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BRICKS MADE FROM WASTE MATERIALS

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ABSTRACT

Bricks are a popular building and construction material used all over the world. Historic bricks are made of clay and fired at high temperatures, or from ordinary Portland cement (OPC) concrete, and have a high embodied energy and a huge carbon footprint. There is already a scarcity of natural source material for the production of traditional bricks in many parts of the world. Extensive study on the bricks made from waste materials has been performed for environmental protection and sustainable development. This document provides an up-to-date review of research on the use of waste materials to make bricks. Although a wide range of waste materials have been investigated for use in the production of bricks using various processes, commercial production of bricks from waste materials is still quite limited. The methods for creating bricks from waste materials, the potential contamination from the waste materials utilized, and the lack of necessary information are all possible factors. However, commercial production of waste-derived bricks is currently quite limited. The processes for creating waste-based bricks, the potential contamination from the waste materials utilized, the lack of applicable standards, and the tardy acceptance of trash-based bricks by industry and the general public are all possible explanations. Further research and development is required for widespread production and application of waste-derived bricks, not only in terms of technical, economic, and environmental aspects, but also in terms of standardization, government policy, and public education related to waste recycling and sustainable development.

1.Introduction

For a long time, bricks have been a popular building and construction material. The first usage of dried clay bricks was in 8000 BC, while the first use of burnt clay bricks was around 4500 BC . Brick production is currently over 1391 billion pieces per year worldwide, with demand expected to continue to rise . Ordinary Portland cement (OPC) concrete or clay are used to make traditional bricks. Quarrying for clay uses a lot of energy, has a negative impact on the environment, and produces a lot of waste. Kiln burning at high temperatures consumes a lot of energy and emits a lot of greenhouse gases [1]. In recent years, comprehensive tailings usage, particularly recovery, has gotten a lot of

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attention. Extracting iron and other metals and various reusable materials from tailings, which is a well-known method due to its significant cost savings. However, it reintroduces disposal and secondary pollution concerns. Also it may zero-emission tailings wastes be achieved, but would provide a new raw material for the construction sector, which would be alternative to resource recovery that is more effective .[2]

The large use of natural clay to produce brick has caused decrease in natural resources represented by clay to preserve it and the environment, some countries started to limit use of bricks that made from clay such as China, these countries looking for achieving sustainability requirements [1].In order to protect clay resources and develop environmentally friendly building materials, the Chinese government has banned the production and use of ordinary clay solid bricks in many cities, and has actively promoted the use of solid wastes for building materials to achieve the phase-out of ordinary clay solid bricks made of solid material [37] .

The Brundtland Commission of the United Nations first defined sustainability in 1987 as "development that satisfies the requirements of the present without harming future generations' ability to satisfy their own needs. There have been enormous increases in development, industrialization, and population expansion over the previous 30 years. Concerns have been expressed that the consequent damage to the earth's ecology and future generations' quality of life will be irreversible [3].

Therefore ,many academics have investigated the use of waste materials to manufacture bricks for environmental preservation and sustainable development [29,30,31,32,33,34,35,36]. Fly ash, mine tailings, slags, C&D waste, , cotton waste, limestone powder, paper production residue, petroleum effluent treatment plant sludge, kraft pulp production residue, cigarette butts , rice husk ash, crumb rubber, wood sawdust and cement kiln dust have all been investigated. To make bricks from waste materials, a variety of ways have been utilized [1].

This paper provides an up-to-date review of research on the use of various types of waste materials to make bricks. The benefits and drawbacks of several ways for producing bricks from waste materials are discussed. Concerns about the use of waste resources to make bricks are also raised.

2. Review of research on utilization of waste materials to produce bricks

Many researchers have studied the production of bricks from waste materials to achieve sustainability:

Gencel, O, et al (2015) [4], Production of porous and lightweight clay bricks with enhanced thermal conductivity was studied. Pumice was used as an additive to an earthenware brick to produce the pores. SEM-EDS, XRD, XRF and TG-DTA analysis of the raw materials were initially performed. Mixtures containing brick raw materials and pumice were prepared at different proportions (up to 40 wt %). The semi-dry mixtures were compressed by a hydraulic press under 20 MPa pressure into the mould, and the green bodies were dried, and then fired at 900 and 1000°C for 2 hours. The loss on ignition values of fired samples were investigated, as well as, the bulk density, apparent porosity and water absorption measurements by Archimedes method. Thermal conductivities and mechanical strengths of the fired samples were also measured. Results showed that the use of pumice decreased the fired density of the bricks. Thermal conductivity of the brick with added 40 % pumice produced (

Saleem, et al (2017) [5], studied the clay bricks produced by the addition of the two agricultural waste materials i.e. sugarcane bagasse and rice husk ash. Disposing off these waste materials is a very challenging task and is a hazard to environment. The sugarcane bagasse and rice husk ash were collected locally from the cities of Peshawar and Wazirabad, respectively. These were mixed with the clay for brick manufacturing in three different proportions i.e. 5, 10 and 15% by weight of clay. Mechanical i.e. compressive strength and modulus of rupture and durability properties i.e. water absorption; freeze-thaw and sulphate resistance of these bricks were evaluated. Test results indicated that the sulphate attack resistance and efflorescence of clay bricks incorporating sugarcane bagasse and rice husk ash were increased significantly. However, no significant effect on mechanical properties was observed. Furthermore, the additions of wastes were reduced the unit weight of bricks which decrease the overall weight of the structure leading to economical construction. Therefore, it can be concluded that the addition of waste materials in brick manufacturing can minimize the environmental burden leading towards more economical and sustainable construction.

Sarat Chandra V and Lingeshwaran N (2020)[6], studied the load-bearing walls. In order to beautify the splendid of building and its sustainability besides sacrificing strength, stability, performance, the existence of the structure and environmentally fine properties, the utilization of unique eco-friendly materials is viewed in a load-bearing masonry structure. Later as an introduction of framed constructions and improvement of working stress method and limit state method has been constructed. But the modern find out about reintroduces load-bearing partitions with a hollow brick wall which will be carrying more load-bearing potential with reasonable economy when in contrast to that of the framed structure of the identical load.

Munir et al (2018) [7], studied the development of eco-friendly burnt clay bricks incorporating recycled waste marble powder (WMP). Waste marble powder was collected from the local marble industry and used to manufacture brick specimens at a local brick manufacturing facility with dosages ranging from 5 to 25% by clay weight. The mechanical and durability performance of bricks incorporating WMP were investigated. The WMP produced lighter weight bricks with reduced linear shrinkage. It also decreased the compressive strength of bricks because of enhanced porosity, as shown by scanning electron microscopy (SEM) analysis. However, bricks incorporating up to 10% of WMP achieved compressive strength values within the specified limits of the local building code. All tested bricks satisfied the minimum standard flexural strength requirements. Using 5% WMP in fired clay bricks yielded similar efflorescence and resistance to sulfate attack compared with control bricks without WMP. Leaching tests on brick specimens indicated that leached species from WMP-modified bricks were well below regulatory thresholds. Full-scale implementation of WMP in burnt clay brick manufacturing could mitigate the landfilling of this by-product and lead to the development of eco-friendly, nonhazardous and economical masonry construction.

Gencel, O. et al (2020)[8], studied focuses on evaluation of concrete waste in the production of fired clay brick. Ground concrete waste powder was replaced with the clay up to 15% by weight. Samples were shaped in the form of cylinder pellets in uniaxial press and then fired in oven at 1000 and 1100°C for 2 h. Loss on ignition, bulk density, apparent porosity, water absorption capacity, compressive strength, thermal conductivity, dilatometric, leach analysis and efflorescence analysis were done on the fired brick samples in addition to microstructure investigations. It was observed that loss on ignition, porosity and water absorption values slightly increase while compressive strength and thermal conductivity values decrease by depending on the increment in concrete waste content. Even though the brick containing 2.5% concrete waste gives better results, the bricks containing concrete waste up to 15% present compressive strength above 7 MPa which is the minimum limit. The efflorescence levels of bricks are in the slight level. It can be concluded that concrete waste can be used in the fired clay brick production.

Loryuenyong, V.et al (2009)[9], studied wasted glasses from structural glass walls up to 45 wt.% were added into clay mixtures in brick manufacturing process. Physical and mechanical properties of clay bricks were investigated as functions of the wasted glass content and the firing temperature. The results indicated that with proper amount of wasted glasses and firing temperature, clay bricks with suitable physical and mechanical properties could be obtained. The compressive strength as high as 26–41 MPa and water absorption as low as 2–3% were achieved for bricks containing 15–30 wt.% of glass content and fired at 1100° C. When the glass waste content was 45 wt.%, apparent porosity and water absorption was rapidly increased.

Hassan, K. et al (2014)[10], used the arsenic–iron sludge in making bricks and to analyze the corresponding effects on brick properties. The water treatment plant sludge is extremely close to brick clay in chemical composition. So, the sludge could be a potential substitute for brick clay. This study involved the addition of sludge with ratios 3%, 6%, 9% and 12% of the total weight of sludge–clay mixture. The physical and chemical properties of the produced bricks were then determined and evaluated and compared to control brick made entirely from clay. Results of different tests indicated that the sludge proportion and firing temperature were the two key factors in determining the quality of bricks. The compressive strength of 3%, 6%, 9% and 12% sludge containing brick samples were found to be 14.1 MPa, 15.1 MPa, 9.4 MPa and 7.1 MPa, respectively. These results indicate that the compressive strength of prepared bricks initially increased and then decreased with the increase of sludge proportion. Leaching characteristics of burnt bricks were determined with the variation of pH at a constant temperature. The optimum amount of sludge that could be mixed with clay to produce good bonding of clay–sludge bricks was found to be 6% (safely maximum) by weight.

S.E. Chidiac and L.M. Federico (2007)[11],studied The optimization of the production of fired clay brick is essential for the sustainability of the clay brick industry. While there exist areas for improvement of these bricks' properties when they are used in severe climates, concerns — including nonrenewable resource depletion, increasing energy costs, and waste management — have become increasingly important in Canadian and global industries. One strategy to address these concerns is to use waste additives as fluxing agents in bricks. Use of these additives can decrease the dependency of the industry on nonrenewable resources and can improve brick strength and durability. The effect nonrecycled waste glass additives have on fired brick durability and mechanical and transport properties was investigated in these study. The variables studied were waste glass particle size and percentage added by mass. Microstructure was investigated using mercury intrusion porosimetry to determine the effect on pore structure. The results yielded an optimal percentage addition of waste glass.

Cusidó, J. A & Cremades, L. V. (2012)[12], showed some leachability and toxicity tests (outgassing and offgassing) which demonstrate the environmental compatibility of these ceramic products to be used as building materials and even in deconstruction of the building once its useful life is ended.

Rezaie et al (2019) [13], investigated the effect of the axial load and shear span ratio on the wall behaviour, notably on the wall stiffness, strength, and drift capacity where shear compression tests. It was found that the drift at crack onset is only half of that in previous campaigns on stone masonry walls, likely because one face of each wall was plastered, making the damage more visible. Additionally, splitting cracks opening between the wall leaves appear to play a key role in the collapse mechanism. Finally, testing the walls up to the loss of their axial-load-bearing capacity provides new input for the collapse risk analysis of stone masonry buildings.

Kazmi, S. et al (2016) [14], used waste materials (rice husk ash and bagasse ash) for brick production has been attempted. Clay bricks were prepared incorporating 5% by clay weight of rice husk ash (RHA) and sugarcane bagasse ash (SBA) to investigate the mechanical and durability properties. It was observed compressive strength and modulus of rupture decreased with incorporation of RHA and SBA in burnt clay brick. However, compressive strength and modulus of rupture satisfied the requirements of building bricks according to Pakistan building code and ASTM standard guidelines. Furthermore, clay bricks incorporating RHA and SBA can be potentially used in the production of lighter bricks. Lighter weight of bricks can result in reduction of structural loads and helpful in achieving economy. Test results confirmed the use of clay bricks incorporating RHA and SBA as moderate weather resistive bricks. Moreover, resistance against efflorescence was improved after incorporating RHA and SBA. The microstructure was examined by scanning electron microscopy (SEM) and found that burnt clay bricks incorporating RHA and SBA were more porous than burnt clay bricks. Based on that study, it can be concluded that the addition of 2 RHA and SBA is not only helpful in controlling environmental pollution but also results into a more sustainable and economical construction.

Gencel, O. et al (2021) [15], studied the global generation of millions of tonnes of water treatment sludge (WTS) per day is triggering waste management problems and the up-cycling of WTS in masonry bricks is an eco-friendly solution. Effect of different dosages of WTS on the performance of clay bricks was studied. Scant work is available regarding the performance of no-clay bricks i.e. bricks made exclusively with the WTS. It was investigated the engineering performance of no-clay bricks having WTS, glass, and marble wastes. For this reason, WTS bricks are manufactured with different dosages of glass and marble wastes (i.e. 0–15%). Empirical relationships were derived between the compressive strength, thermal conductivity, porosity, and density of brick specimens developed in this study can be used to predict the performance of WTS bricks. Therefore, no-clay WTS bricks having glass and marble wastes can be used to produce strong, durable, and sustainable buildings leading towards a cleaner environment and natural clay conservation.

Muñoz, P et al (2020)[16], explored the mineral and technological properties of brick made by using different percentages of paper pulp residues and fired at 900 °C. Results indicate that by increasing the replacement ratio, blend requires larger amounts of water which leads to a proportional increasing of shrinkage during drying. In spite of mineral transformations are not influenced by paper pulp residue, the porosity is linearly increased which leads to reduce compressive strength and thermal conductivity up to 30% for 20% of replacement ratio, in both cases. Thus, it was concluded that series made by replacing up to 10% show compressive strength above 5 MPa, water absorption beyond 20% and toxicity indexes meet the mandatory requirements.

Abbas O et a l(2021)[17], focused on unfired clay brick where the clay is the main material. To ensure that the clay is pure and clean, it was excavated from the depth of 2 m below the natural ground level. Different types of unfired clay bricks produced by adding different materials to the clay to improve its properties and especially large deformation due to shrinkage. The added materials are classified into three concepts, the first additives are the natural fibers (straw, sawdust, and rice husk) and they are used to improve the tensile strength of brick and reduce the cracking due to shrinkage. The second additives included added the fine and coarse sand as a stabilizer to reduce the volumetric changes. The third additives are adding cement to increase the adhesive and cohesion of the mud matrix. The measurements included compressive strength of brick, mortar, and masonry and the flexural strength of bricks alone. The behaviour of unfired masonry prisms was also compared to the traditionally fired clay brick prisms. The results indicate that higher compressive strength of bricks was got for the mix that included clay, coarse sand and straw. The maximum flexural strength of bricks was got for the mix that included clay and sawdust, while for unfired masonry prism the higher compressive strength was obtained with a mix that included clay, coarse sand and straw. Finally, a proposed formula to obtain the compressive strength of unfired brick masonry from the compressive strength of brick and mortar is presented.

KHITAB, Anwar, et al (2021)[18], studied the feasibility of using a composite mixture of waste brick powder (WBP) and waste ceramic powder (WCP) as a replacement for depleting natural resource “clay” in brick manufacturing. Based upon the previous studies, the replacement levels were kept as (4 + 5)%, (8 + 10)%, and (12 + 15)% of WCP and WBP, respectively. The brick specimens were evaluated in terms of compressive strength, modulus of rupture, density, water absorption, efflorescence, apparent porosity, resistance to chemical attack and sulfate attack, and freeze-thaw resistance. The study revealed that about 27% of clay can be replaced with ceramic waste powder and waste brick powder, which can preserve a massive amount of natural clay without compromising the quality of the bricks.

Kazmi, S. M et al (2016)[19], aimed to evaluate the effect of the waste addition produced from two major crops: sugarcane and rice in clay bricks manufacturing. It was, sugarcane bagasse ash (SBA) and rice husk ash (RHA) were collected locally from a sugar mill and bull’s trench kiln, respectively. Brick specimens were manufactured at an industrial brick kiln plant using various dosages (5%, 10% and 15% by clay weight) of SBA and RHA. Mechanical and durability properties of those bricks were studied. It was observed that clay bricks incorporating SBA and RHA exhibited lower compressive strength compared to that of clay bricks without SBA and RHA. However, compressive strength of bricks with 5% of SBA and RHA satisfied the Pakistan Building Code requirements (i.e. >5 MPa). Scanning electron microscopy (SEM) analysis confirms the porous microstructure of the brick specimens incorporating SBA and RHA, which resulted into lesser unit weight leading to lighter and economical structures. Furthermore, resistance against efflorescence was improved in all the tested bricks incorporating SBA and RHA. Based on that study, it can be concluded that the brick specimens incorporating lower dosage of SBA and RHA (i.e. 5% by clay weight) will not only relieve the environmental burden but also result into a more sustainable and economical construction.

Pinto et al in 2020[20], studied the mechanical characterization of eight rubble stone masonry walls from different structures of a Portuguese monument and on the assessment of their quality using the Masonry Quality Index (MQI) and the Italian Building Code Commentary [7]. Rebound hammer tests were used to evaluate the quality of stone units and mortar joints, and flat-jack tests to assess the mechanical properties of masonry walls. The results allowed to propose new quantitative criteria to rate the quality of mortars and stones in MQI and to support the decision of applying the multiplication factor concerning the quality of mortars in IBCC 2019 methodology. Image processing was used to quantify several features of masonry walls and introduce new quantitative criteria on MQI. The results identified the amount of mortar, the mortar quality, the shape features of stone units and the horizontal alignment of joints as key parameters in the mechanical resistance of rubble masonry made of irregular hard stone and lime-based mortars. The mechanical properties obtained by IBCC 2019, MQI and double flat-jacks tests showed good correlations, highlighting the advantages that come from the quality assessment of masonry to estimate masonry mechanical properties.

Ukwatta, A, et al (2015)[21], investigated to assess their suitability as a partial replacement material for the clay in fired-clay bricks. The results of classification tests including liquid limit, plastic limit and sieve analysis indicated that the three biosolids samples were clayey sand and poorly graded silty sand. The linear shrinkage of the biosolids samples varied from 10% to 15% and the organic content varied from 6% to 14%. Control clay bricks with 0% biosolids and clay–biosolids bricks with 25% by weight of biosolids were made and the properties including the compressive strength, shrinkage, density, Initial Rate of Absorption (IRA), and water absorption were determined whereas thermal conductivity was estimated from an empirical model. Furthermore, the effect of adding biosolids on the microstructure of the fired-clay bricks was evaluated by scanning electron microscopy (SEM). The results showed that the compressive strength of clay–biosolids bricks were 25.9, 17.4 and 16.2 MPa for the bricks with the three different biosolids samples used in the study. This was mainly because of the addition of biosolids samples with different organic content, which resulted in fired-bricks with higher apparent porosity and thus lower density and compressive strength. The compressive strength of the control fired-clay bricks was 36.1 MPa.

Chen, Y, et al (2011)[22], investigated besides hematite tailings, the additives of clay and fly ash were added to the raw materials to improve the brick quality. Through the process of mixing, forming, drying and firing, the bricks were produced. The optimum conditions were found to be that the hematite tailings content were as high as 84%, forming water content and forming pressure were respectively in the range of 12.5–15% and 20–25 MPa, and the suitable firing temperature was ranged from 980 to 1030 C for 2 h. Under these conditions, the mechanical strength and water absorption of the reddish fired specimens were 20.03–22.92 MPa and 16.54–17.93%, respectively, and the other physical properties and durability were well conformed to Chinese Fired Common Bricks Standard (GB/T5101-2003). The phases and morphologies of the green tailings and fired specimen were characterized by XRD and SEM. The results showed that the main mineral phases of the product were hematite, quartz, anorthite and tridymite, which were principally responsible for the mechanical strength of bricks.

Abbas, S, et al in (2017)[23], studied, bricks were manufactured using fly ash (by-product of coal) and conventional earthen materials. Fly ash was acquired from the coal power plant. Manufacturing of brick specimens was done in a local brick industry. The main variable it was the percentage of fly ash (i.e. 0 to 25% of clay). Results indicate that the compressive strength of bricks incorporating fly ash was lower as compared to that of clay bricks without fly ash. However, compressive strength of bricks incorporating up to 20% of fly ash satisfied the minimum requirements of the Pakistan Building Code. Reduction in weight was also observed in the fly ash bricks which would lead to overall weight reduction of the structures. Furthermore, less efflorescence was observed in bricks incorporating fly ash. Therefore, it can be concluded that clay bricks incorporating fly ash can be helpful in producing more sustainable bricks leading to economical solution.

Gencel, O, et al (2013)[24], studied the effect of ferrochromium slag, zeolite and combinations on physical, mechanical, thermal conductivity and microstructure properties of bricks was investigated. They were substituted to brick raw material. Semi-dry mixtures were compressed with 20 MPa. Samples were fired at rate of 5 °C/min until 900 °C for 2 h. Characterization of fired bricks, density, porosity, water absorption, weight loss, compressive and bending strength, thermal conductivity properties and microstructural and phase analysis of bricks were determined. Mechanical strengths of bricks were higher than 7 MPa. Thermal conductivity of samples decreases 42.3%. Results showed that bricks with zeolite and slag could be used as construction material.

Sutcu, M, et al (2019)[25] , studied on the properties of bricks containing clay, fly ash (FA), and bottom ash (BA). A total of 12 batches of bricks were manufactured and experimental tests were conducted 6 at two firing temperature of 950 and 1050 °C to determine the apparent porosity, water absorption, apparent specific gravity, bulk density, compressive strength, and thermal conductivity. Microstructural analysis was undertaken to describe the reasons for the obtained experimental results. The results showed that the bricks fired at 1050 °C exhibit slightly lower apparent porosity and water absorption but slightly higher bulk density and thermal conductivity than those fired at 950 °C. The results also show that an increase in the FA content leads to an increase in the apparent porosity and water absorption but a decrease in bulk density and thermal conductivity of the bricks. BA content does not have any significant influence of the properties of the bricks. It is also shown that bricks containing 5% FA, 5% BA, and 10% BA exhibit a similar compressive strength to those containing only clay. The leaching results showed that the leaching of heavy metals from fired bricks is significantly lower than that of the limit concentrations. The leaching concentrations of the samples show that the heavy metals were immobilized in the ceramic structures of all fired bricks. These highly promising findings suggest that up to 30% replacement of wastes with ashes can provide bricks to reduce the environmental impact of abundant waste products and conserve non-renewable natural resources.

Faria, K. C. P, et al (2012)[26], investigated the recycling of sugarcane bagasse ash waste as a method to provide raw material for clay brick bodies, through replacement of natural clay by up 20 wt.%. Initially, the waste sample was characterized by its chemical composition, X-ray diffraction, differential thermal analysis, particle size, morphology and pollution potential. Clay bricks pieces were prepared, and then tested, so as to determine their technological properties (e.g., linear shrinkage, water absorption, apparent density, and tensile strength). The sintered microstructure was evaluated by scanning electron microscopy (SEM). It was found that the sugarcane bagasse ash waste is mainly composed by crystalline silica particles. The test results indicated that the sugarcane bagasse ash waste could be used as a filler in clay bricks, thus enhancing the possibility of its reuse in a safe and sustainable way.

Munir, M. J, et al (2021)[27], studied burnt clay bricks are prepared to investigate the synergistic and individual effect of glass sludge (GS), marble sludge (MS), and rice husk (RH) on the physical, mechanical, durability, and thermal properties of brick samples. Results showed that the addition of waste materials (GS, MS, and RH) reduces the shrinkage, weight per unit area, and thermal conductivity of brick samples. All the brick samples incorporating different waste materials show efflorescence much lower than 10%. Furthermore, no brick sample faced any cracking even after 50 freeze-thaw cycles. The mass loss of brick samples incorporating 25% of GS is observed lower than the specified limit of ASTM C67 and are classified as freeze-thaw resistant brick samples. All the brick samples incorporating different waste materials satisfy the minimum compressive strength and modulus of rupture requirements for building bricks and can be used in a moderate weather-resistant environment, leading to sustainable masonry construction. Furthermore, all the brick samples showed leaching toxicity values much lower than the specified limits of the Environmental Protection Agency. The scanning electron microscopic images also support the results of porosity and water absorption of brick samples observed in this study. Based on the results, all the combinations of waste materials considered in this study for making brick samples can be used for masonry construction leading towards landfill reduction and the production of eco-friendly bricks.

Phonphuak, N et al (2016)[28], investigated the enhancement of physical- mechanical properties of fired clay brick by incorporating waste glass in order to reduce the firing temperature. The ground waste glass was incorporated to the clay body at the dosages of 0, 5 and 10% by weight. Three temperatures viz., 900, 950 and 1000 °C were used for firing. Compressive strength, water absorption, density, and porosity of the fired clay bricks were tested. The study showed that the incorporation of up to 10 wt.% of waste glass to clay bricks and fired at the temperatures of 900-1000 °C enhanced the properties of fired clay bricks. The SEM micrographs showed the increased glass phase and reduced porosity with waste glass addition. The use of 10 wt.% waste glass and firing at 900 °C yielded bricks with similar strength ;compared to that of normal clay brick fired at 1000 °C. This allowed the use of low firing temperature of 900 °C instead of the normally used 1000°C. The study also revealed that in addition to the glass phase fused-bond with the clay brick bodies, the fusion of crystalline quartz in clay also played an important role in enhancing the properties of clay bricks. As a conclusion, waste glass can be utilized in making brick to enhance the physical-mechanical properties of the fired clay brick or to lower the firing temperature.

Table (1) The range of material and tests for brick

no	material	The range of material	Testes	Test result
1	samples with pumice were prepared to obtain an insulating building material.	Effect of pumice addition in the ratio of 10 %, 20 %, 30 % and 40 % by weight in powder	Bulk Density . Apparent porosity . Water absorption . Compressive strength .Thermal conductivity . XRD analysis	Pumice addition decreases compressive strength when compared to those of reference brick which are 31.7 MPa at 900°C and 32.9 MPa at 1000°C. Still, all bricks with pumice have sufficient strengths over 18 MPa that satisfies the requirement in TS EN 771 and disaster regulation for a building material and can be used in the structural applications.
2	Clay was attained from a brick kiln in Pakistan. Similarly, RHA and SBA were obtained from a sugar milland industrial brick kiln located in Pakistan respectively	(5,10,15)% From RHA (5,10,15)% From SBA	.Weight per unit area .Compressive strength .Modulus of rupture . Apparent porosity . Water absorption . Initial rate of absorption . Efflorescence	Brick specimens after incorporating RHA and SBA showed less compressive and flexural strength. An addition of 5% of waste in burnt clay bricks strength Furthermore, porosity, water absorption and initial rate of absorption was increased with the addition of waste in burnt clay bricks. High porosity is usually related with good insulation properties.
3	. Cement . Coarse aggregate . Fine aggregate . Water .Hollow clay brick	For this investigation, a mortar ratio of 1:3 was chosen. The beams]. With the assistance of mason, brick size walls with 1:3 of the mortar ratio of 230 mm * 105 mm * 70 mm	. Compressive strength of brick	The flexural capacity is more for framed structure wall while comparing with hollow brick wall. The comparison is less when compared to that of framed structure.

4	Clay and WMP were used as raw materials for manufacturing bricks	A wet mixture was prepared after adding plasticity water (21.4–18.2%) (Lumps for each brick were prepared and placed into 228 × 114 × 76-mm brick molds	.Linear Shrinkage . Weight per Unit Area . Compressive Strength . Flexural Strength . Porosity . Water Absorption . Initial Rate of Absorption . Resistance to Freezing and Thawing Cycles . Efflorescence . Sulfate Resistance .ultrasonic Pulse Velocity Test . Leaching Toxicity and Heavy Metals Content . Microstructure and Color	Adding WMP in burnt clay bricks reduced the brick compressive and flexural strengths, bricks incorporating up to 10% WMP satisfied the minimum compressive strength requirements of the local building code. • Increased porosity because of higher WMP proportion in burnt clay bricks was recorded, leading to higher water absorption. Clay bricks with 5% WMP had water absorption less than 22% and could be used in moderate weather. • No cracks in bricks were observed during freeze-thaw cycles. Mass loss subsequent to 35 freeze-thaw cycles was greater than 3% for all tested bricks • The resistance to efflorescence and sulfate attack was similar for control burnt clay specimens and specimens incorporating 5% of WMP. • All tested brick specimens exhibited UPV values in the range of 1,000–2,000 m/s. • The presence of heavy metals in control bricks was higher than that in bricks incorporating WMP, but was within the threshold limits of the U.S. EPA for all tested bricks. • The leaching toxicity of all tested brick specimens was well below the specified U.S. EPA limits. Hence, burnt clay bricks incorporating WMP were considered nonhazardous.
5	The concrete wastes, milling process and its powder form	Concrete waste was replaced with the clay up to 15%. The powder raw materials for brick production were sieved	.Analysis of dilatometer Loss on ignition .Bulk density . Apparent porosity . Water absorption	Water absorption, 11.1%-13.6%, increases as parallel to porosity. Compressive strengths of bricks, 14.7 MPa-23.4 MPa, decrease when concrete waste increases in brick body. Compressive strength of brick with 15% concrete waste presents more than twice the strength, 7 MPa, given literature. Concrete waste increases up to twice the loss on ignition of the

		under 100 mm size and these fine dimensional powders were used in the experimental studies.	. Compressive strength Thermal .conductivity .Leaching analysis .Efflorescence characteristics of fired bricks .Microstructure and phase analysis	brick without causing crack in the brick body. This also is a factor resulting in the increment of porosity.
6	In this study, wasted glasses from structural glass walls up to 45 wt.% were added into clay mixtures in brick manufacturing process	The test samples were prepared by mixing the raw materials (glass powders/rice husk and ball clays) in different proportions. Water was added, in the amount of 30 wt.% based on the total weight, to combine clay mixture	bulk density, apparent density, water absorption, and apparent porosity. The compressive strength and modulus of rupture	Clay bricks prepared with 15–30 wt.% were able to meet the minimum requirements in a wide range of applications and even in some load-bearing structures. The compressive strength and the modulus of rupture of clay bricks decreased as the wasted glass content increased.
7	The arsenic–iron sludge waste used for this study was collected from arsenic–iron removal plant (AIRP)	In this study, the specific dimension of brick was 250 mm 125 mm 75 mm. Two wooden frames were used for molding of bricks. The side walls of the mold was 12.5 mm thick. The lower end of the mold	.Leaching characteristics . Effects of firing temperature .Characteristics of prepared clay–sludge bricks . Proposals for sludge–clay bricks	The compressive strength of prepared bricks initially increased and then decreased with the increase of sludge proportion. the specific gravity and water absorption capacity of prepared bricks were found to be increased with the gradual increase in sludge proportion. Test results also indicate that moisture content of the prepared bricks decreases with the increase in sludge proportion. Tests on leaching characteristic identified that the amount of arsenic and iron leaching from the sludge-bricks were higher for both acidic and alkaline mediums and

		was fixed with a plate of wood to facilitate the pouring process. A total of 4 brick samples for each sludge–clay mixture proportion of 3%, 6%, 9% and 12% were prepared in the laboratory.		thus the prepared bricks should not be exposed to those mediums.
8	.Clay .Waste glass Baco3 .Water .Chemical admixture	The glass particle sizes selected were smaller than 300µm and larger than 45 µm	.Compressive strength .Transport properties .Freeze-thaw durability .Mercury intrusion porosimetry .Sintering and shrinkage .Firing temperature	(1) The compressive strengths of specimens containing 10% coarse, 15% coarse, and 15% fine waste glass increased significantly, by as much as 104% over that of the control. Percentage of waste glass was the most influential variable in the increase of the compressive strength. (2) The particle size of the waste glass influenced the mechanical strengths less than the transport properties, as both coarse and fine particles improved strength at a comparable rate. (3) Results of IRA testing showed direct correlations between both the increasing percentages of waste glass, which tended to decrease IRA, and the particle size of the waste glass, where fine particles tended to decrease the IRA at a greater rate than the coarse particles. (4) Both the 24 h CWA and the 5 h BWA absorptions decreased significantly for specimens containing 10% fine, and 15% coarse and fine waste glass. (5) There were significant decreases in the overall porosity of specimens as the percentage of waste glass increased. Waste glass particle size also influenced these decreases, as fine

				waste glass caused a greater rate of decreased porosity than coarse waste glass. (6) The pore size distributions within the fired clay bodies were altered by the addition of waste glass. These changes in pore distributions, especially in the volume balance of the pore sizes over a greater range, significantly influenced absorption properties. (7) Specimens with 10% fine waste glass and 15% waste glass did not experience any significant F/T damage at the conclusion of 100 cycles of testing. (8) The changes in pore distribution, porosity, and pore connectivity may be the influencing factors in the decreases of mass loss experienced by specimens with increased waste glass contents. (9) At 5% addition of waste glass, there was no statistical improvement in the properties of the brick, although a slight trend of improvement was observed. This trend was more visible when the fine particles were added. Moreover, the shrinkage and colour darkening effects of the waste glass were negligible. (10) At 10% addition of coarse waste glass, the results were comparable to those achieved with 5% waste glass addition. However, there was a slight increase in darkening and shrinkage. (11) At 10% addition of fine waste glass, there was a statistically significant improvement in the properties of the brick. (12) At 15% waste glass addition, there was a statistically significant improvement in the properties of the brick for both coarse and fine waste glass. The strength and transport properties were found to improve as a result of the alteration of the pore structures.

				However, the high percentage of waste glass led to an increase in shrinkage and warping, and a noticeable darkening of the fired product
9	samples tested consisted of ceramic pieces made with different WWTP sewage sludges: physico-chemical, biological and from paper industry.	. These pieces were prepared by mixing variable percentages of clays, sludges, and eventually forest waste (sawdust)	Products analyzed Evaluation Outgassing and offgassing tests for toxicity evaluation	Leaching tests according to the standards NEN 7345, ESA PSS-01-702 and ESA PSS-01-729 show that there are no environmental restrictions on the use of clay bricks made with sewage sludges from either biological treatment, physico-chemical or paper industries . There were no significant variations depending on the type of clays and/or source of WWTP sludges. This suggests that the process of inerting sludge on clay bricks could be used without adverse effects on the health of users of the final products. . In addition, no significant differences are observed in the concentrations of heavy metals in the eluates obtained from ceramic pieces with different contents of sewage sludges. In fact, there are no quantitative differences with regard to eluates from pieces made of 100% clay. The enormous productive capacity of the ceramic industry is a huge potential for incorporating sewage sludges from WWTP in the industrial process. Taking into account that the nominal production of clay bricks in a typical mediumsized ceramic company is higher than 200 tons per day, it could daily consume 30 tons of sewage sludges, which are generated at a medium WWTP in one day.
10	Stone masonry elements are typically composite structures consisting of units (stone),	Six large-scale walls	. The effect of the axial load and shear span ratio on the wall behaviour, notably on the wall stiffness,	The effect of the axial load and shear span ratio on the wall behaviour, notably on the wall stiffness, strength, and drift capacity, was investigated. It was found that the drift at crack onset is only half of that in previous campaigns on stone masonry walls,

	mortar, and in-fill material between the wall leaves		strength, and drift capacity, was investigated.	likely because one face of each wall was plastered, making the damage more visible. Additionally, splitting cracks opening between the wall leaves appear to play a key role in the collapse mechanism ,also testing the walls up to the loss of their axial-load-bearing capacity provides new input for the collapse risk analysis of stone masonry buildings.
11	.clay .Rice husk ash .whereas, sugarcane	For brick manufacturing, RHA (5% by clay weight) and SBA (5% by clay weight) were mixed in desired proportions with the clay to form the mixture .	Weight per Unit Area . Compressive Strength Modulus of Rupture Water Absorption . Initial Rate of Absorption Apparent Porosity . Efflorescence Freeze and Thaw Sulfate Test Ultrasonic Pulse Velocity Test . Microscopic Analysis and Color	The properties of clay bricks after incorporating rice husk ash (RHA) and sugarcane bagasse ash (SBA) were investigated. Utilization of RHA and SBA wastes in the manufacturing of clay bricks not only helpful in disposal of these wastes safely but also imparts useful properties to the burnt clay bricks. From the experimental results, it can be concluded that: 1. Clay bricks after incorporation of RHA and SBA can be potentially used in the production of lighter bricks. Addition of these wastes result into 6% lighter bricks. This decrease in the weight of bricks can result in the reduction of structural loads and helpful in achieving economy. 2. Compressive strength and modulus of rupture decrease after addition of RHA and SBA in brick clay. However, the results still satisfy the requirements of building bricks according to Pakistan building code and ASTM standard guidelines. 3. Porosity and water absorption increases after incorporation of RHA and SBA. 4. The resistance against efflorescence has been improved after incorporation of RHA and SBA in clay bricks. However, the use of modified bricks under severe sulfate attack is not preferred.

12	local water treatment, glass manufacturing, and marble cutting facilities. WTS, glass, and marble wastes	This study investigated the engineering performance of no-clay bricks having WTS, glass, and marble wastes. WTS bricks were manufactured with different dosages of glass and marble wastes (i.e. 0–15%).	.Characterization of raw materials .Characterization of brick specimen .Density specimen .Apparent porosity .Water absorption .Compressive strength . Thermal conductivity . Loss on ignition .Efflorescence of brick specimens .Microstructural investigation	WTS bricks (S100) showed the highest compressive strength of 33.8 MPa among all the specimens having WTS, glass, and marble. All the bricks manufactured in this study showed higher compressive strength and satisfy the international building code requirements. Furthermore, no-clay WTS bricks satisfy ASTM C902 requirements for the paving bricks exposed to light vehicular traffic. Therefore, no-clay WTS bricks may be used for such load-bearing road paving applications and masonry structures leading towards stronger, sustainable, and cleaner construction
13	mix KP and clay,	small amounts of clay and KP were randomly collected from stock piles.	. Mineral and chemical composition Physical characterization Mechanical properties Thermal behavior Leaching test Thermal analysis of firing process	In this study, the fB trend remains quite constant. Among the reasons for the increase in the value of fB for 15% of addition, the extrusion pressure variation may be considered. Although plasticity was proportionally increased for easing extrusion, by adding more water to the clay-KP mixture A85P15 samples were formed with quite less water compared to the rest of series. Hence, it is suggested KP addition might lead to an increase in friction at the extruder mould which could also increase the pressure formation and therefore the fired fB, in accordance with Li et al. (2011). Regardless of the discussed scattering effect, fC verifies that amounts of additive of up to 10% do meet the regulatory levels, based on CTE and Chilean standards. Although higher percentages should not be considered for load-bearing masonries, nonstructural masonry (e.g. envelopes, roof tiles, internal partition, etc.) may

				take advantage of the enhancement of thermal properties and lower density
14	soil, cement, sand, and water	The soil was used from the south Amarah City, from a depth of 2 m below natural ground level, The liquid limit of this soil was 37 %, and the plastic limit was 21 %. the Ordinary Portland cement type I And the retained sand on sieve No. 4 was added to the mix	.masonry unit due to its a brittle .strength and plasticity of the brick .compressive strength	The mechanical properties or investigation of compressive strength of straw reinforced unfired clay bricks for sustainable building construction, the following conclusions were obtained: 1) The use of clay alone is not appropriate as a masonry unit due to its a brittle and fastcracking material. Additional materials should be added to the mix to increase its strength and flexibility of the brick. The maximum compressive strength for this mixture was 1.1 MPa. 2) Adding straw increased the strength and plasticity of the brick. Increased plasticity of the bricks by adding straw was an important thing. Despite the great deformations that have to happen to it, the cracks were not shown on its surface as well as not get collapse. It can benefit from this property in areas where earthquakes get. The maximum compressive strength for this mixture was 2.4 MPa. 3) Adding rice husk somewhat increased the strength of the bricks but its small size did not give a high bonding strength to the bricks. The maximum compressive strength for this mixture was 2.4 MPa. 4) Sawdust is considered one of the best additive materials that was used in this research. It is thick, long, and not hollow as in straw increased brick compressive and bonding strength when adding it to the mix. Also, it decreases the cracks that occurred during the drying period. The maximum compressive strength for this mixture was 2.85 MPa.

				5) Using the sand in the production of bricks was considered a good addition. Whether the sand is fine or coarse, it increased its strength and decreased the deformation that occurred to it during the test. The maximum compressive strength for this mixture was 2.87 MPa. 6) Using the cement in the production of bricks was considered as a bad addition because the cement made the mixture brittle, weak, and fast-cracking material. The maximum compressive strength for this mixture was 0.9 MPa. 7) The maximum compressive strength of masonry unfired brick was 1.9 MPa which was made of clay, coarse sand, and straw. The compressive strength of masonry bricks was close to the compressive strength of unfired bricks and mortar. This was because the bricks and mortar were made of the same material and have the same Poisson ratio.
15	fresh clay, waste bricks from demolished masonry, and waste ceramic from broken ceramic pottery	(4 + 5)%, (8 + 10)%, and (12 + 15)% of waste brick powder (WBP) and waste ceramic powder (WCP), respectively.	compressive strength, modulus of rupture, density, water absorption, efflorescence, apparent porosity, resistance to chemical attack and sulfate attack, and freeze-thaw resistance	• Bricks containing waste ceramic and brick powder were free of efflorescence and had equal resistance against chemical attack, as observed in the ASTM C67 standard test. • Bricks containing 27% (15% WBP + 12% WCP) waste materials possessed the same density, porosity, and water absorption capacity as those containing 100% clay. • Bricks containing 27% (15% WBP + 12% WCP) waste materials possessed a 27% decreased initial water absorption rate compared to the control specimens. • Bricks with 9% (5% WBP + 4% WCP) waste materials had a compressive strength of 11 MPa, more than the control specimens with 9.8 MPa strength. However, bricks with 27% waste materials had a strength of 8.1 MPa.

				• Bricks with 9% (5% WBP + 4% WCP) waste materials had a modulus of rupture of 3.32 MPa, more than that of the control specimens with 3.26 MPa strength. However, bricks with 27% waste materials had a strength of 1.84 MPa. • The combination of waste brick and ceramic powder was effective against sulfate attack, and the resistance increased with an increase in the replacement level. • Bricks with 9% (5% WBP + 4% WCP) waste materials showed the highest resistance against freeze and thaw (only 0.87% weight loss). Nevertheless, the weight loss in all the specimens was found to be less than 1%.
16	common clay (soil), dry sugarcane bagasse and rice husk ashes were used as raw materials for brick manufacturing	. Brick specimens were manufactured at an industrial brick kiln plant using various dosages (5%, 10% and 15% by clay weight) of SBA and RHA.	. Weight per unit area .Compressive strength .Flexural strength/modulus of rupture . Durability properties of brick .specimens Ultrasonic pulse velocity test .Microstructure and color	The properties of clay bricks incorporating rice husk ash (RHA) and sugarcane bagasse ash (SBA). Utilization of RHA and SBA wastes as a raw material in manufacturing of clay bricks can be an important way of recycling for final disposal of these abundan of fertile soil. The RHA and SBA used in this study were low-cost waste materials, having high percentage of crystalline silica (SiO_2), which may behave as a filler material. RHA and SBA can be potentially used in the production of lighter clay bricks. It was observed that 15% replacement of clay with SBA and RHA wastes result in approximately 15% and 4% lighter bricks respectively, compared to that bricks without RHA and SBA. This decrease in the weight of bricks can reduce the overall dead load and consequently economical structures can be constructed. Although, the compressive and flexural strengths decreased with increased proportions of RHA and SBA. However, brick specimens incorporating 5% by clay

				weight of RHA and SBA showed compressive strength of 6.62 MPa and 7.18 MPa respectively, which satisfies the requirement of compressive strength specified by the Building Code of Pakistan for masonry construction. Similarly, all the tested bricks incorporating RHA and SBA satisfies the minimum modulus of rupture criteria specified by ASTM C67 (i.e. >0.65 MPa).
17	stone masonry walls	eight rubble stone masonry walls		The quality of masonry and mechanical properties showed a good correlation highlighting the reported advantages that come from the quality assessment of masonry in the estimation of its mechanical properties. The collection of useful data that can be used to enlarge the existing information, mostly based on Italian masonry.
18	three biosolids samples	the chemical composition of the brick soil and the three biosolids samples were determined by XRF	Compressive strength of brick samples Firing shrinkage of brick samples. Density of brick samples. Water absorption of brick samples.	The specific gravity, linear shrinkage, and organic content of the biosolids samples varied from 2.43–2.52, 10–15% and 6.3–14.4%, respectively. Bricks (B1-25, B2-25, and B3-25) were then made incorporating 25% of biosolids by weight, while the control bricks had 0% biosolids (B-0) and investigated their physical and mechanical properties The compressive strength test results indicated that strength of the brick samples decreased from 36.1 MPa (B-0) to 25.9, 17.4, and 16.2 MPa for B1-25, B2-25, and B3-25, correspondingly. The density of the brick samples were reduced by 4.3–9.7% after modifying bricks with three different biosolids and the estimated thermal conductivity of B-0, B1-25, B2-25 and B3-25 were 1.08, 0.95, 0.86 and 0.81 Wm1 K1 , respectively.

19	Besides hematite tailings, the additives of clay and fly ash were added to the raw materials to improve the brick quality	. The optimum conditions were found to be that the hematite tailings content were as high as 84%, forming water content and forming pressure were respectively in the range of 12.5–15% and 20–25 MPa, and the suitable firing temperature was ranged from 980 to 1030 C for 2 h. Under these conditions,	.compressive strength, .water absorption and .bulk density	The mechanical strength and water absorption of the reddish fired specimens were 20.03–22.92 MPa and 16.54–17.93%, respectively, and the other physical properties and durability were well conformed to Chinese Fired Common Bricks Standard (GB/T5101-2003). The phases and morphologies of the green tailings and fired specimen were characterized by XRD and SEM. The results showed that the main mineral phases of the product were hematite, quartz, anorthite and tridymite, which were principally responsible for the mechanical strength of bricks
20	The materials used for the manufacturing of bricks were clay, fly ash and water.	A total of 150 brick specimens of size 225×112×75 mm were prepared at brick kiln site plasticity water (20.8 – 18.7%) was added	.Weight per Unit Area .Compressive Strength . Modulus of Rupture: .Flexural Test Breaking load	The compressive strength of bricks incorporating fly ash was lower as compared to that of clay bricks without fly ash. However, compressive strength of bricks incorporating up to 20% of fly ash satisfied the minimum requirements of the Pakistan Building Code. Reduction in weight was also observed in the fly ash bricks which would lead to overall weight reduction of the structures. Furthermore, less efflorescence was observed in bricks incorporating fly ash. Therefore, it can be concluded that clay bricks incorporating fly ash can be helpful in producing more sustainable bricks leading to economical solution.
21	mixtures of brick clay and additives containing ferrochromium	A hydraulic press was used to make bricks with 100 50 20 mm in size.	.Unit weight loss after firing .Porosity .Water absorption	The bricks with 10%, 20% and 30% addition of zeolite to brick clay show a compressive strength of 14.3e22.3 MPa. Compressive strengths of bricks including combination of the slag and

	slag and natural zeolite was accomplished	Semi-dry mixtures were compressed with a pressure of 20 MPa.	.Compressive and bending strength	zeolite ranged between 17.4 and 27.7 MPa. But, both of the bricks with ferrochromium slag and zeolite have sufficient strengths over 14 MPa that satisfies the requirements in TS EN 771 and disaster regulation for a building material to be used in the structural applications.
22	Anexperime-ntal study on the properties of bricks containing clay, fly ash (FA), and bottom ash 5 (BA). A total of 12 batches of bricks	that bricks containing 5% FA, 5% BA, and 10% 15 BA exhibit a similar compressive strength to those containing only clay	.Apparent porosity .Water absorption .Apparent specific gravity .Bulk density Compressive .strength	An increase in FA content results in a significant increase in apparent porosity and water absorption but a significant decrease in the bulk density and thermal conductivity of the bricks. On the other hand, BA content has much less significant influence on the apparent porosity, water absorption, bulk density, and thermal conductivity of the bricks. Furthermore, the apparent specific gravity of bricks containing FA and BA exhibit similar to that of control bricks containing clay only. An increase in FA and BA content led to a significant decrease in the compressive strength of bricks. However, bricks containing 5% FA, 5% BA, and 10% BA exhibit a similar compressive strength to the control bricks.
23	Common clay and a dry sugarcane bagasse ash waste in form of powder were selected as raw materials.	. Selected mixtures containing 0, 5, 10, 15 and 20 wt.% waste were prepared	tensile strength	The limitations for incorporation of the sugarcane bagasse ash waste into clay bricks result from the increase of water absorption, and also from the decrease of mechanical strength. However, under the conditions used in this study, the specification in terms of water absorption for clay bricks was achieved at 1000°C, regardless of the waste amount that had been added to them. The results hereby disclosed also suggest that the use of high concentrations (above 10 wt.%) of such a waste into clay brick body

				should not be recommended, as it tends to decrease the mechanical strength of the fired brick pieces.
24	clay, GS, MS, and RH were used as raw materials	The uniformity coefficients of clay, GS, MS, and RH are observed at 7.5, 3.5, 3.0, and 4.5, respectively, which show the uniform nature and wide variety of particle sizes in raw materials.	.Shrinkage .Weight per unit area .Compressive strength .Modulus of rupture .Apparent porosity .Water absorption .Thermal conductivity . Initial rate of absorption .Efflorescence . Freeze and thaw .resistance Sulfate resistance .Ultrasonic pulse velocity test .Microstructure . Leaching characteristics	• As the addition of waste materials (GS, MS, and RH) reduces the shrinkage of brick samples, all the combinations of GS, MS, and RH considered in this study can be used to produce low shrinkage brick samples. • All the brick samples incorporating different waste materials except G25 brick samples show a decrease in weight per unit area than control brick samples. Therefore, the addition of different waste materials (GS, MS, and RH) affects the weight per unit area of brick samples and can be helpful in producing sustainable brick samples with desired properties. • All the brick samples incorporating different waste materials satisfy the minimum compressive strength and modulus of rupture requirements for building bricks. • Control brick samples show thermal conductivity of 0.53 W/mK, which decreases to 0.52, 0.51, 0.50, 0.48, and 0.45 W/mK for G20M5, M5, G20RH5, RH5, and M5RH5 brick samples. However, the thermal conductivity of 0.59 W/mK is noticed for G25 brick samples. Moreover, the apparent porosity of brick samples shows an inverse relation with the compressive strength and thermal conductivity. • In this study, all the brick samples incorporating different waste materials show efflorescence much lower than 10%. Furthermore, no brick sample faced any cracking even after 50 freeze-thaw cycles. The mass loss of G25 brick samples is observed lower than the specified limit of ASTM C67, and G25 brick samples are classified as

				freeze-thaw resistant brick samples. Control, G25, and G20M5 brick samples also performed better in the sulfate environment. • The SEM images are supporting the results of water absorption and porosity of brick samples observed in this study. Furthermore, all the brick samples incorporating different waste materials show values of leaching toxicity much lower than the specified limits of the Environmental Protection Agency.
25	fired clay brick by incorporating waste glass	. The ground waste glass was incorporated to the clay body at the dosages of 0, 5 and 10% by weight	Firing shrinkage Density Water absorption and apparent porosity Compressive strength	The compressive strength of bricks increased with increases in waste glass addition from 0 to 10 wt.% and firing temperatures from 900 to 1000°C. The values of apparent porosity and water absorption of bricks also decreased with increases in waste glass addition and firing temperatures. The optimum waste glass content of 10 wt.% enabled the clay brick to be fired at lower temperature .

Table (2) the standard specification

no	**code**	**Size of brick (mm)**	**Compressive Strength N/mm2**	**Class of brick**
1	IRAQ STANDARD	240×115×75	18 13 9	Class A Class B Class C
2	ASTM C62-08 ASTM C 216	203×92×57	3000 (20.7) 2500 (17.2) 1500 (10.3) 3000 (20.7) 2500 (17.2)	Grade SW Grade MW Grade NW Grade SW Grade MW
3	BS 3921	215×102.5×65	≥70 ≥50	Class A Class B

4	Indian Standard (IS 1077)	190 x 90 x 90	35'0 30'0 25'0 20'0 17'5 12'5 10'0 7'S 5'0 3'5	Class 35 Class 30 Class 25 Class 20 Class 17'.5 Class 12'5 Class 10 Class 7'S Class 5 Class 3'5
5	Ethiopian standard (ES 86:2001)	240 x120 x60	20 15 10 7.5	Class A Class B Class C Class D
6	TS EN 771- 1	250 x125 x100	7,5 (75) 5,0 (50) 2,5 (25)	Class (7,5) Class (5,0) Class (2,5)

3. Discussion

Tables show that different types of waste materials were used in varied proportions and that different procedures were used to make bricks. Various tests were performed on manufactured bricks to evaluate their qualities in accordance with the various relevant standards. Most studies consider compressive strength and water absorption to be two common criteria that are required by many standards. The process of making bricks from waste materials and burning them is quite similar to the process of making clay bricks. As a result, this technology can be simply implemented without requiring large adjustments to the traditional clay brick manufacturing process. However, pollutants in the waste material may be released during the firing process, resulting in fresh pollution. Furthermore, firing bricks uses a huge amount of energy and emits a large amount of greenhouse emissions. As a result, in terms of energy and environmental issues, technologies for creating bricks without firing appear to be the way to go. Because most waste products contain pollutants, whichever procedure is used to make bricks from waste materials, It's crucial to make sure that the pollutants in the original trash are efficiently and safely immobilized.

4.Conclusions

Based on the review of the various studies on the production of bricks from waste materials, the following conclusions can be drawn:

- A wide variety of waste materials have been studied for the production of bricks.
- The different methods studied for producing bricks from waste materials can be divided into three general categories: firing, cementing and geopolymerization. The firing and cementing

(especially cementing based on added cementing materials) methods for producing bricks from waste materials still have the drawbacks of high energy consumption and large carbon footprint as the conventional brick production methods. The method for producing bricks from waste materials through geopolymerization seems to be the trend to follow in terms of energy and environmental concerns.

- Although much research has been conducted, the commercial production of bricks from waste materials is still very limited. The possible reasons are related to the methods for producing bricks from waste materials, the potential contamination from the waste materials used, the absence of relevant standards, and the slow acceptance of waste materials-based bricks by industry and public
- For wide production and utilization of bricks from waste materials, further research and development is needed, not only on the technical, economic and environmental aspects but also on standardization, government policy and public education.

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