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Sustainable Utilization of Textile Dyeing Sludge and Coal Fly Ash by Brick Production Through Traditional Kilns

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ABSTRACT

The fundamental purpose of this study was to evaluate the technical feasibility of incorporating fly ash (FA) and dyeing sludge (DS) in the production of brick. An attempt was taken to replace 10% to 100% clay by DS and FA in brick-making by volume. A brick firing kiln was used to burn the uniform-shaped bricks after replacing clay with DS and FA. Size and shape, hardness, soundness, water absorption, efflorescence, dry density, loss of ignition, firing shrinkage, specific gravity, compressive strength, and leaching tests were carried out to study the properties of these bricks. The compressive strength of the brink ranged from 6.25 MPa to 0.33 MPa and indicates a decreasing pattern in strength with the increase in the volume of DS and FA. Only 18.8% water absorption capacity was found in control bricks without DS and FA, while a maximum absorption of 40.19% was found for a particular combination of DS and FA. Similarly, dry density decreased with the increase in the volume of DS and FA. Besides, efflorescence in bricks was found within the allowable limits for certain combinations of DS and FA, which exceeded the allowable limits for other combinations. The presence of heavy metals (Ni, Zn, Cr, Cu, and Pb) in the extraction solution was insignificant. Based on the results of this study, we recommend that up to 10% clay can be substituted with DS and FA without substantially affecting the quality of bricks.

INTRODUCTION

The textile sector plays an invaluable role in facilitating job creation, tax collection, and economic growth in many developing countries like Bangladesh. Considering the significant presence of textile industries in Bangladesh and many other countries, it is important to address the adverse environmental effects that these industries. Textile operation includes the refining or conversion, by various methods, of raw resources into finished products that involve the use of a high volume of water and the generation of wastewater that requires treatment before disposal. In Bangladesh, approximately 1500 textile industries produce about 2.82 million cubic meters of effluent daily (Concern 2014). The accelerated growth of the textile industry over the past decades and the discharge of untreated or poorly treated effluent into the environment has become a serious environmental concern. The volume of wastewater from textile industries is projected to cross 349 million m^3 by 2021, if traditional dying activities remain in use, from an estimated amount of 217 million m^3 in 2016 (Hossain et al. 2018). Earlier research reported that the concentrations of contaminants in textile effluent exceed the national discharge standards (Ahsan et al. 2019).

Apart from effluent from textile industries, the management of sludge generated during the treatment of textile wastewater is also becoming a major concern. Many textile industries are finding it difficult to manage the sludge generated at their effluent treatment plants (ETPs) (Gomes et al. 2012). Textile sludge typically contains high amounts of metal ions and phosphorus, potassium, and nitrogen from chemical agents used in different phases of textile dyeing/processing [in particular aluminum (Al) and iron (Fe) from coagulants, flocculants depending upon the treating process] (Ghaly et al. 2014). Conventional treatment of textile effluent has the potential to contribute approximately 1.14 kg of sludge per cubic meter of effluent treated (Concern 2014). Uncontrolled disposal of textile sludge at landfills or waste dumping sites can, therefore, cause contamination of water and soil (Ashraf et al. 2014).

Diverse approaches for sludge treatment exist in developing nations to minimize sludge mass and decrease possible health risks associated with sludge disposal and treatment. Popular processing and disposal approaches in developing countries include incineration, composting, and landfilling (Guha et al. 2015). Landfilling of textile sludge could significantly contribute to the pollution of air, water, and soil (Iqbal et al. 2014). Incineration of solid sludge necessitates the use of an appropriate furnace, fuel, and specialized/trained personnel; possible air pollution from incineration is a major concern. Landfilling and composting are often not the preferred sludge management methods due to the presence of heavy metals and volatile organic compounds in sludge (Patel & Pandey 2009). Consequently, appropriate treatment and processing of such sludge are needed for sustainable management (Liew et al. 2004). Research works have been carried out for the treatment/processing of various industrial sludge, including sludge from the paper factory (Goel & Kalamdhad 2017), tannery industries (Juel et al. 2017), water treatment (Ponkarthikeyan et al. 2016), etc. Several studies have been undertaken for processing or stabilizing toxic sludge as a substitute for soil in fried clay bricks and tiles. Balasubramanian et al. (2006) reported that specimens of sludge-cement did not reach the requirements for structural use; however, quality as well as other characteristics of certain products e.g., paving tiles and blocks, were acceptable for non-structural uses. Jahagirdar et al. (2013) proposed that sludge could be used in various building products at a maximum of 15%; the durability was, nonetheless, decreased to near 3.5 MPa. On a lab scale, most of the studies showed favorable outcomes for bricks in a controlled environment, however, limited experiments were conducted to manufacture bricks in the kiln (Juel et al. 2017).

Coal is the world's most important and plentiful fossil fuel. The fly ash (FA), produced throughout the coal combustion process in the thermal electricity generation, is one of the byproducts which contributes to significant environmental pollution. It has been estimated that the global generation of fly ash is around 0.60 billion tons each year. Its consumption has not matched the growing amount of fly ash generated worldwide. In comparison with their production, the consumption of FA is far less. The most significant and widespread application of fly ash in Bangladesh is the partial substitution in Portland cement, clay, and the production of construction materials. Numerous studies into the utilization of FA as a substitute raw resource in the production of new materials are being undertaken around the World (Behera et al. 2014). Many scholars have researched the application of FA in bricks made from clay (Balasubramaniam et al. 2021, 2006). FA is suitable for 10% lighter brick manufacturing in comparison with clay bricks (Moyo et al. 2019). FA often possesses pozzolanic properties, which further improve durability and decrease absorption of water (Yao et al. 2014). Leiva et al. (2016) reported that FA bricks improved their strength properties at 1000 °C, and claimed that FA bricks have superior heat resistance to traditional clay bricks.

Brick is the most prominent and common building material being used worldwide. A variety of bricks are being used as a building material, e.g., sundried or unburnt clay brick, FA brick, burnt clay brick, sand-lime or calcium silicate brick, and concrete brick. Clay-fired bricks are mostly utilized as a traditional building material in most developing countries. Because burnt clay bricks are stronger than sun-dried clay bricks. Using topsoil of agricultural lands is the traditional method of obtaining the clay needed for the manufacture of bricks (Biswas et al. 2018). Environment-friendly alternatives to clay for brick making might be a solution to maintain soil fertility and topsoil. With the exception of financial growth and the conservation of agricultural fertile land, the replacement of clay with textile dyeing sludge (DS) and FA often achieves the sustainable goal of safe disposal of waste materials (Moyo et al. 2019).

To the best of our knowledge, textile dyeing sludge (DS) and coal fly ash (FA) are not experimented with together in brick making. In the current study, we focused on the use of DS and FA together in brick manufacturing. The prime focuses of this study were (i) sustainable utilization of DS and FA in brick making with the partial replacement of clay, (ii) burning the DS-FA clay bricks in a traditional kiln, and (iii) investigating its influence on several mechanical and durability properties, and (iv) to examine the leaching of heavy metals from the developed bricks.

MATERIALS AND METHODS

Materials Collection

Textile dyeing sludge (DS) and Coal fly ash (FA) have been used as partial replacements for clay for making bricks, and the properties of these bricks have been evaluated to assess the potential use of DS and FA in bricks. DS was collected from the biological effluent treatment plant of Epyllion Fabrics Limited, Gazipur, Bangladesh which has a capacity of dyeing 30000 kg of textile/day. On the other hand, FA was collected from the coal used in a Barapukuria Thermal Power Plant (BTPP), Dinajpur, Bangladesh; clay was collected from the local area of Gazipur, which is used to manufacture bricks in brickfields.

Materials Characterization

Collected DS was dewatered using sunlight for three days, and pulverized followed by oven-drying at 110ºC for 24 hours to analyze physical and chemical properties. DS, FA, and clay were diluted by distilled water at a ratio of 1:5 and mixed completely using a mechanical shaker to test physio-chemical parameters. The blend was then filtered by Whatman filter paper and tested for pH and EC using a digital multimeter (Multi 3430). Chloride and sulfate concentrations of the diluted samples were determined by the Mohr method and a Spectrophotometer (HACH DR-2800), respectively. Besides, the physical properties of the samples were determined according to ASTM D854-00 and ASTM D

2216. Atterberg limits of the mixed materials were computed following ASTM D 4318. Also, the chemical composition of DS, FA, and clay was quantified using X-Ray Fluorescence (XRF) analysis (Shimadzu XRF-1800). Additionally, the concentration of heavy metals in DS was determined using atomic absorption spectrophotometer (AAS). An acid extraction procedure (aqua regia) was employed to digest the solution to quantify the concentrations of heavy metals (Santoro et al. 2017).

Experimental Design and Brick Making

Ten different combinations of clay, DS, and FA have been used to fabricate bricks with three replications of each presented in Fig. 1. Brick, which is made of clay only, has been considered as a control or reference brick. The volume of clay was replaced by DS and FA up to 100% gradually, as presented in Table 1. A wooden mold of 254×127×76 mm was used to cast and shape the brick. Water was added depending on the nature of the raw material and their plasticity and it was 1920, 1950, 2050, 2130 2240, 2350, 2450, 2660, 2800, 2920, and 3000 ml in C-0, C-1, C-2, C-3, C-4, C-5, C-6, C-7, C-8, C-9, and C-10, respectively. After the formation of brick, they were sun-dried for 6 days to remove the free water and burnt in the conventional brick kiln for 15 days at 2100°F (approximately).

Field and Laboratory Tests of Brick

Field tests have been carried out according to ASTM C134-95, ASTM C88, and the fingernail scratch method. The compressive strength and water absorption capacity of fabricated brick were determined according to ASTM C67M-21. After curing, their frog marks were filled and

(a) (b) (c)

Fig. 1: Brick making, (a) wooden mold, (b) sun-dried bricks, (c) burnt bricks.

Table 1: Combination of materials for brick fabrication.

Combination ID	No. of replications	Volumetric percentage of material		
		Clay	Dying sludge (DS)	Fly ash (FA)
C-0	3	100	0	0
C-1	3	90	5	5
C-2	3	80	10	10
C-3	3	70	15	15
C-4	3	60	20	20
C-5	3	50	25	25
C-6	3	40	30	30
C-7	3	30	35	35
C-8	3	20	40	40
C-9	3	10	45	45
C-10	3	0	50	50

flushed by 1:4 thin cement sand mortar. Then the bricks were cut into two equal pieces along their lengths before tests for compressive strength (Fig. 2). On the other hand, efflorescence and specific gravity (for brick chips or coarse aggregate) were determined following ASTM C67M-20 and ASTM 127-15 methods. Some other physical properties of the fabricated bricks, i.e., loss of ignition (LOI), dry density, firing shrinkage, and thermal conductivity, were determined according to ASTM D7348-13, ASTM C20-00, ASTM C210-95, and ASTM C177-19 methods, respectively. The heavy metal leaching test of brick was tested for all combinations where the European standard method stated at prEN 1744-3:2000 was followed. Leachate was collected on the 1st, 4th, 7th, 15th, and 30th days after curing in distilled water.

RESULTS AND DISCUSSION

Replacing the clay with more than 70% by DS and FA made the brick too soft at the time of burning, the combination from C-8 to C-10 was found unburnable whereas bricks of other combinations (C-0 to C-7) could be burnt. That is why the results of C-0 to C-7 have been taken, analyzed, and presented in this study.

Characteristics of Materials

The pH of DS, FA, and clay was found to be 6.45, 6.8, and 7.11, respectively, indicating that the pH of all raw materials is in the neutral range. From a previous study, it has been found that pH DS and FA are 6.9and 6.2, respectively (Gebrati et al. 2019). The EC values of DS, FA, and clay are 4.06, 0.25, and 0.72 mS.cm^{-1}, respectively. The specific gravity of DS, FA, and clay was found to be 1.36, 2.30, and 2.84, respectively. The specific gravity of the DS and FA is less than clay; therefore, the addition of these materials can reduce the subsequent unit weight of the material.

The porosity of DS, FA, and clay was found to be 60%, 48%, and 37%, respectively (Table 2). The porosity of DS and FA has been found comparatively higher than clay, which indicates the liquid limit of DS and FA would be higher than clay. Sulfate concentration in DS and FA was 14.40 mg.kg^{-1} and 4.80 mg.kg^{-1}, respectively, whereas it was found below the detection limit in the clay. On the other hand, the existence

(a) (b) (c)

Fig. 2: Testing properties of brick, (a) prepared bricks for a compression test, (b) mortar layered brick, (c) crushing strength test using UTM.

Table 2: Characteristics of raw materials.

Parameter	Unit	Raw materials		
		Dyeing sludge	Fly ash	Clay
pH		6.45	6.80	7.11
EC	mS.cm^{-1}	4.06	0.32	0.72
Specific gravity		1.36	2.30	2.84
Moisture content	%	89.00	00.03	15.71
Porosity	%	60	48	37
Void ratio		1.50	0.92	0.58
Dry density	kg.m^{-3}	850.50	1554	2072
Chloride	mg.kg^{-1}	182	12	9
Sulphate	mg.kg^{-1}	14.4	4.8	Nil

of chloride and sulfate indicates the presence of salt that can give rise to efflorescence (Sing et al. 2018).

The major chemical components of brick clay are silica, alumina, iron oxide, magnesia, lime, and alkalis (Šveda et al. 2017). In this study, it has been observed that silica content in clay and FA were 65.40% and 64.19%, respectively, which presents good quality sample characteristics (Punmia et al. 2004). However, the silica content in DS was very low (29.26%) compared to the other two samples (Fig. 3). Besides, alumina determines the plasticity in the soil, where 20 to 30% alumina is suitable for brick. Higher than this range can make the brick too hard or brittle (Punmia et al. 2004). The alumina content in clay, FA, and DS has been found at 12.08%, 22.69%, and 0.70%, respectively. It indicates the unsuitability of DS for brick manufacturing because of the low amount of alumina. The effect of moisture on the plasticity of the pulverized materials has been evaluated by the Atterberg limits test. In the current study, PI decreased with the increase in the volume of DS and FA (Fig. 4). The highest PI was found to be 17.2% in the control combination, whereas the lowest was 9.38% in the combination of 30% clay, 35% in DS, and 35% in FA. In general, a plasticity index (PI) greater than 23 is suitable for good-quality bricks.

Heavy metal content i.e., nickel, zinc, chromium, copper, and lead in dry DS was determined after extraction through acid digestion (aqua regia) by AAS. The concentration of Zn, Cu, Cr, Pb, and Ni were found at 177, 314, 1.0, 2.4, and 10.4 $mg.kg^{-1}$, respectively (Table 3).

The existence of unwanted heavy metals in brick might be an issue of concern if it comes out with water or leach. It may be a good technique to handle sludge containing heavy metals by brick-making at a low cost if it does not leach metals (Kadir et al. 2018).

Field Investigations of Brick

The relative size of a brick (average of 3 combinations) made utilizing FA and DS was almost similar up to combination C-3 compared to the control bricks (Table 4). From visual observation, no porous surface was found in the bricks of

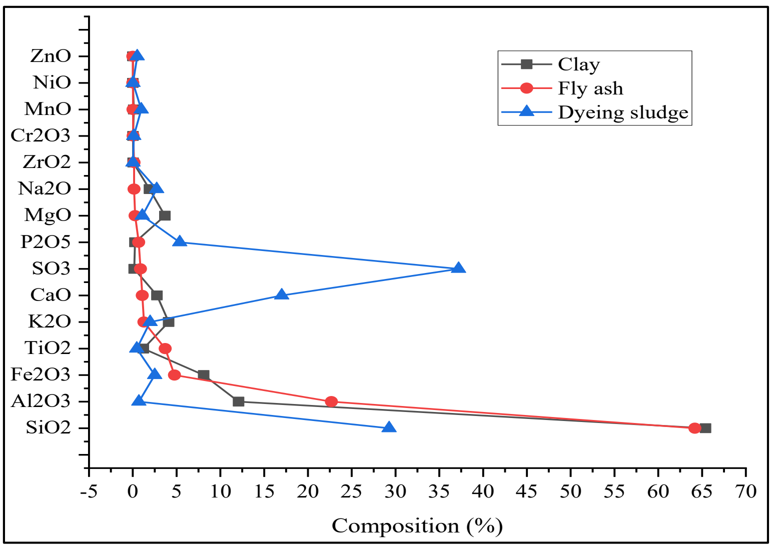

Fig. 3: Chemical compositions dyeing sludge, fly ash, and clay.

Table 3: Heavy metal concentration in textile dyeing sludge.

Heavy metal	Unit	Concentration
Zn	$mg.kg^{-1}$	177
Cu	$mg.kg^{-1}$	314
Cr	$mg.kg^{-1}$	1.00
Pb	$mg.kg^{-1}$	2.40
Ni	$mg.kg^{-1}$	10.40

Table 4: Results from field investigation of fabricated brick.

Combination	Dimension of brick [mm]	Soundness	Hardness	Structure
C-0	241.10 × 113.17 × 69.78	Metallic	Hard	Non-Porous
C-1	241.50 × 114.76 × 70.11	Metallic	Hard	Non-Porous
C-2	243.28 × 114.60 × 70.12	Metallic	Hard	Non-Porous
C-3	246.22 × 116.67 × 70.77	Metallic	Hard	Non-Porous
C-4	246.43 × 117.10 × 71.26	Metallic	Hard	Non-Porous
C-5	246.50 × 117.59 × 71.67	Metallic	Hard	Non-Porous
C-6	247.10 × 118.17 × 72.60	Non-Metallic	Not Hard	Porous
C-7	247.41 × 118.29 × 72.42	Non-Metallic	Not Hard	Porous

combination C-1 to C-5. However, fabricated bricks of combination C-6 and C-7 showed a negligible amount of pore space on their surfaces. The porosity of brick affects not only its strength but also density, thermal conductivity (Fig. 5f), specific gravity, and water absorption capacity (Šveda et al. 2017).

Brick specimens of combination C-0 to C-5 are sufficiently hard when it was tested by the fingernail scratching method, whereas C-6 and C-7 have been found comparatively less when scratch marks were visualized during fingernail scratching.

Laboratory Test Results of Brick

It is observed that the water absorption capacity of bricks increased with an increase in the volume of DS and FA (Fig. 5a). It is 18.8% in control, whereas it increased up to 40.2% in the C-7 combination. The recommended water absorption for good brick ranges from 15% to 20%. From a previous study, 14% and 27% water absorption capacity was calculated when mixed by 6% and 30% textile DS, respectively (Baskar et al. 2006).

In this study, it was found that the specific gravity (from brick chips) ranges from 2.40 to 1.99 for combinations of C-0 to C-7, respectively (Fig. 5b). The decreasing pattern of specific gravity of brick chips is in agreement with the previous result during material characterization (Table 2).

The weight loss of the bricks during burning is mostly due to the organic and the inorganic compounds because organic compounds in the compact specimen can gasify and/or oxidize to CO_2 and H_2O while the $CaCO_3$ decomposes at high temperature (Wang et al. 2011). For a standard clay brick, the maximum weight loss on ignition (LOI) criterion is 15% (Juel et al. 2017), whereas the brick up to C-5 combination reaches the standard in the current study (Fig. 5c).

From the experimental results, it is also observed that dry density ranges from 1.43 $g.cc^{-1}$ to 0.95 $g.cc^{-1}$ for combinations C-0 to C-7. Also, the dry density decreased with the increase of the volume of DS and FA (Fig. 5d). A proportional relationship between the dry density and waste materials (FA and DS) has been observed, with the obvious reason being textile DS and FA. The dry density was 1.45 $g.cc^{-1}$ for bricks made with 35% of sludge with clay in this study, whereas a dry density of 1.80 $g.cc^{-1}$ was reported in a previous study (Jahagirdar et al. 2013).

Compressive strength is the most significant characteristic for determining a construction material's engineering application. It was observed that compressive strength declined from 6.25 MPa for combination C-1 to 0.33 MPa for combination C-7. The compressive strength of the control combination was found to be 6.64 MPa (Fig. 6).

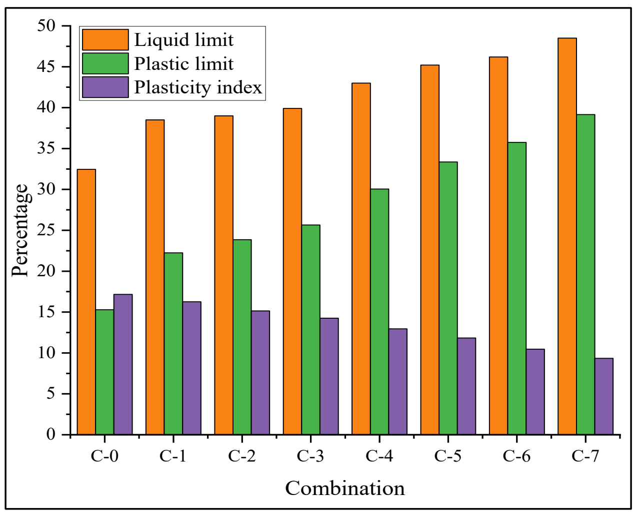

Fig. 4: Atterberg limits of the combinations of clay, DS and FA.

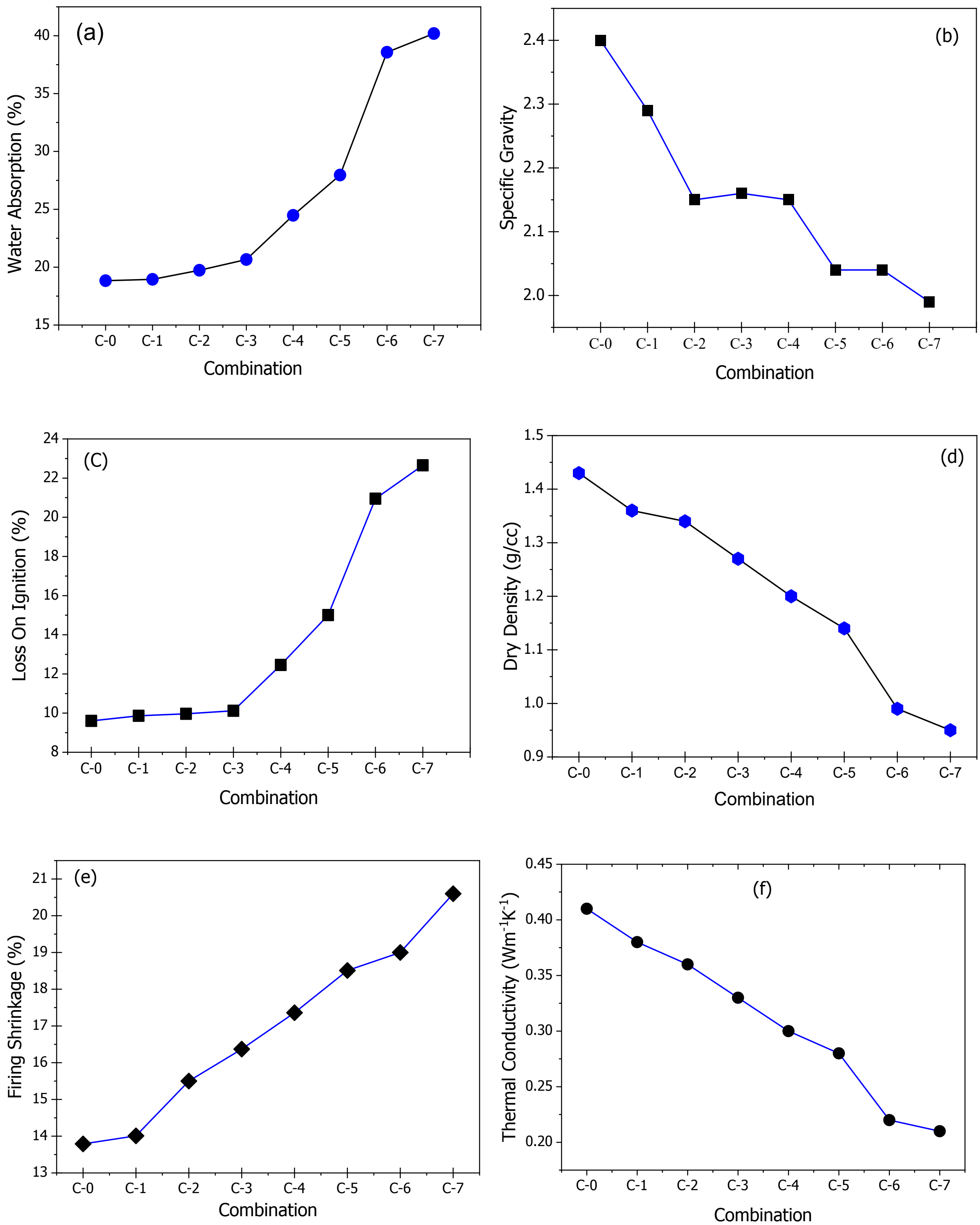

Fig. 5: Laboratory investigations of manufactured brick; (a) water absorption capacity, (b) specific gravity of brick chips, (c) loss on ignition, (d) dry density of brick, (e) shrinkage due to firing, (f) thermal conductivity of brick.

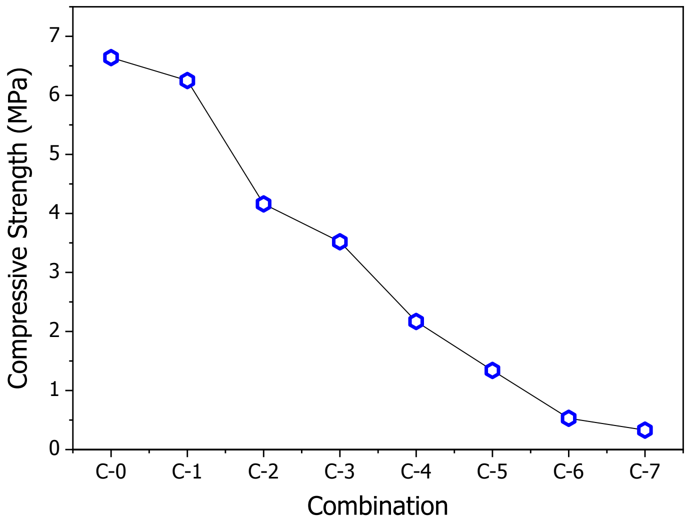

Fig. 6: Compressive strength of brick made by clay, dyeing sludge, and fly ash.

Besides, it was observed that the strength of the brick specimens declined with the increasing volume of DS and FA in brick. The probable reason for this decreasing strength pattern is that the adhesiveness of the mixture decreased and the internal pore size of the brick increased with the increase of DS and FA gradually. Compressive strength is 6.50 MPa when 10% clay was replaced by waste materials, and this is in agreement with a previous study that10% replacement of clay by textile dyeing sludge can bring 3.65 to 6.5 MPa compressive strength (Jahagirdar et al. 2013).

Table 5 presents the efflorescence that occurs due to the presence of trapped or dissolved salts in water. It normally finds its way out of the material through the tiny pores after being dissolved in water. In the current study, efflorescence increased with the increase of DS and FA; hence it was contaminated by salts. Outcomes of efflorescence are humid wall leading to multiple damages namely unhygienic conditions, corrosion, insect attack of woodwork, destruction of brickwork, damage to interior decoration decorations, cracking of plaster, etc.

Toxicity Characteristics Leaching Procedure (TCLP) test results of the dyeing sludge are given in Table 6. The leaching test was carried out only for the C-7 combination due to the maximum amount of DS and FA in this combination. An insignificant concentration of Cr and Cu was detected at the combination of 30% clay, 35% dyeing sludge, and 35% fly ash (C-7).

Table 5: Efflorescence status of brick.

Combination	Efflorescence			
	Nil (No deposition area by salt)	Slight (≤10% covering area by salt)	Moderate (≤50% covering area by salt)	High (≥50% covering area by salt)
C-0		√		
C-1		√		
C-2		√		
C-3		√		
C-4			√	
C-5			√	
C-6				√
C-7				√

Table 6: Concentrations of heavy metals from leaching test.

Comb.	Heavy metals [mg.L^{-1}]	1 day	4 days	7 days	15 days	30 days	Concentration limits (USEPA 1996)
C-7	Zn	ND	ND	ND	ND	ND	1200
	Pb	ND	ND	ND	ND	ND	500
	Ni	ND	ND	ND	ND	ND	8
	Cr	ND	0.00030	0.00090	0.00110	0.00140	20
	Cu	.00009	0.00009	0.00010	0.00010	0.00010	800

CONCLUSION

Based on experimental findings, we have come to the following conclusions: the highest compressive strength of brick has been obtained in control brick (6.64 MPa), while a range of 6.25 MPa and 0.33 MPa have been measured from combination C-1 to C-7. Water absorption, loss of ignition, firing shrinkage, and efflorescence increased with the consequent increase in the volume of DS and FA. This is due to the presence of degradable substances in raw materials. However, it appears that up to a combination of C-3 bricks can be used as a non-load bearing structure like partition wall, parapet wall, etc. Besides, the maximum thermal conductivity of the bricks was estimated to be 0.41 $Wm^{-1}.K^{-1}$ in the control specimen and the minimum was 0.21 $Wm^{-1}.K^{-1}$ in combination with C-7. A linear relationship between thermal conductivity and the volume of waste materials was observed. However, the addition of DS and FA improved the thermal insulation capacity of the bricks. Therefore, a leaching test was carried out to check the presence of heavy metals extracted from the bricks made with DS and FA. Metal leachate was found insignificant and according to the acceptable sludge regulated limit set by USEPA.

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