Hindawi
Journal of Engineering
Volume 2023, Article ID 7607677, 7 pages
https://doi.org/10.1155/2023/7607677

Research Article

Production and Characterization of Bricks from Bottom Ash and Textile Sludge Using Plastic Waste as Binding Agent

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Received 8 September 2023; Revised 16 November 2023; Accepted 7 December 2023; Published 26 December 2023

Academic Editor: Ashish Nayak

The production of traditional clay bricks consumes a large amount of energy and resources and can lead to the depletion of natural resources like clay. On the contrary, the improper disposal of waste materials such as bottom ash, textile sludge, and plastic waste can lead to environmental pollution and health hazards. Bricks and concrete blocks have been widely used in construction, but the continuous exploitation of raw materials can negatively impact the environment. This study aimed to produce bricks made from municipal solid waste, incinerated bottom ash, and textile sludge, using plastic waste as a binder. It assessed the potential use of these bricks as an alternative material for brick block production. The physical and chemical characteristics of the raw materials were determined using standard test methods. The crushed plastic waste was melted and mixed with dried textile sludge and bottom ash in various ratios, including 1 : 1 : 1, 2 : 1 : 1, 1 : 2 : 1, 1 : 1 : 2, and 1 : 2 : 2 for plastic, municipal incinerated bottom ash, and textile sludge, respectively. The mixed sample was then placed into molds until it dried, and the resulting bricks were tested for compressive strength, water absorption, efflorescence, and leachability. The results indicated that the bricks had suitable physical and chemical properties, with compressive strength ranging from 8.527 to 16.4 MPa and water absorption percentages ranging from 1.3 to 3.4%. Slight efflorescence was observed for the 1 : 2 : 2 ratios. The production of traditional clay bricks consumes a large amount of energy and resources and can lead to the depletion of natural resources like clay. On the other hand, the improper disposal of waste materials such as bottom ash, textile sludge, and plastic waste can lead to environmental pollution and health hazards.

1. Introduction

The global urbanization trend and changes in lifestyle have resulted in a significant increase in solid waste generation. Unfortunately, a substantial portion of this waste is not properly recycled, leading to extensive dumping and inadequate waste management practices [1]. Sub-Saharan African countries, in particular, face significant challenges in waste management due to inadequate storage and collection systems, as well as a lack of disposal facilities, resulting in open dumping [2]. Insufficient data on waste disposal exacerbate the situation, suggesting that the actual volume of waste disposed through open dumping is even higher [3]. Ethiopia, for example, struggles with poor solid waste management practices [4].

Conventional waste disposal methods, such as landfilling, have several disadvantages, including high transportation costs, difficulty in finding suitable landfill sites, leaching of heavy metals into the soil, and the release of harmful gases [5]. Improper waste dumping near water bodies also leads to surface water pollution as toxic substances leach into the water during rainfall [6]. Therefore, there is an urgent need to find environmentally friendly alternatives for solid waste management.

One promising approach is the utilization of municipal solid waste incinerated bottom ash (MSWIBA) and textile sludge in the brick-making industry. MSWIBA refers to the residue remaining after waste combustion in power plants, boilers, furnaces, or incinerators. The brick-making industry has shown compatibility with various waste materials, as they can be incorporated into brick production [7]. Textile sludge, containing significant mineral compositions similar to cement, contributes to environmental pollution due to its high concentration of toxic heavy metals [8].

By incorporating these waste materials into brick production, it is possible to create a safe, inert, and useful medium that diverts solid waste from landfills [9, 10]. This approach offers a cost-effective building design solution while addressing the pollution concerns associated with waste disposal [11]. Previous research has explored the utilization of various waste materials as partial substitutes for traditional building materials, resulting in reduced raw material requirements and lower firing temperatures for bricks [12]. Furthermore, incorporating waste materials as binders in brick production has shown the potential to enhance the strength and durability of fired bricks without compromising quality [13].

This study focuses on the utilization of municipal waste incinerated bottom ash and textile sludge as key components in brick production. Different proportions of these waste materials, along with melted waste plastic as a cement substitute, were used to develop brick specimens. The study specifically targets the municipal solid waste generated from the Reppie waste-to-energy power plant, where well-managed disposal landfills are lacking, resulting in the disposal of byproducts in open landfills. Substituting conventional brick production raw materials with these waste materials presents a significant opportunity to protect natural resources and the environment from the adverse impacts of waste disposal.

In conclusion, this study aims to investigate the potential of utilizing municipal waste incinerated bottom ash and textile sludge in brick production as a sustainable solution to solid waste management. By incorporating these waste materials into brick production, not only can the challenges of waste disposal be addressed but also the waste can be transformed into valuable construction products. Through the adoption of environmentally friendly practices, a more sustainable approach to waste management can be established, promoting the conservation of natural resources for future generations.

2. Materials and Methods

2.1. Sample Preparation and Characterization

2.1.1. Sample Collection and Preparation. The MSWIBA sample was randomly collected from the Reppie waste-to-energy power plant in Addis Ababa, where approximately 1,400 tons are produced daily. The TS sample was obtained from Kanoria Africa Textile Plc. located near the Addis Ababa-Adama expressway. The low-density polyethylene (LDPE) waste plastic sample was sourced from local markets and households, considering the absence of a separate collection system. LDPE is one type of thermoplastics that have either linear or branched structures and can be amorphous or semicrystalline materials. These plastics can be remolded, reshaped, and reused. To do the study, segregation and sorting were necessary due to the mixed nature of household waste plastic.

The collected MSWIBA and TS samples were air-dried for one week to eliminate excess moisture. Subsequently, they were milled to reduce the particle size, ensuring uniformity for brick production. The LDPE waste plastic samples underwent a treatment process involving washing, sun-drying, and chopping into small pieces, facilitating the melting process as shown in Figure 1.

After the sample preparation steps, the dried MSWIBA, TS, and waste plastic samples were ready for mixing. Various proportions were determined based on the desired composition, bearing in mind the objective of the research to study the properties of produced bricks.

2.1.2. Characterization of Municipal Solid Waste, Incinerated Bottom Ash, and Textile Sludge. This subsection describes the characterization methods employed, such as pH determination ASTM-D4972-01 [14], loss of ignition (ASTM-D7348-13) [15]; sieve analysis, X-ray diffraction (XRD) for heavy metal detection, density determination GB/T 208-201 [16] and specific gravity Xade specific gravity of textile sludge (TS) was determined using the ASTM C128 [17] standard method, which involves the SSD (Saturated Surface Dry) method. In this method, the mass of a given volume of the sample is compared to the mass of an equal volume of water at 4°C.

This study provides a concise and comprehensive overview of the sample preparation methodology for alternative brick production using MSWIBA, TS, and waste plastic, and the proximate results of the raw materials are shown in Table 1.

2.2. Preparation of Brick and Characterization. In this study, the utilization of municipal waste, incinerated bottom ash, textile sludge, and plastic waste as substitutes for traditional bricks was investigated. The textile sludge and municipal waste incinerated bottom ash samples were dewatered and subjected to open-air drying until their weight reached a constant value. Subsequently, the textile sludge and bottom ash samples retained on the 4.75 sieve were crushed using a 1 mm crusher to attain uniform particle sizes.

The dried textile sludge and bottom ash were then added in predetermined ratios as shown in Table 2 (1 : 1 : 1, 2 : 1 : 1, 1 : 2 : 1, 1 : 1 : 2, and 1 : 2 : 2) along with the melted plastic waste. The plastic waste was melted on a plate until it transformed into a liquid state. The dried textile sludge and bottom ash were then added in accordance with the desired proportion, and the mixture was thoroughly hand-mixed for a duration of 5 to 8 minutes.

Following the mixing process, the mixture was placed into molds and allowed to dry, thereby forming bricks for further testing. Various tests were conducted on each

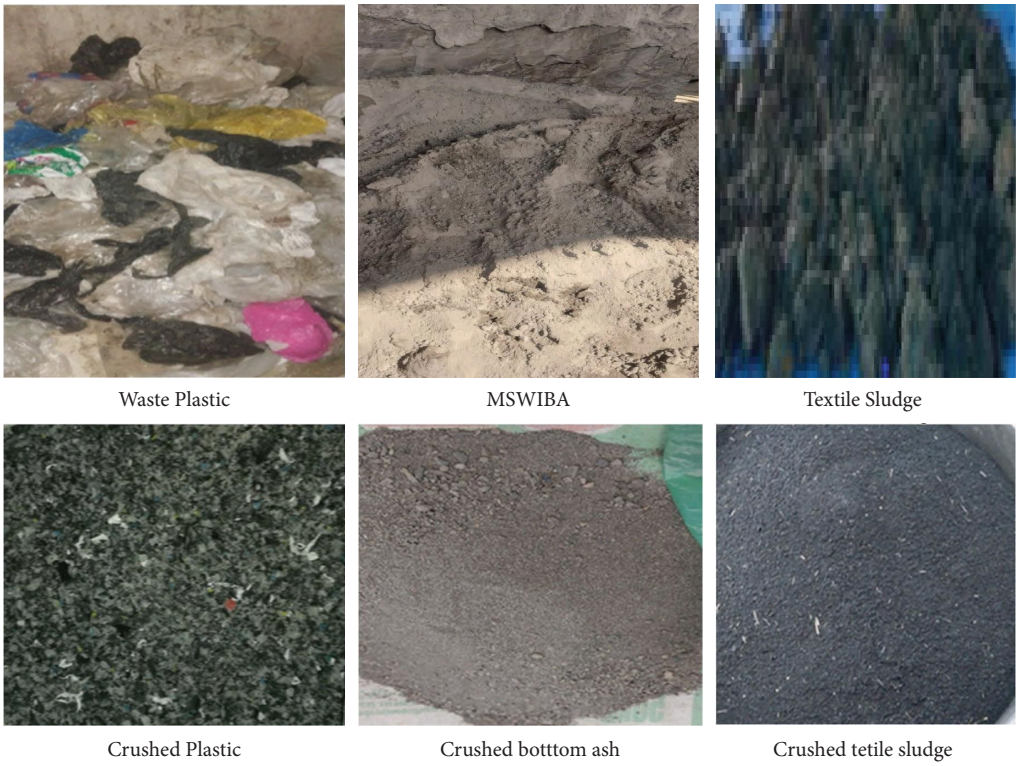

Figure 1: Material collection and preparation.

Table 1: Proximate analysis of MSWIBA and TS.

Properties	MSWIBA	TS
pH	8.55	11.34
Loss of ignition	44	4.5
Specific gravity	3.17	1.037
Moisture content	32.48	13.0789

combination of bricks, including compressive strength, water absorption, and efflorescence assessment.

Overall, this study examined the preparation methodology and evaluated the properties of bricks made from a combination of municipal waste, incinerated bottom ash, textile sludge, and plastic waste. The output of the mix design (the produced bricks) are shown in be Figure 2 below.

2.2.1. Water Absorption. The water absorption of the brick samples was determined by oven-drying them at 105°C for 24 hours. After cooling to room temperature, the bricks were submerged in distilled water at 27°C for 24 hours. Surface water was wiped off, and the weight of each brick was measured within 5 minutes of removal from the water bath. The water absorption was calculated based on the weight difference before and after the submersion process [18].

$$\text{Water absorption\%} = \frac{\text{Ws} - \text{Wd}}{\text{Wd}}, \tag{1}$$

where W_s = wet weight of the sample and Wd = dry weight of the sample.

2.2.2. Compression Strength Test. The sample of produced brick was placed in the compression strength testing machine. After placing it, the load was applied to the brick without any shock. The load was increased at a rate of 140 kg/cm^2 per minute continuously until the specimen's resistance to the increasing load broke down, following the guidelines of the Indian Standard 3495: 2002 (method of testing of burnt clay building brick) published by the Bureau of Indian Standards, New Delhi. The equation (2) used to conduct the compressive test.

$$\text{Compressive} = \frac{\text{maximum load applied (KN)}}{\text{initial cross sectinal area (mm2)}}. \tag{2}$$

2.2.3. Flexural Strength Test. The flexural strengths of $40 \times 40 \times 160$ mm mortar specimens were determined using the ASTM C78/C78M test method. Three specimens were cast from the same mortar batch, cured, and placed on support blocks of a four-point loading device with a 120 mm distance between the outer loading points. The load was applied at a constant rate to the center of each specimen until failure, recording the maximum load and corresponding deflection. Flexural strength was calculated for each specimen, and the average strength of the three specimens was reported (ASTM C78/C78M).

$$\text{Flexural strength} = \frac{3\text{PL}}{(2bd\wedge 2)}, \tag{3}$$

Table 2: Mix design and setup.

Experimental trial	Plastic (%)	Bottom ash (%)	Textile sludge (%)	Ratio of plastic to other material
1	33.333	33.333	33.333	1 : 2
2	50	25	25	1 : 1
3	25	50	25	1 : 3
4	25	25	50	1 : 3
5	25	50	50	1 : 4

where P is the maximum load, L is the span length between support points, b is the width of the specimen, and d is the depth of the mortar.

2.2.4. Leachability Test of Bricks. The leaching of toxic heavy metals from textile sludge-based bricks was investigated. The bricks were immersed in water for a specific duration, and the resulting leachate was analyzed using the FAAS analysis method to determine heavy metal concentrations. The leaching process involved the dissolution of soluble constituents from the bricks into the contact water phase. Assessing the concentration of leached heavy metals was crucial for evaluating the potential environmental impact. The FAAS analysis method was employed to precisely quantify the heavy metal concentrations in the leachate.

2.2.5. Effloresce Test. The presence of alkalis in bricks, which can be harmful, was detected. Alkalis often result in the formation of grey or white patches on the brick surface. A flat-bottom container with sufficient distilled water was utilized. The brick was immersed in distilled water, with an immersion depth of 25 mm, and left for a day. To prevent excessive evaporation, the container was covered with a plastic sheet. Subsequently, the brick was removed from the container and allowed to dry for the same duration, corresponding to the amount of water that evaporated from an open container without the brick or the sheet, following the standard guidelines of 3495, 2002 (part: 2)

Figure 2: Image of produced brick.

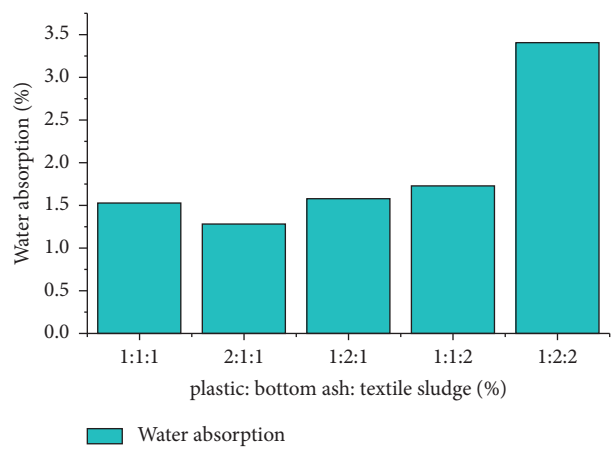

Figure 3: Water absorption.

3. Results and Discussion

3.1. Water absorption. The water absorption percentages of different brick ratios were determined and higher percentages of textile sludge and bottom ash resulted in increased water absorption. As illustrated in Figure 3, sample 5 with a ratio of 1 : 2 : 2 of plastic, bottom ash, and textile sludge exhibited the highest water absorption percentage of 3.4%. However, even with this higher percentage, the material still outperforms conventional bricks, which typically have around 20% water absorption. The plastic bottom ash and textile sludge mixture demonstrated significantly lower water absorption, making it a desirable construction material. Previous studies by Priyadharshini [19] and Kasaw et al. [20] also observed increased water absorption with higher percentages of textile sludge. Additionally, the authors of [21] found that as the plastic percentage increased, water absorption decreased.

3.2. Compressive Strength of Brick. The compressive strength of the plastic bottom ash and textile sludge mixtures was found to be comparable to that of conventional bricks, which typically have a compressive strength ranging from 7 to 21 MPa. Increasing the proportion of bottom ash generally improved the compressive strength, while reducing the proportions of plastic and textile sludge. Sample 3 with a ratio of 1 : 2 : 1 exhibited the highest compressive strength of 16.4 MPa, followed by sample 2 with a ratio of 2 : 1 : 1 at 12.96 MPa. Sample 5, with the highest percentage of textile sludge and plastic and the lowest percentage of bottom ash, had a lower compressive strength of 8.527 MPa (Figure 4). It should be noted that specific compressive strength values may vary across studies due to different testing methodologies and materials used in the research.

For instance, the authors of [22] reported compressive strength values for textile sludge-incorporated bricks ranging from 2.73 to 30.43 MPa, with a decrease in strength

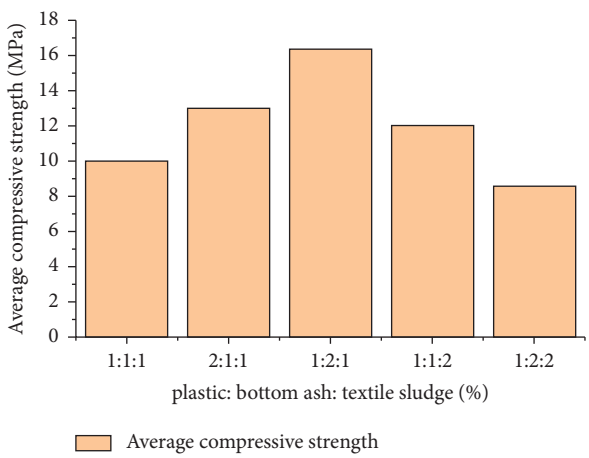

Figure 4: Compressive strength of brick.

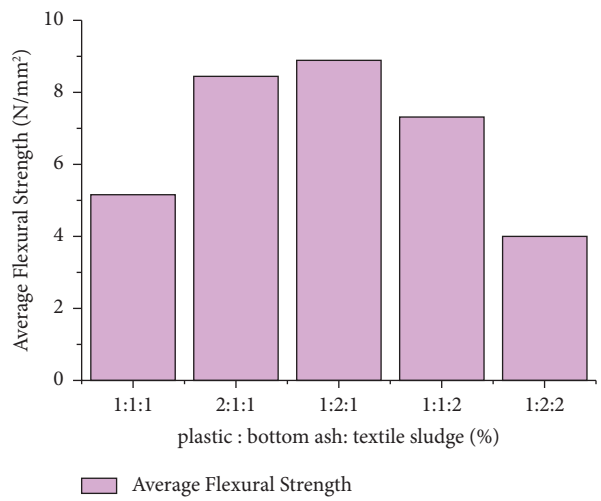

Figure 5: Flexural strength test.

as the percentage of textile sludge increased. Similarly, the authors of [20] found that the compressive strength of incinerated textile sludge bricks decreased with higher percentages of incinerated textile sludge. The authors of [19] observed a decrease in compressive strength with increasing textile sludge percentage in burnt bricks.

3.3. Flexural Strength Test. The flexural strength of the mortar specimens ($40 \times 40 \times 160$ mm) was determined using the ASTM C78/C78M test method. Three rectangular beam specimens were cast from each mortar mixture. The flexural strength varied depending on the percentage of plastic, bottom ash, and textile sludge used in each mixture. Specimen 3, with a ratio of 1 : 2 : 1, exhibited the highest average flexural strength of 8.9374 N/mm^2 (Figure 5). Specimen 2, with a ratio of 2 : 1 : 1, showed a relatively high average flexural strength of 8.40622 N/mm^2. Conversely, specimen 5, with a ratio of 1 : 2 : 2, had the lowest average flexural strength of 3.983 N/mm^2. Specimen 1 (ratio 1 : 1 : 1) and specimen 4 (ratio 1 : 1 : 2) had similar average flexural strengths of 5.132475 N/mm^2 and 7.3155 N/mm^2, respectively. Figure 5 presents the details of the results of the flexural strength test.

In summary, the flexural strength of the mortar was significantly influenced by the ingredient ratios. Higher percentages of bottom ash contributed to increased flexural strength, while higher percentages of textile sludge resulted in decreased flexural strength.

3.4. XRD Raw Material Heavy Metal Content Result. Table 3 shows that the concentrations of heavy metals in both sludge and bottom ash samples are significantly higher than the permissible limits set by WHO, indicating potential environmental and health hazards. The toxic heavy metals obtained in the order of highest to lowest concentration are Fe, Zn, Pb, Cd, and Cr, and the concentrations of Fe and Zn in both sludge and bottom ash are high. Among the toxic heavy metals, chromium and cadmium are of particular concern due to their known toxicity and potential for bioaccumulation in the food chain. The high concentration of chromium in the sludge sample is alarming, as it is a known carcinogen and poses significant health risks to humans and wildlife.

Table 3: XRD heavy metal result.

Analytes	Chemical analysis	Bottom ash (ppm)
Cd	7229.62	46.549
Pb	21102.71	45.011
Zn	46041.14	146.049
Fe	228425.47	1604.393
Cr	44324.25	71.568

3.5. Leachability Analysis. Table 4 provides information on the heavy metal content (in ppm) in different mixtures of plastic, bottom ash, and sludge and compares them with the regulatory limits set by the USEPA for these metals.

The leachability test was conducted on two samples, one with a high amount of textile sludge and the other with a low amount of textile sludge. This specific selection was made due to the high concentration of heavy metals present in textile sludge. By testing samples with both high and low concentrations, we can make generalizations about the leaching behavior of heavy metals. It observed that the heavy metal concentrations in most of the sample elements are below the regulatory limits set by the USEPA. For example, the concentrations of chromium, cadmium, and zinc in all samples are below the regulatory limits, which indicate that these metals are not a significant concern in the mixtures. The lead concentration in sample 2 (2 : 1 : 1) is slightly above the regulatory limit, but it is within acceptable limits. On the other hand, the iron concentration in all samples is higher than the regulatory limit, but this is not a concern as iron is not considered a toxic heavy metal and is commonly found in soil and rocks. Similarly, the amount of these toxic heavy metals decreased significantly, as observed by Basheh et al. [22] and Zhan et al. [23] Kassaw [20]. As illustrated in Figure 6, FAAS analysis method was employed to precisely quantify the heavy metal concentrations in the leachate.

Table 4: Leach analysis result.

Metals	Heavy metal content (ppm)		USEPA regulatory limit (ppm)
	Plastic : bottom ash : sludge (1 : 2 : 2)	Plastic : bottom ash : sludge (2 : 1 : 1)	
Chromium (Cr)	ND (nondetectable)	ND	5
Lead (Pb)	ND	0.0442	5
Iron (Fe)	0.8654	1.2142	11
Cadmium (Cd)	ND	ND	100
Zinc (Zn)	ND	ND	500

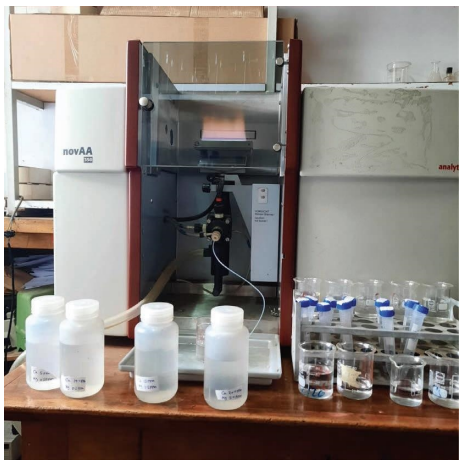

Figure 6: FAAS testing.

3.6. Efflorescence Test. During the efflorescence test observation, slight efflorescence was observed in the plastic sand brick with a ratio of 1 : 1 : 2 for plastic, bottom ash, and textile sludge. This minimal efflorescence can be attributed to the lower presence of soluble salts in the plastic component. The results demonstrate a significant reduction in efflorescence for the plastic brick, indicating compliance with the Bureau of Indian Standards, New Delhi, 2002.

Considering efflorescence in construction can have several potential implications because it can significantly affect the aesthetics of construction materials and surfaces. The white, powdery deposits can make walls, bricks, concrete, or other masonry look unsightly and dirty, and also, it can affect the structural integrity even if efflorescence by itself does not directly impact the structural integrity of construction materials, and it can be an indication of underlying moisture-related issues.

The presence of efflorescence suggests the migration of water and salts through the material. Over time, repeated cycles of moisture absorption and drying can potentially lead to damage, such as cracking, or deterioration of the material, which can compromise its structural stability, and it has the ability to affect the durability in long term through salts that accumulate on the surface can absorb moisture, and when this moisture evaporates, it can leave behind salt crystals. The growth and contraction of these crystals can cause microcracks within the material, making it more susceptible to water penetration, freeze-thaw damage, and other environmental stresses. Over time, this can accelerate the aging and deterioration of the material, reducing its lifespan. So, using low efflorescence material during construction can eliminate those problems.

4. Conclusion

In conclusion, the bricks produced from the mixture of raw materials had acceptable compressive strength, efflorescence, and hardness, indicating that they could be used for construction purposes. It is a promising solution for solid waste management and environmental conservation. The study showed that the bricks produced from the mixture of raw materials had acceptable physical and chemical properties, and their potential use as an alternative material for the production of brick blocks was demonstrated. The use of these bricks can help reduce the environmental impact of waste disposal and contribute to sustainable development. Further research will be needed to assess the major properties and performance of bricks for long-term impact and investigate the suitable technologies that make the brick-making process easiest and optimize the composition and ratios of the raw materials, including plastic waste, municipal solid waste incinerated bottom ash (MSWIBA), and textile sludge (TS).

Data Availability

The data supporting the current study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Israel Tessema and Zena Fantahun generated the idea and designed the study. Zena carried out the data collection, data analysis, and write-up. Israel provided statistical assistance and read and revised the manuscript. Finally, all authors read and approved the final version of the manuscript.

Acknowledgments

We wish to express our profound gratitude to Addis Ababa Science and Technology University for their laboratory support in accomplishing this paper.

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