Compressed unfired blocks made with iron ore tailings and slag

H K Thejas and Nabil Hossiney

Cogent Engineering (2022), 9: 2032975
Compressed unfired blocks made with iron ore tailings and slag

H K Thejas¹ and Nabil Hassiney¹*

Abstract: Growing demand for houses in urban India has increased the requirements for construction materials such as clay fired bricks and cement blocks. At the same time, conventional practice of brick manufacturing is not environment friendly due to high energy consumption and CO₂ emissions during various stages of its production. Therefore, recent trend in research has been directed towards utilization of various industrial wastes and methods, which emerge as sustainable alternatives for environmental concerns arising in the construction industry. This study focused on utilizing mining waste, namely iron ore tailing (IOT) in development of stable blocks. It has reported various properties of compressed unfired blocks formed by IOT and ground granulated blast furnace slag (GGBS) in varying proportions and with a fixed amount of lime. The combination of GGBS and lime was found to be suitable in stabilizing IOT towards block production. Furthermore, a maximum compressive strength of 7.7 MPa was achieved for blocks after 28 days of air curing. Also, the addition of GGBS has reduced the water absorption and apparent porosity of the IOT blocks, confirming the positive interaction between IOT, GGBS and lime. It also indicates the prospective of blended binders in improving the compactness of the blocks, which will have direct influence on the durability and service life of the blocks. Finally, the results show that most of the developed blocks satisfy the requirement of IS 1077 specification and can be used in various applications such as load and non-load bearing walls, framed structures, foundations and pedestrian walkways.

ABOUT THE AUTHOR

H K Thejas holds a B.E. (Civil) and MTech (Structural Engineering) degree. Currently, he is pursuing PhD in Civil Engineering at CHRIST (Deemed to be University), Bangalore, India. He is working with CHRIST (Deemed to be University) as Assistant Professor in the Department of Civil Engineering from last 5 years. He has published articles in various national and international journals. He is the project guide for BTech and MTech students of CHRIST (Deemed to be University). His research interests include studies on Sustainable building materials.

PUBLIC INTEREST STATEMENT

The ambitious plan of “Housing for all” launched by the government of India is expected to increase the demand for houses in urban and semi-urban regions of the country in the coming years. At the same time, the increased use of conventional materials such as fired bricks and cement blocks contributes to global carbon emissions annually. Therefore, a need arises to look for alternative materials and methods to reduce the environmental burden. This study reports the experimental results of compressed unfired blocks made with waste iron ore tailings and slag. It shows the potential of blended binders in stabilizing iron ore tailings towards block production. Furthermore, it reduces the environmental damage associated with conventional methods of brick production and also reduces the burden of discarding waste tailings at dumping sites, thus encouraging sustainable practices in the construction industry.
Subjects: Environmental; Waste & Recycling; Construction Materials

Keywords: Compressed block; iron ore tailings; slag; strength; porosity

1. Introduction

India’s vision of “Housing for all by 2022” an initiative by the government of India focuses on providing housing to the urban poor by year 2022. Accordingly, it is believed that the core demand for housing units in urban and rural regions accounts for a total of 90 million units (Funding the vision—“Housing for all by, 2022”). This will significantly increase the utilization of construction materials like bricks and blocks in the industry. Furthermore, due to complete dependency on conventional materials, burden on the existing natural resources has increased. Therefore, use of industrial waste in manufacturing of bricks has caught the attention of several researchers (Elahi et al., 2018; Hassiney et al., 2018; Rivera et al., 2021). The common building blocks used are fired clay bricks and cement blocks. However, in case of fired bricks, the manufacturing technique is not environment friendly, since firing process leads to CO₂ emission. Furthermore, cement block manufacturing is dependent on Portland cement, and its manufacturing process also contributes towards CO₂ emissions. Therefore, most recent studies are oriented towards the use of alternative binders in block production (Elahi et al., 2021; Nshimiyimana et al., 2021, 2020). The practice of industrial ecology, which focuses on conserving and reusing resources, can address some of the above-mentioned issues in the construction industry. Furthermore, waste of one industry as a raw material substitute for another would be an ideal preference.

In India, iron ore and steel industries play a major role in economic development of the country. At the same time, this industry generates various types of solid waste. One such waste is iron ore tailing (IOT), which is generated during beneficiation process of iron ore. Also, the ratio of IOT generated to that which is utilized is high, due to lack of advanced beneficiation techniques for low-grade ores in iron making process (Patra et al., 2019), and hence, a large quantity of these tailings are dumped at the mine sites or tailing ponds. Therefore, there is a need to find alternative reuse techniques of IOT in the construction industry. With respect to application of IOT as a civil engineering material, various studies have been attempted in recent past (Filho et al., 2017; Kuranchie et al., 2015; Xu et al., 2021; Zhang et al., 2020; Zhao et al., 2021). However, its use in development of stable blocks would be desirable due to aforementioned scenario in the construction industry. Furthermore, there are very few research studies on utilization of IOT as a raw material in compressed unfired building blocks (Das et al., 2019; Kuranchie et al., 2016; Nagaraj & Shreyasvi, 2017), particularly its combination with ground granulated blast furnace slag (GGBS) and lime. Therefore, the present study is focused on the production of compressed unfired blocks using IOT as base material, GGBS as pozzolanic material and lime for chemical activation.

2. Research objectives and significance

This article has twofold objective, which is development of stable building blocks with utilization of IOT, GGBS and lime, and investigate the physical and mechanical properties of developed IOT blocks and ascertain their applicability as per the Indian standards. Till date, very limited studies have explored the potential of IOT as building block, and therefore, this study helps to fill the gap in this research area. Furthermore, the outcome of this study will help to effectively utilize the waste IOT and address the needs of the construction industry in an environment-friendly manner.

3. Materials and methods

3.1. Materials

IOT was acquired from BMM ISPAT mines located in Bellary, Karnataka, India, while GGBS was acquired from a ready-mix concrete plant. Lime used in this study was hydrated lime acquired from the local market. The physical and chemical properties of lime were provided by the supplier, while for GGBS and IOT, various techniques were adopted to determine their physical and chemical properties. X-ray fluorescence (XRF) was used to perform the elemental analysis, and X-ray
diffraction (XRD) was used for mineralogical composition. Furthermore, the textural behavior of the sample was studied using scanning electron microscope (SEM). Table 1 presents the physical and chemical properties of the raw materials. Elemental analysis shows that IOT primarily consists of silica and iron, and its crystalline phase is shown in Figure 1. As seen, the majority of iron phase is in the form of silicate minerals, such as aerinite as identified in this study, and therefore, the presence of iron is still predominant, since separation of such materials with traditional methods is not effective. The GGBS used in this study satisfies various standards. For instance, the ratio of (CaO + MgO/ SiO₂) is greater than 1, and it satisfies the BS 146 (1996) requirements. Also, sulfur content is less than 2.5%, which satisfies the (ASTM C989/C989M-18a, 2018) requirements. Furthermore, Figure 2 confirms the amorphous nature of GGBS. Finally, Figure 3 reveals the smooth surface angular particles of GGBS in comparison with the relatively rough surfaced irregular particles of IOT.

3.2. Mix proportioning

In India, the generation of GGBS is expected to grow from 44 Mt per annum in 2020 to 95 Mt per annum in 2030 (Existing and Potential Technologies for Carbon Emissions Reductions in the Indian Cement Industry, 2013). Therefore, effective use of GGBS can play a major role in achieving sustainable solutions in the construction industry (B et al., 2021). Thus, in this study, GGBS was considered as a pozzolanic material. Furthermore, lime was also used, since it promotes the pozzolanic reactivity of GGBS (Oti et al., 2008). Table 2 presents the mix proportions considered in this study. Before finalizing the mixes, various laboratory trials were studied and it was observed that mixes with greater than 10% water did not perform, since they were wet and demoulding the compacted blocks was not possible. Also, water demand reduced as IOT percent increased, which was attributed to the particle size of IOT. Finally, after various trials, a total of five different combinations were selected for the preparation of building blocks, with mix/block ID designation as 421-44 G, which represents 42% IOT and 44% GGBS, respectively. As seen, IOT replacement varied from 42 to 82% with combined (lime + GGBS) varying from 48 to 11%, respectively. These replacement rates were selected to maximize the utilization of IOT. Also, for effective activation of

| Table 1. Physical and chemical properties of raw materials |
|----------------------------------------------------------|
| **Composition or property**                              | **IOT** | **GGBS** | **Lime** |
| SiO₂ (%)                                                | 35.49   | 32.5     | 1.54     |
| Al₂O₃ (%)                                               | 8.89    | 17.54    | 1.17     |
| Fe₂O₃ (%)                                               | 40.19   | 1.36     | 0.02     |
| CaO (%)                                                 | 3.30    | 37.10    |          |
| MgO (%)                                                 | 1.24    | 7.34     | 0.15     |
| K₂O (%)                                                 | 0.25    | 0.31     |          |
| TiO₂ (%)                                                | 7.14    | 0.85     |          |
| Na₂O                                                    | -       | 0.57     |          |
| SO₃                                                     | -       | 0.63     |          |
| Ca (OH)₂                                                | -       | -        | 96.62    |
| CaCO₃                                                   | -       | -        | 0.50     |
| Loss on ignition (%)                                    | 3.5     | 1.8      |          |
| Specific gravity                                        | 3.20    | 2.65     | 2.10     |
| Fineness modulus                                        | 2.70    | 2.83     |          |
| Color                                                   | Brownish red | Grey   | White    |
| Form                                                    | Powder                          | Powder                          | Powder                          |
GGBS, 3–8% of lime is considered favourable for various soil stabilization applications (Oti et al., 2009). Therefore, in this study, lime replacement was fixed at 4% by weight of the mix.

3.3. Block preparation
For preparation of the blocks, raw materials were weighed as per the quantities mentioned in Table 2. Later, all the materials were dry mixed thoroughly. Water was added and mixing continued till consistent mixture was achieved. Then, the mixture was introduced into steel moulds of size (230 × 110 × 70) mm and compacted with a hand pressing Mardini block making machine. Figure 4 (a) shows the Mardini block making machine with specimen preparation in progress. After compaction, the specimens were removed from the mould and kept for air drying, as shown in (Figure 4b).

3.4. Test methods
Laboratory tests were performed on the prepared blocks following standard procedures. Table 3 presents the different tests conducted on the air-dried blocks. For each of the tests, three trials were
Compressive strength test was performed after 7, 14 and 28 days of curing according to IS 1 to 4 (1992). The observed uneven bed faces of the blocks were removed by grinding the parallel faces and immersed in water at room temperature for 24 hours, before testing in compression testing machine. Load was applied axially at a uniform rate of 14 N/mm² per minute till failure. Compressive strength was determined by considering the maximum load at failure. Water absorption test was performed as per IS-3495 part 2, 1992. Initially the specimens were dried in a ventilated oven at a temperature of 105 °C, till they attained constant mass. Later the specimens were cooled to room temperature and their dry weights was noted. Afterwards, the specimens were immersed in clean water for 24 hours and then removed, surface cleaned and weighed. Water absorption was

| Mix / block ID | Material (%) | Material per block (kg) |
|----------------|--------------|-------------------------|
|                | IOT | GGBS | Lime | Water | IOT | GGBS | Lime | Water |
| 421-44 G       | 42  | 44   | 4    | 10    | 1.68 | 1.76 | 0.16 | 0.4   |
| 521-35 G       | 52  | 35   | 9    | 2.08  | 1.4  |     |     | 0.36  |
| 621-26 G       | 62  | 26   | 8    | 2.48  | 1.04 |     |     | 0.32  |
| 721-17 G       | 72  | 17   | 7    | 2.88  | 0.68 |     |     | 0.28  |
| 821-7 G        | 82  | 7    | 7    | 3.28  | 0.28 | 0.28 |     | 0.28  |

Figure 3. Micrographs of (a) GGBS and (b) IOT.

Figure 4. (a) Mardini block making machine and (b) prepared blocks.
determined by knowing the difference in the weight of wet and dry specimens and divided by its dry weight. Apparent porosity of the blocks was determined in accordance with \( \text{ASTM C20-00, 2015} \). The air-cured block was cut into four equal pieces and was kept in the ventilated oven for 24 hours. After drying in oven, it was taken out and weighed, the weight was noted as “D”. Then, the specimen was kept in the boiling water bath for 2 hours. Later, the specimen is allowed to cool for 12 hours while still submerged completely in water. The suspended weight of the specimen was determined and noted as “S”, and the saturated weight of brick is noted as “W”. The apparent porosity and bulk density of block was determined using equations (1) and (2).

\[
\text{Apparent porosity (\%)} = \frac{W - D}{W - S} \times 100 \tag{1}
\]

\[
\text{Bulk density (g/cm}^3) = \frac{D}{V} \tag{2}
\]

Where, \( W \) = saturated weight, \( D \) = dry weight, \( S \) = suspended weight, \( V \) = exterior volume of block including the pores.

Table 3. Tests performed on the prepared blocks

| Tests                      | Curing period (Days) | Standard                        |
|---------------------------|----------------------|--------------------------------|
| Compressive strength      | 7, 14, 28            | IS 3495 (Parts 1 to 4): (1992)  |
| Water absorption          | 28                   |                                |
| Efflorescence             | 28                   |                                |
| Dimensions and tolerances | 28                   | IS 1077: (1992)                 |
| Apparent porosity         | 28                   | ASTM C20-00 (2015)             |
| Bulk density              | 28                   |                                |

Figure 5. Various tests in progress (a) compressive strength, (b) water absorption, (c) efflorescence, (d) dimensions and tolerances, (e) apparent porosity.
Visual observations were made to study the internal structure of the blocks. Efflorescence test was conducted as per IS-3495 part 3, 1992. Initially, the air cured specimen was kept in a metal tray in such a way that part of the specimen is immersed in water. While, care was taken to ensure that the specimen is immersed in water up to 25 mm height from the bottom of the tray. After 24 hours of immersion, the specimen was taken out and kept in shade to observe if any efflorescence is formed on the specimen. Dimensions and tolerances was conducted as per IS 1077 (1992); a total of 20 blocks were randomly selected for the test, which are free from defects like cracks, flaws, etc. All the blocks were arranged lengthwise in contact with each other in a straight line on a level surface; overall dimensions of the arranged blocks were measured to get the average dimension of each unit. Figure 5 shows the progress of various tests conducted.

4. Results and discussion

4.1. Compressive strength and block density
Masonry is a material which is characterised by its strong behavior in compression and weak behavior in tension. Therefore, in the selection process of the blocks for load bearing structures, it is crucial to know its compressive strength. Figure 6 shows the compressive strength of various blocks prepared. As seen, the performance of blocks improved with increase in GGBS content, especially after 28 days of curing. The average compressive strength of 7.7 MPa for 42I-44 G was the best among all the block types. Such improvements can be attributed to the complex reaction mechanism of GGBS and lime with IOT. Generally, when GGBS and lime are blended with soil, it causes a distinct reaction. This includes an exothermic reaction causing rapid ion exchange and
a much slower pozzolanic reaction, which results in soil improvement and stabilization, respectively (Oti et al., 2009). Furthermore, there is possibility of calcium ion exchange from lime and GGBS with metallic ions in the IOT. Also, slower reaction of calcium with silica and alumina in IOT forms much stable silicates and aluminates providing better strength and durability over time. (Figure 7a) shows the failure of a block in compression. It was observed that cracks initiated at the edges of the block and propagated, causing failure. (Figure 7b) shows the internal structure of the block. The blocks showed well compacted structure with very small voids randomly distributed. Furthermore, the presence of GGBS particles was also evidenced.

The density of a block is one of the key parameters in the design of masonry structures. For conventional fired bricks or earthen blocks, the density ranges between 1.8 and 1.9 g/cm³. However, in the present study, introduction of IOT exhibited slightly higher density, which was in the range of 2.15 to 2.2 g/cm³ for various block types, as shown in Figure 8. Furthermore, such

| Block type | Parameter | Standard size of block (mm) | Average of 20 blocks (mm) | Observed difference (mm) | Allowable difference as per IS 1077–1992 (mm) |
|------------|-----------|-----------------------------|---------------------------|--------------------------|-----------------------------------------------|
| 42I-44 G   | Length    | 230                         | 228                       | 2                        | ±5                                            |
|            | Width     | 110                         | 107                       | 3                        | ±3                                            |
|            | Depth     | 70                          | 67                        | 3                        | ±3                                            |
| 52I-35 G   | Length    | 230                         | 227                       | 3                        | ±5                                            |
|            | Width     | 110                         | 108                       | 2                        | ±3                                            |
|            | Depth     | 70                          | 68                        | 2                        | ±3                                            |
| 62I-26 G   | Length    | 230                         | 227                       | 3                        | ±5                                            |
|            | Width     | 110                         | 108                       | 2                        | ±3                                            |
|            | Depth     | 70                          | 67                        | 3                        | ±3                                            |
| 72I-17 G   | Length    | 230                         | 227                       | 3                        | ±5                                            |
|            | Width     | 110                         | 107                       | 3                        | ±3                                            |
|            | Depth     | 70                          | 68                        | 2                        | ±3                                            |
| 82I-7 G    | Length    | 230                         | 226                       | 4                        | ±5                                            |
|            | Width     | 110                         | 107                       | 3                        | ±3                                            |
|            | Depth     | 70                          | 67                        | 3                        | ±3                                            |

Figure 8. Density of prepared blocks.
increase can be attributed to tight packing of fine IOT particles and slightly higher specific gravity of IOT.

4.2. Water absorption, apparent porosity and efflorescence

The durability of blocks can be understood by determining its water absorption. Lower absorption for blocks can provide better resistance to damage due to freezing. It also helps to understand the pores in the blocks. Generally, most standards recommend the water absorption for clay bricks to be less than 20%. Figure 9 shows the water absorption test results. As seen, the best performance was observed for 42I-44 G, which is similar to that of compressive strength results. This can be attributed to the presence of lime and GGBS, which improves the pozzolanic reaction of such system and leads to the formation of alumino-silicates. Furthermore, for the blocks with higher GGBS, exothermic reaction initiates a faster dissolution of amorphous silica in IOT and GGBS. This also gives rise to generation of pozzolanic reaction products, which fill up the pores and make such blocks denser, and further reduce its water absorption. Finally, all the prepared blocks demonstrate water absorption within the permissible limits of IS 1077 (1992).

Apparent porosity is an important test to validate the quality of refractory bricks. ASTM C20 uses this property in practice for selection criteria for various industrial applications as well as to evaluate and compare the quality of the bricks. It indicates the compactness of the material and its particle size composition. Generally, lower porosity provides higher compressive strength and better durability for the blocks. Figure 10 shows the apparent porosity of the prepared blocks. As seen, the lowest porosity was obtained for 42I-44 G, and it is comparable with that of conventional fired bricks which possess apparent porosity in the range of 33–44% (Hossiney et al., 2018). This finding reassures the performance of 42I-44 G, which is in line with the findings of compressive strength and water absorption. It also indicates that increasing the GGBS content
has improved the compactness of the blocks due to its fine size particles. Furthermore, the products of the pozzolanic reaction help fill the small voids and thereby reduce the porosity of the blocks.

Efflorescence is attributed to the deposit of the soluble salts on the brick surface. It is very common when there is presence of water-soluble salt, water and porous medium in the brick. Figure 11 shows the efflorescence test results on the prepared blocks. Most of the blocks did not show any sign of efflorescence, except for 821-7 G which showed mild efflorescence. This suggests that prepared blocks were compact with minimum pores, which avoid the movement of the soluble salt through such medium. It also assures the potential of such blocks in practical applications and further suggests the positive interaction between GGBS, lime and IOT in developing much stable and durable building blocks.

4.3. Dimensions and tolerances
The dimensions and tolerances of compressed blocks are important to ensure uniformity in the design of the joints in the masonry work. Furthermore, in field practice, the contractor expects the average dimensions of the blocks to be in conformity with nominal dimensions. This ensures the quality of masonry work. Therefore, most international standards expect dimensions and tolerances to be in the permissible limits. Any dimension change in blocks can be attributed to the volumetric changes due to the reaction of various materials in the block. Table 4 presents the test results of dimensions and tolerances. As seen, most of the blocks satisfy the limit set by IS 1077—1992.

4.4. Environmental benefits
Sustainable building blocks should be able to reduce inputs from natural resources and also minimize environmental impact during various stages of production. Therefore, to understand the environmental benefits of prepared blocks, it is important to know the total energy consumption and CO₂ emissions. While it is difficult to establish accurate environmental benefits of the proposed blocks due to lack of existing information on iron ore tailings, it is still possible to appreciate the benefits of such construction materials by the outcome of study by (Oti & Kinuthia, 2012). According to the authors, unfired blocks produced with GGBS and lime substantially reduce energy usage and total CO₂ emissions. As seen in Figure 12, it translates to 84% lower energy usage and 80% lower CO₂ emissions for unfired blocks when compared to fired bricks, respectively. Furthermore, there are ill-effects of waste IOT disposed at tailing dams, which has also resulted in devastating effects on the environment (Hk & Hossiney, 2021; Protasio et al., 2021). Therefore, utilization of IOT in compressed unfired blocks will incur benefits such as minimization of waste at the dumping sites and reduced use of virgin raw materials for block production. Furthermore, IOT building blocks can be a perfect candidate for energy-efficient masonry wall structures and also aid towards construction of cost-effective houses in developing countries.
Figure 12. Estimate of carbon dioxide emission and energy usage for production of 1 tonne of various types of brick.

5. Conclusions
In the present study, compressed unfired IOT blocks stabilized with GGBS and lime have been investigated. Based on various standard tests on the blocks, following important findings and conclusion can be drawn.

(1) There is significant enhancement in the compressive strength of IOT blocks with incremental addition of GGBS. The best performance of 7.7 MPa after 28 days of curing was observed for block 42I-44 G. Such improvement can be attributed to distinct reaction between GGBS and lime with IOT, which provides better strength over time. Furthermore, it indicates the prospective of blended binders in development of stable IOT blocks.

(2) The density of the developed blocks varied between 2.15 and 2.2 g/cm³, which is slightly higher than the conventional clay blocks due to higher specific gravity of the IOT particles and also tight compaction during casting of blocks.

(3) The water absorption of 13% and apparent porosity of 36% for 42I-44 G was the lowest among all the block types. This assures the positive interaction between GGBS, lime and IOT, which improves the compactness of the blocks primarily due to filling up of the voids with products of pozzolanic reaction and GGBS particles. Furthermore, lack of efflorescence for such blocks corroborates its practical feasibility.

(4) The proposed method of utilizing IOT, GGBS and lime in developing building blocks can significantly reduce environmental damage associated with conventional firing method of brick production. The unfired blocks with waste IOT will also reduce the burden at dumping sites and encourage sustainable practice in construction industry.

(5) Based on the findings of this study all the blocks satisfy the requirement of IS 1077 for compressive strength, water absorption, dimensions and tolerances, and efflorescence. Furthermore, it can be used for various applications such as partition walls in framed structures, load bearing and non-load bearing walls, foundations and pedestrian walkways.

Acknowledgements
The authors would like to thank the lab staff of Civil and Mechanical Engineering Department at CHRIST (Deemed to be University) for providing support for this study.

Funding
The authors received no direct funding for this research.

Author details
H K Thejas
ORCID ID: http://orcid.org/0000-0003-2978-3822
Nabil Hossiney
E-mail: nabil.jalali@christuniversity.in
ORCID ID: http://orcid.org/0000-0001-5999-5653
1 Department of Civil Engineering, Christ (Deemed to Be University), Bangalore, India.

Disclosure statement
No potential conflict of interest was reported by the author(s).

Citation information
Cite this article as: Compressed unfired blocks made with iron ore tailings and slag, H K Thejas & Nabil Hossiney, Cogent Engineering (2022), 9: 2032975.

References
ASTM C20-00. (2015). Standard test methods for apparent porosity, water absorption, apparent specific gravity, and bulk density of burned refractory brick and shapes by boiling water. ASTM International.
ASTM C989/C989M-18a. (2018). Standard specification for slag cement for use in concrete and mortars. ASTM International.
B. R. Y., Y. R. R., Hossiney, N., & T. D. H. (2021). Properties of high strength concrete with reduced amount of portland cement—A case study. Cogent Engineering, 8(1), 1938369. https://doi.org/10.1080/23311916.2021.1938369

BS 146. (1996). Specification for portland blast furnace cements (9th ed.). BSI.

Das, P., Beulah, M., Hossiney, N., Dunna, U. M., & Kavitha, S. (2019). A probable mathematical relationship between (Si/Al) ratio and (Ca/Si) ratio on the compressive strength of an iron ore tailings sample arising out of geopolymeric reactions. Journal of Mining and Metallurgy A: Mining, 55(1), 27–36. https://doi.org/10.5937/JMMA1901027D

Elahi, T. E., Shahriar, A. R., & Islam, M. S. (2021). Engineering characteristics of compressed earth blocks stabilized with cement and fly ash. Construction and Building Materials, 277, 123357. https://doi.org/10.1016/j.conbuildmat.2021.122367

El-Mohlawy, M. S., Kondeel, A. M., Abdel Latif, M. L., & El-Nagor, A. M. (2018). The feasibility of using marble cutting waste in sustainable building clay industry. Recycling, 3(3), 39. https://doi.org/10.3390/recycling3030039

Existing and Potential Technologies for Carbon Emissions Reductions in the Indian Cement Industry. (2013) A set of technical papers produced for the project ‘low carbon technology road map for the Indian cement industry.

Filho, J. N., S., Do, S. N., Silva, G. C., Mendes, J. C., & Peixoto, R. A. F. (2017). Technical and environmental feasibility of interlocking concrete pavers with iron ore tailings from tailings dams. Journal of Materials in Civil Engineering, 29(9), 9, 04017104. https://doi.org/10.1061/(ASCE)MT.1943-5533.0001937

Funding the vision – Housing for all by. (2022). Banking conclave by KPMG. Accessed at KPMG-NAREDCO-Funding-the-vision.pdf.

HK, T., & Hossiney, N. (2021) A short review on environmental impacts and application of iron ore tailings in development of sustainable eco-friendly bricks. Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2021.09.522

Hossiney, N., Das, P., Mohan, M. K., & George, J. (2018). In-plant production of bricks containing waste foundry sand—A study with Belgian foundry industry. Case Studies in Construction Materials, 9, e00170. https://doi.org/10.1016/j.cscm.2018.e00170

IS 377. (1992). Compressed burnt clay building bricks — Specifications. Bureau of Indian Standards.

IS 3495 - Parts 1 to 4. (1992). Methods of Tests of burnt clay building bricks. Bureau of Indian Standards.

Kuranchie, F. A., Shukla, S. K., & Habibi, D. (2016). Utilisation of iron ore mine tailings for the production of geopolymer bricks. International Journal of Mining, Reclamation and Environment, 30(2), 92–114. https://doi.org/10.1080/17480930.2014.993834

Kuranchie, F. A., Shukla, S. K., Habibi, D., & Mohyeddin, A. (2015). Utilisation of iron ore tailings as aggregates in concrete. Cogent Engineering, 2(1), 1083137. https://doi.org/10.1080/23311916.2015.1083137

Nagaraj, H. B., & Shreyasvi, C. (2017). Compressed stabilized earth blocks using iron mine spoil waste - an explorative study. Procedia Engineering, 180, 1203–1212. https://doi.org/10.1016/j.proeng.2017.04.281

Nahmirymano, P., Messan, A., & Courard, L. (2020). Physico-mechanical and hygro-thermal properties of compressed earth blocks stabilized with industrial and agro by-product binders. Materials, 13(17), 3760. https://doi.org/10.3390/ma13173769

Nahmirymano, P., Messan, A., & Courard, L. (2021). Hydric and durability performances of compressed earth blocks stabilized with industrial and agro by-product binders: Calcium carbide residue and rice husk ash. Journal of Materials in Civil Engineering, 33(6), 04021121. https://doi.org/10.1061/(ASCE)MT.1943-5533.0003745

Oti, J. E., & Kinuthia, J. M. (2012). Stabilised unfired clay bricks for environmental and sustainable use. Applied Clay Science, 58, 82–99. https://doi.org/10.1016/j.clay.2012.01.011

Oti, J. E., Kinuthia, J. M., & Bai, J. (2008). Using slag for unfired-clay masonry-bricks. Construction Materials, 16(14), 147–155. https://doi.org/10.1680/coma.2008.16.14.147

Oti, J. E., Kinuthia, J. M., & Bai, J. (2009). Engineering properties of unfired clay masonry bricks. Engineering Geology, 107(3–4), 130–139. https://doi.org/10.1016/j.enggeo.2009.05.002

Patra, S., Pattanaik, A., Venkatesh, A. S., & Venugopal, R. (2019). Mineralogical and chemical characterization of low grade iron ore fines from barseus area, eastern India with implications on beneficiation and waste utilization. Journal Geological Society of India, 93, 443–454. https://doi.org/10.1007/s12594-019-1199-4

Protasio, F. N. M., de Avillez, R. R., Letichevsky, S., & de Andrade Silva, F. (2021). The use of iron ore tailings obtained from the Germano dam in the production of a sustainable concrete. Journal of Cleaner Production, 278, 123929. https://doi.org/10.1016/j.jclepro.2020.123929

Rivero, J., Coelho, J., Silva, R., Miranda, T., Castro, F., & Cristelo, N. (2021). Compressed earth blocks stabilized with glass waste and fly ash activated with a recycled alkaline cleaning solution. Journal of Cleaner Production, 284, 124783. https://doi.org/10.1016/j.jclepro.2020.124783

Xu, F., Wang, S., Li, T., Liu, B., Li, B., & Zhou, Y. (2021). Mechanical properties and pore structure of recycled aggregate concrete made with iron ore tailings and polypropylene fibers. Journal of Building Engineering, 33, 101572. https://doi.org/10.1016/j.jobe.2020.101572

Zhang, W., Gu, X., Qiu, J., Liu, J., Zhao, Y., & Li, X. (2020). Effects of iron ore tailings on the compressive strength and permeability of ultra-high performance concrete. Construction and Building Materials, 260, 119917. https://doi.org/10.1016/j.conbuildmat.2020.119917

Zhao, J., Ni, K., Su, Y., & Si, Y. (2021). An evaluation of iron ore tailings characteristics and iron ore tailings concrete properties. Construction and Building Materials, 286, 122968. https://doi.org/10.1016/j.conbuildmat.2021.122968
