Experimental study of the mechanical properties of burnt clay bricks incorporated with plastic and steel waste materials

M Ebadi-Jamkhaneh\textsuperscript{1,5}, M Ahmadi\textsuperscript{2} and D-P N Kontoni\textsuperscript{3,4,5}

\textsuperscript{1}Department of Civil Engineering, School of Engineering, Damghan University, Damghan, Iran (E-mail: m.ebadi@du.ac.ir)
\textsuperscript{2}Department of Civil Engineering, School of Engineering, Ayatollah Boroujerdi University, Boroujerd, Iran (E-mail: masoud.ahmadi@abru.ac.ir)
\textsuperscript{3}Department of Civil Engineering, School of Engineering, University of the Peloponnese, GR-26334 Patras, Greece (E-mail: kontoni@uop.gr)
\textsuperscript{4}School of Science and Technology, Hellenic Open University, GR-26335 Patras, Greece (E-mail: kontoni.denise@ac.eap.gr)

\textsuperscript{5}Corresponding authors’ e-mails: m.ebadi@du.ac.ir, kontoni@uop.gr

\textbf{Abstract.} Traditional masonry bricks are made of clay burnt under high temperatures, resulting in high energy consumption, environmental contaminations and decreased natural raw materials. In order to limit nature risks, inorganic materials have been used to make brick. Four types of materials, including fine and coarse plastic, cast iron, and iron swarf, have been used to make bricks. A total number of 64 specimens were made and tested. The tests results were presented in the form of compressive strength, rupture module, water absorption percentage, and initial water absorption ratio. The result showed that using cast iron powder caused the maximum compressive strength amongst all the samples, and was 46\% larger than for the reference bricks. On the other hand, the maximum initial water absorption occurred within the first three hours, while the maximum rate was associated to samples with higher coarse plastic contents.

1. Introduction
Masonry brick is one of the oldest and important construction materials around the world. Brick was considered the main ground material in the ancient Egyptian, Roman, and Mesopotamian eras. The compressive strength and durability of the brick upon baking the clay had made it a valuable material that has been used in the construction of every building for thousands of years. The common and traditional processes to make brick included mixing raw ingredients, grinding brick clogs, drying and baking them to achieve a certain compressive strength, or through using regular Portland cement, resulting in the production of concrete blocks. On the other hand, uncontrolled exploitation of ground soil materials resulted in extensive removal of raw materials and high energy intake (roughly 300\% more than the energy consumed to produce concrete blocks). Therefore, there is a need to review the process of production and materials used for brick as a means to decrease environmental risks due to an increase in greenhouse gases. On the other hand, cementitious bricks are a combination of cement and sand. Cement is also considered to be an anti-environmental substance in which quite a high volume of CO\textsubscript{2} is generated for its production [1]. Environmental-friendly methods and approaches are
required to remove environmental pollutions, reduce the generation of debris and wastes and preserve raw materials from destruction. In order to do so, several scholars have made significant efforts to develop and produce various types of bricks by taking benefit from natural and artificial wastes and materials [2]. Therefore, the procedure of brick making during the recent two decades using materials wastes resulting in a decrease in the defects of traditional brick making method. Several studies have conduct relating to making brick using different materials and wastes. Principally, the bricks may be produced and offered in two main types of burnt and unburnt bricks. In this study, the burnt brick has been focused on, and therefore, the studies conducted by the relevant scholars in this regard are addressed. The process of making brick using clay includes preparing clay, drying, and eventually burning the same inside furnace under a certain temperature. Several studies have been completed on making burnt bricks, which may be classified into two groups of using natural and non-natural materials and wastes [3].

Several researchers have done research on burnt bricks composed of organic and inorganic materials. In these investigations, materials such as diatomaceous earth residues (DER, refining of vegetable oils and brewing), degraded municipal solid waste (DMSW), tammy sludge (TS), cigarette butts (CBs), rice husk ash (RHA), sewage sludge waste (SSW), bagasse ash (SBA), fly ash (FA), and sago husk waste (SHW) were used. Generally, the test results exhibited that these materials improve the mechanical properties (compressive strength, water absorption, and etc.) of the burnt bricks [4-7].

The aforementioned studies include the effects of using natural wastes materials on the compressive strength, water absorption, burnt brick density under various temperatures range between 550 to 1200°C. Concerning the foregoing, the compressive strength of most of the bricks that contained more than 40% various wastes was still less than the limit prescribed by ASTM C62 [8] for construction bricks. Inorganic waste materials are non-recyclable materials containing chemicals out of minerals. Researchers have conducted several studies on using artificial wastes [9-11]. In these investigations, inorganic materials such as waste glass sludge (WGS) [9], sugar filter mud (SFM) [10], brick waste (BW) [11], waste marble powder (WMP) [12], automotive waste sludge (AWS) [13], glass waste (GW) [14], wood ash (WA) [15], and arsenic-iron sludge (AIS) [16] were used. Most of the test results revealed a decrease in dry shrinkage, firing shrinkage, apparent density and cold crushing strength, and enhanced the mechanical behavior of the bricks.

It was observed during the completed studies that the use of non-natural materials to make bricks has an important effect on compressive strength and other characteristics. Most of these results demonstrated that compressive strength decreases in the case of using inorganic materials. In some cases, an increase in inorganic waste materials (more than 10%) results in an improvement in brick compressive strength, such as BG and WG. Considering the necessity of environmental protection and suggesting environmentally-friendly production methods, the inorganic materials, such as fine and coarse granules made out of plastic wastes, powdered cast iron, and iron swarf to make burnt brick. After burning and testing, the mechanical characteristics and features of the bricks have been studied and compared with those of ordinary bricks.

2. Methodology

Different stages shall be taken to prepare and burn the brick. These stages include preparing clay, treating soil, making mud, molding, drying unburnt brick, and firing brick. The clay used in making brick is composed of SiO$_2$ (60%), Al$_2$O$_3$ (18%), Fe$_2$O$_3$ (7%), CaO (13%), and MgO (2%). For the purpose of treatment, a soil, free from clogging and external materials, was prepared and exposed to air. Then water weighed roughly 20% of soil weight was added to that and penetrated into all soil particles through kneading. After preparing mud and treating of the same, it is placed into the mold (Figure 1) to shape bricks. The dimensions 5.1cm × 10.5cm × 21cm are the internal sizes of the mold. After making unburnt bricks, they were dried. In order to do so, a bigger surface of the unburnt brick was exposed to air, which lasted for four days. The last step commenced through taking clay chemical water, in a way that Aluminum Hydro-Silicate is converted into Aluminum Silicate. This action was conducted using a heat roughly equal to 900 °C, brick physical water is dried out and up to 500 °C clay
chemical water is evaporated, and up to 900 °C clay particles start acting plastically and therefore, clay grains inside the brick have adhered together, and brick has resulted. Burning was made inside a furnace with fixed flame and fixed brick inside a chamber of 1m size for 3 days. Sixteen (16) sample groups of brick were made using main materials based on clay. The physical and mechanical features of each group were assessed using three methods. In order to do so, totally 64 bricks were made and tested. In Table (1), the characteristics of bricks and additives weight percentages have been presented.

![Mold of brick](image1)

![Kiln](image2)

**Figure 1.** Apparatuses of brick manufacturing.

| Row | Specimen name | In-organic material weight (gr) | Description |
|-----|---------------|--------------------------------|-------------|
| 1   | B             | 0                              | Reference clay brick |
| 2   | BF25          | 25                             | Clay brick+25 (gr) fine grained plastic granule |
| 3   | BF50          | 50                             | Clay brick+50 (gr) fine grained plastic granule |
| 4   | BF100         | 100                            | Clay brick+100 (gr) fine grained plastic granule |
| 5   | BF150         | 150                            | Clay brick+150 (gr) fine grained plastic granule |
| 6   | BC25          | 25                             | Clay brick+25 (gr) coarse grained plastic granule |
| 7   | BC50          | 50                             | Clay brick+50 (gr) coarse grained plastic granule |
| 8   | BC100         | 100                            | Clay brick+100 (gr) coarse grained plastic granule |
| 9   | BC150         | 150                            | Clay brick+150 (gr) coarse grained plastic granule |
| 10  | BC11          | 85                             | Clay brick+ Group 1 of cast iron powder |
| 11  | BC12          | 170                            | Clay brick+ Group 2 of cast iron powder |
| 12  | BC13          | 255                            | Clay brick+ Group 3 of cast iron powder |
| 13  | BC14          | 340                            | Clay brick+ Group 4 of cast iron powder |
| 14  | BC15          | 850                            | Clay brick+ Group 5 of cast iron powder |
| 15  | BF-R          | 100                            | Clay brick+ Regular iron wire |
| 16  | BF-IR         | 100                            | Clay brick+ Irregular iron wire |

3. Results of test specimens

3.1. Compressive strength

Structurally perspective, compressive strength is a key parameter for each sample among other variables. Bricks with different compressive strengths are extensively used in proportion to structural and architectural applications. Masonry materials compressive strength values made from synthetic ingredients were reported after 7 days of making the bricks and were tested as per ASTM C67-11 Standard [17]. The compressive strength of inorganic bricks was determined on their stretcher face only. The influences of waste materials in bricks on the compressive strength are written in Table 2. When tested in accordance with DKS 2802-1 [18], the compressive strength for clay units for non-load bearing blocks shall not be less than 3 MPa, and the compressive strength for clay units for load
bearing blocks shall not be less than 7 MPa. Meanwhile, according to the Iranian Building Code [19], the minimum compressive strength of hand-made bricks shall exceed 8 MPa. In the case of non-load bearing brick, such strength shall not be less than 4 MPa.

Table 2. Mechanical characteristic results of test specimens.

| Row | Specimen name | Area (cm²) | Load (kg) | Applied pressure (kg/cm²) | Modulus of Rupture (MOR) (Pa) | Absorption (%) |
|-----|---------------|------------|-----------|--------------------------|-------------------------------|----------------|
| 1   | B             | 200        | 14600     | 73.0                     | 0.086                         | 25.7           |
| 2   | BF25          | 200        | 147500    | 87.5                     | 0.083                         | 21.9           |
| 3   | BF50          | 200        | 11000     | 55.0                     | 0.082                         | 22.4           |
| 4   | BF100         | 200        | 9100      | 45.5                     | 0.082                         | 28.3           |
| 5   | BF150         | 200        | 6700      | 33.5                     | 0.081                         | 26.5           |
| 6   | BC25          | 200        | 15500     | 77.5                     | 0.073                         | 26.9           |
| 7   | BC50          | 200        | 11400     | 57.0                     | 0.070                         | 27.2           |
| 8   | BC100         | 200        | -         | -                        | 0.023                         | 36.2           |
| 9   | BC150         | 200        | -         | -                        | 0.009                         | 33.4           |
| 10  | BC11          | 220.5      | 13600     | 61.7                     | 0.091                         | 28.3           |
| 11  | BC12          | 220.5      | 16890     | 76.6                     | 0.092                         | 28.0           |
| 12  | BC13          | 220.5      | 19000     | 86.2                     | 0.094                         | 28.4           |
| 13  | BC14          | 220.5      | 20300     | 92.1                     | 0.096                         | 27.5           |
| 14  | BC15          | 220.5      | 23500     | 106.6                    | 0.099                         | 24.1           |
| 15  | BF-R          | 220.5      | 19500     | 88.5                     | 0.085                         | 29.0           |
| 16  | BF-IR         | 220.5      | 12300     | 55.8                     | 0.093                         | 24.2           |

According to Table 2, the minimum compressive strength is related to BF150 specimen (using plastic particles) except for two BC100 and BC150 specimens, and the maximum value is related to BC15. Therefore, there is a wide range of load bearing and non-load bearing bricks. The results demonstrate that adding merely 3% polyethylene plastic fine particles and 1.5% plastic coarse particles may include the burnt clay brick as load bearing bricks. On the other hand, adding powdered cast iron of any content results in an increase in specimen compressive (except for BC11 specimen). Also, using regular steel rings has resulted in bearing a pressure of 88.5 (Kg/cm) for clay brick, while using irregular rings has resulted in the inclusion of brick in the non-load bearing members group. In cement particles contained specimens, using various cement contents have had close results. However, adding 3.5% and 7% resulted in the inclusion of clay brick in non-load bearing members, and higher cement contents used to make bricks has caused the relevant brick to be included in load bearing members. Evidently, all the bricks are included in the defined permitted range for load bearing and non-load bearing members. Merely two clay bricks with coarse plastic grains were subject to break due to brick making and melted plastic particles and porosity, as shown in Figure 2.

![Figure 2](image-url)
3.2. Modulus of Rupture (Flexure Test)

Brick specimens were put inside a flexure test machine. The distance between two supports in all specimens with respect to each other has been taken as 160 mm. Therefore, modulus of rupture of specimens was found as per Table 2. The rupture modulus of ordinary brick is equal to 0.086 Pa. It is seen upon adding plastic particles that rupture modulus decreases, while the minimum rupture modulus is related to BF150 (0.081 Pa), which has decreased roughly 6%. Among bricks with plastic granules, the BC150 specimen with 0.009 Pa rupture modulus has the minimum value, which is roughly 90% less in comparison to the reference specimen. The best specimen in this group in terms of rupture modulus is 15% (0.073 Pa) less than the reference specimen, which is also due to spherical porosity caused by melted and evaporated plastic granules. It was known in specimens made from adding a variety of contents of powdered cast iron into clay, that by further powdered cast iron, rupture modulus has increased, in a way that in BC15 sample, rupture modulus has become equal to 0.099 Pa (15% increase in comparison to reference sample). This is the maximum value in comparison to all specimens.

In two BF-R and BF-IR specimens, the one with steel scrap geometrical irregularity managed to involve more particles and soil mass due to the formation of several spiral and nonhomogeneous loops. In other words, it generated more confinement pressure for the same irregular type comparison to regular specimens located in advance. It was seen in specimens with different cement contents that by adding different cement contents, rupture modulus has roughly decreased by 13% in comparison to reference specimen (0.075 Pa).

3.3. Absorption

All specimens were weighed dry initially and then drowned into the water for 24 hours, and the water absorption percentage of each specimen was calculated through calculating weight and fulfilling calculations. Therefore, ordinary clay brick had a water absorption percentage of 25.7%. The maximum acceptable water absorption in an ordinary clay brick is 30%. Regarding powdered plastic bricks, the water absorption criterion is within a permitted range, in a way that the maximum water absorption is related to two specimens by adding 100gr and 150gr into clay. It was seen in the case of using the same weights in specimens with plastic granules that water absorption percentage was beyond the permitted range, and therefore, these specimens cannot be used as bricks for facade or exposed to sea water or rain. It was seen in the case of using different powdered cast iron weights for clay that all the specimens managed to be placed in a range less than 30% to meet the water absorption percentage criterion.

3.4. Initial Rate of Absorption

The level of water absorbed for each of the sunk samples was measured in 1, 4, 15, and 30 minutes and 1, 3, 5-, 7-, 17-, and 24-hours intervals. Different bricks were used for each brick and time. Upon starting each test, the bricks were under dry conditions. Prior to the test, each brick was named and weighed, and dust was removed. Meanwhile, the size of the brick bottom and cross-section area of each were determined, and next, the brick bottom was placed in water (depth of 3mm) for the mentioned period of time, and after that, the surface and excessive water was removed using moisture cloth, and the sample was weighed at once. The difference in brick weight before and after the test denotes the level of absorbed water. The water absorption characteristic and behavior of each sample have been given in Figure 3. The level of unit area absorbed water (m) to time square root (t) has been drawn. Most of the samples reached saturation within less than three hours, while according to Figure 3, the said procedure continues with changes a little while after the mentioned time. The total amount of water absorbed varies from 0.06 g.cm\(^{-2}\) of sample B to about 0.16 g.cm\(^{-2}\) of samples BCE4 and BC150. After all, the total water absorption complies with two main trends. The first part includes initial water absorption, which has a steep slope, while such a trend disappears after a certain period of time.
4. Concluding remarks

In this study, totally 64 clay bricks in 16 groups were made. Four types of materials, i.e., fine and coarse plastic, cast iron, and iron swarf, were used as supplements of clay for brick production. A variety of weight percentages and sizes were also used. Specimens were subject to different tests to investigate the performance of bricks in terms of compressive strength, absorption percentage, modulus of rupture, and initial water absorption rate. The study highlighted findings are as follow:

1. The maximum compressive strength is related to specimens with higher powdered cast iron content, equal to 106.6 kg/cm, i.e., 46% more than the reference specimen. Also, adding different fine and coarse plastic particles percentages (except for BF25 specimen) caused this group of bricks are considered as non-load bearing and even unusable ones (concerning BC100 and BC150).
2. Highest modulus of rupture is for a specimen with higher powdered cast iron for 0.099 Pa, 15% more than the same for reference specimen. Also, it was observed that in cement contained specimens increased cement weight decreases MOR. Additionally, adding different weights of polyethylene coarse granules, highly decreases MOR up to 90% in BC150 in comparison to reference.
3. Using different coarse plastic granules weights in making clay bricks (even for limited values) results in an increase in water absorption out of the permitted range. Therefore, specimens with any cement contents cannot also be used to make facade bricks.
4. According to water absorption percentage changes at different times, water absorption changes behavior in all specimens may be classified into two groups. Specimens significantly absorb water within the first three hours with a relatively high slope, and after that, water absorption changes slope approaches zero.

References

[1] Iftikhar S, Rashid K, Haq E U, Zafar I, Alqahtani F K and Khan M I 2020 Synthesis and characterization of sustainable geopolymer green clay bricks: An alternative to burnt clay brick Construction and Building Materials 259 119659

[2] Kazmi S M S, Abbas S, Munir M J and Khitab A 2016 Exploratory study on the effect of waste rice husk and sugarcane bagasse ashes in burnt clay bricks Journal of Building Engineering 7 372–8

[3] Ebadi Jamkhaneh M, Ahmadi M and Shokri Amiri M 2021 Sustainable reuse of inorganic materials in eco-friendly clay bricks: special focus on mechanical and durability assessment Journal of Materials in Civil Engineering 33 (6) 04021111
[4] De Silva G S and Perera B.V.A 2018 Effect of waste rice husk ash (RHA) on structural, thermal and acoustic properties of fired clay bricks Journal of Building Engineering 18 252–9
[5] Mohajerani A, Kadir A A and Larobina L 2016 A practical proposal for solving the world’s cigarette butt problem: Recycling in fired clay bricks Waste Management 52 228–44
[6] Faria K C P, Gurgel R F and Holanda J N F 2012 Recycling of sugarcane bagasse ash waste in the production of clay bricks Journal of Environmental Management 101 7–12
[7] Ornam K, KimSan M and Ngkoimani L O 2017 Study on physical and mechanical properties with its environmental impact in Konawe-Indonesia upon utilization of sago husk as filler in modified structural fly ash-bricks Procedia Computer Science 111 420–26
[8] ASTM C62-17 2017 Standard Specification for Building Brick (Solid Masonry Units Made from Clay or Shale) (West Conshohocken, PA: ASTM International)
[9] Kazmi S M, Abbas S, Nehdi M L, Saleem M A and Munir M J 2017 Feasibility of using waste glass sludge in production of ecofriendly clay bricks Journal of Materials in Civil Engineering 29 (8) 04017056.
[10] Man J, Gao W, Yan S, Liu G and Hao H 2017 Preparation of porous brick from diatomite and sugar filter mud at lower temperature Construction and Building Materials 156 1035-1042
[11] Schackow A, Stringari D, Senff L, Correia S L and Segadães A M 2015 Influence of fired clay brick waste additions on the durability of mortars Cement and Concrete Composites 62 82–9
[12] Sutcu M, Alptekin H, Erdogmus E, Er Y and Gencel O 2015 Characteristics of fired clay bricks with waste marble powder addition as building materials Construction and Building Materials 82 1–8
[13] Erdogmus E, Harja M, Gencel O, Sutcu M and Yaras A 2021 New construction materials synthesized from water treatment sludge and fired clay brick wastes Journal of Building Engineering 42 102471
[14] Kazmi S M S, Munir M J, Wu Y F, Hanif A and Patnaikuni I 2018 Thermal performance evaluation of eco-friendly bricks incorporating waste glass sludge Journal of Cleaner Production 172 1867-1880
[15] Okunade E A 2008 The effect of wood ash and sawdust admixtures on the engineering properties of a burnt laterite-clay brick Journal of applied sciences 8 (6) 1042–8
[16] Hassan K M, Fukushi K, Turikuzzaman K and Moniruzzaman S M 2014 Effects of using arsenic–iron sludge wastes in brick making Waste Management 34 (6) 1072–8
[17] ASTM C67-11 2011 Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile (West Conshohocken, PA: ASTM International)
[18] DKS 2802-1 Kenya Standard 2019 Masonry units – Methods of test, Part 1: Determination of compressive strength (Nairobi, Kenya: Kenya Bureau of Standards)
[19] Iranian Ministry of Housing and Urban Development 2014 Iranian National Building Code, Part 8: Masonry Buildings, 2nd Edition (Tehran, Iran: Ministry of Roads and Urban Development)