050°C, reveled the first class standard [12]. NBB with 20% EMHS and PBB with 30% EMHS can be prescribed for the uses of nonloading purposes such as ornamental bricks, and decoration purpose, fence of garden.

There was a linear and statistically significant relationship among different properties of NBB with firing temperature and percentage of EMHS in mixtures (Table 2). Various

Table 2: R^2 values of different properties of NBB at different firing temperatures (950, 1000, and 1050°C) and percentages of EMHS in soil.

	R^2					
	0%	10%	20%	30%	40%	50%
Weight loss on ignition	0.95	0.97	0.96	0.95	0.89	0.96
Shrinkage on ignition	0.81	0.85	0.99	0.98	0.98	0.98
Compressive strength	0.81	0.83	0.8	0.85	0.97	0.68

metals' content in EMHS was subject to solidification in different BBs and hence ultimately reduced the disposal problem of metals containing sludge.

There are several mechanisms of solidification of heavy metals containing waste sludge [38] like *Physical Encapsulation*—as EMHS contained very small pores, it could encapsulate the contaminated particles; *Adsorption*—EMHS also contained a large number of micro and poorly crystallized pores, which led to a high specific surface area and so that heavy metal ions can be adsorbed on the poorly crystallized particles; *Precipitation*—the hydration products of cement such as $Ca(OH)_2$ led to a high alkaline environment and many heavy metals can be transformed to hydroxides which have a very low solubility. These hydroxides can be then precipitated on the surface of the hydration products, especially on the calcium silicate hydrates and in this way the heavy metals were immobilized.

4. Conclusion

The textile industry is treated as the flagship of Bangladesh for its contribution in top foreign exchange earning trade of the country. As the amount of sludge produced by wastewater or effluent treatment plant of such industries is increased, effective reuse and safe disposal of residue become a vital issue. Sludge accumulation is a burden to the industry and affects the environment adversely. Present study systematically investigated the reuse feasibility of EMHS from textile industry in the manufacturing of BB as a partial replacement of soil. To assess the quality weight loss on ignition, firing shrinkage, water adsorption, and compressive strength of the manufactured blocks were inspected. EMHS amount and firing temperature were two key factors determining the overall merits of products. Higher firing temperature and EMHS proportion in the mixture resulted in an increase in weight loss and shrinkage of BB. With the increasing firing temperature and less EMHS proportion, less water adsorption was observed. Compressive strength of BB increased with higher firing temperature and lower EMHS proportion. EMHS containing up to 20 and 30% for NBB and PBB, respectively, and fired at 1050°C produced good quality blocks and these blocks can be used for nonloading purposes. Therefore, EMHS seems to be reused feasibly in the manufacturing of building materials like BB.

Acknowledgments

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