



## Utilization of Iron Ore Tailings for Brick Manufacture from Donimalai Mines of Karnataka, India

Ranjeet Kumar Singh<sup>1,2</sup>, Debjit Pal<sup>3</sup>, Shailendra Kr Singh<sup>1,2</sup>, Nimisha Tripathi<sup>4</sup> and Raj S Singh<sup>1,2\*</sup>

<sup>1</sup>Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201 002 India

<sup>2</sup>CSIR-Central Institute of Mining and Fuel Research, Barwa Road Dhanbad – 826 015 India

<sup>3</sup>Jadavpur University, Kolkata, West Bengal 700 032 (India)

<sup>4</sup>IU-CERI, University of Greenwich, Chatham Maritime ME4TB, UK

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The iron tailings were mixed in various proportions with different combinations of cement, sand, and sodium silicate to obtain or value-added product out of iron tailing waste which is suitable for use in the construction industry. Bricks were made using a variety of compositions of iron tailings, Ordinary Portland Cement, sodium silicate, and sand in cuboid mould (9"X 5"X 3"). The bricks were dried for 24 hours, and then kilned at  $115 \pm 10^\circ\text{C}$  for 24 hours. Mechanical features such as water absorption, compressive strength, and efflorescence are tested. The maximum compressive strength rating of  $8.58 \text{ N/mm}^2$  was recorded with ratios of 8:2 (Iron tailing and cement). However, in process of making it economical, the ratio of 9:1 has opted and this ratio complies with the requirement of the Indian standard (IS: 1077:1992) of the common burnt clay building bricks. Water absorption for the proposed bricks is less than that of burnt clay bricks. The lower capillary pore can prevent the formation of efflorescence. This process, with the same parameters, can be exchanged commercially, and a large number of wastes of iron ore can be used to make bricks. Therefore, the technological processes identified in this paper can convert large amounts of hazardous waste into the environment into value-added products. Iron tailing can be seen as a stable addition to clay soils, its use when restricted to making bricks. This research helps to open a new area of research.

**Keywords:** Building materials, Clay brick, Compressive strength, Efflorescence, Water absorption

### Introduction

India ranks fourth concerning iron ore production in the world.<sup>1</sup> In 2019, the total world production of iron ore was 2,850 million tons (approx.) with an Indian contribution of around 230 million tons.<sup>2</sup> The unavailability of cost-effective technology for the extraction of iron ore leads to the generation of a huge amount of waste.<sup>3</sup> The stripping ratio in Indian iron ore mine ranges from 1–3:1.<sup>4</sup> Tailing waste is the material other than mineral which is generated during the excavation process, these wastes generated during beneficiation and processing, can at times be very high (when the ore is of a low grade).<sup>4</sup> The iron tailing (FeT) composition and amount vary from site to site depending on the characteristics of the host rock and the ore body. The unscientific and unplanned management of this waste in Indian mines is the chief cause of environmental degradation. Behra *et al.*<sup>5</sup> developed bricks by mixing iron ore tailing and clay in different proportions and found the highest

compressive strength (CS) of 25.40 MPa at  $950^\circ\text{C}$  in 40:60 proportions of clay and waste, respectively. Further, water absorption (WA) of iron ore bricks was low in comparison to fly ash and clay bricks. Modi *et al.*<sup>6</sup> manufactured bricks by mixing iron ore mine wastes with cement and sand in 40:30:30 proportions. The compressive strength and water absorption of bricks were 42.98 MPa and 2.42% respectively. The studies demonstrate that non fired bricks can be prepared from iron ore wastes without compromising their quality. Bricks manufactured from gold mine waste,<sup>7</sup> lime-slag with sand,<sup>8</sup> copper tailings<sup>9</sup> were also found suitable as building materials. Brick efflorescence is defined as a crystalline deposit of white, soluble salts,<sup>10,11</sup> generally fine, a powdery deposit of water-soluble salts left on the surface of bricks as the water evaporates<sup>12–14</sup> and all soluble salt that find its way into the materials may appear as efflorescence.<sup>15</sup> Formation of efflorescence can be reduced by reducing the proportion of sodium silicate and enhancing the proportion of cement for manufacturing the bricks. Therefore, the environment and its precious resources like soil must be preserved

\*Author for Correspondence  
Email: rajsscimfr@gmail.com

and conserved urgently to avoid worsening the situation. Solidification or stabilization is considered an effective solution for the long term. Since the method of solidification minimizes the environmental pollution risk and helps in natural resources conservation; it is a good substitute for other methods for disposal and remediation of the hazardous waste which are discarded improperly.<sup>16</sup> Clay component in tailing is the major raw material required for producing bricks.<sup>17</sup> Huge extraction of natural clay for brick manufacturing has resulted in substantial depletion of precious clay (a non-renewable resource). Commonly used clay bricks are prohibited in some countries and they are emphasizing the bricks made of solid waste for construction sites to eradicate the commonly burnt clay bricks.<sup>18,19</sup> Replacing clay with iron tailing is an eco-friendly and economic solution to produce bricks with inorganic substances and trace of metallic components (Fe, Al, and few heavy metals)<sup>18-20</sup>. Prefeasibility study indicated that the mine waste can be used as a natural resource for the manufacturing of bricks and have all the requisite physical and chemical properties of the normal burnt clay bricks used for the construction of dwellings. Several workers used different methods for utilizing different wastes to manufacture bricks, which need high temperature, kiln firing, or use a binder like sodium hydroxide with  $\text{Na}_2\text{SO}_3$  (Sodium silicate) and cement. They were also making bricks/block in cubic size or small sizes and bricks making process taken a longer time. The drawbacks of the methods were complex nature, time-consuming, longer production cycle, costly, and high energy consumption when compared to the present study. In this paper, an attempt has been made to manufacture alternative bricks from iron ore tailings of Donimalai mines of Bellary, Karnataka, India which fulfil the necessities of the international and national standards requirement of load and non-load bearing units using the minimum amount of cement content. This can be used by the infrastructure development of the country and also the preservation of natural resource the clay.

## Material and methods

### Raw materials

The study site is a hilly terrain in the Bellary district of south-west Karnataka, India. The iron tailing was acquired from hilltops and slopes of Donimalai. The mine site falls between  $15^\circ 02' 00''$  N and  $15^\circ 06' 30''$  N latitude, and  $76^\circ 36' 00''$  E and  $76^\circ 38' 30''$  E longitude.

The tailings (Fig.1) were acquired from National Mineral Development Corporation (NMDC) in Donimalai, Bellary Karnataka. Ordinary Portland Cement (OPC) and sodium silicates (SS) were procured from the local market of the Dhanbad district of Jharkhand. The riverine sand of Barakar River was used for brick making with casting and curing by tap water. The pH was almost neutral with the same electrical conductivity.

### Method of preparation

The flow chart of the manufacturing method of bricks is shown in Fig. 2. The experimental program is to produce iron tailing bricks to fulfilling the necessities of the national and international standards (i.e., IS and ASTM) either for load-bearing units or non-load bearing units using FeT with a minimum amount of OPC content. Simultaneously for achieving the target different ratios of FeT, OPC, S, and SS were utilized. The basic proportions in which the mixture of the different materials used was divided into four categories i) FeT, OPC and Sand in the ratio of (10:02:01, 09:03:01 and 08:04:01), ii) FeT, SS and OPC in the ratio of (09:01:01, 18:01:03, and 18:03:01), iii) FeT and SS in the ratio of (09:01,17:03 and 08:02), and iv) FeT and OPC in the ratio of (09:01, 17:03 and 08:02). To maintain the workability constant, more water was used to compensate for the higher WA and angular shape of FeT compare to clay

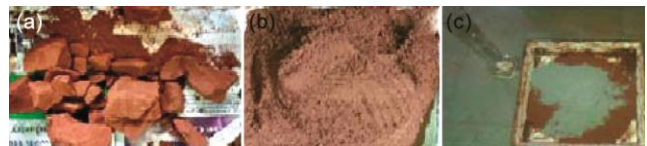
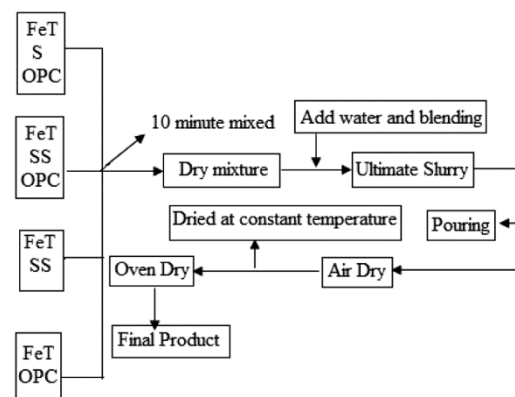


Fig. 1 — (a) Iron tailing (b) Size reducing less than 2 mm of Iron tailing, (c) Mixture (Iron tailing and binding agent)



FeT- Iron tailing, S- Sand, SS- Sodium silicate, OPC- Ordinary Portland cement

Fig. 2 — Flow chart of manufacturing bricks

bricks. The proportion of various components in the raw material for the manufacture of the FeT bricks are given in Table 1.

#### Mixing, curing, and testing

The dry mixtures with different proportions of FeT, C, SS, and S were mixed thoroughly for about 10 min and subsequently, water was added to create a homogenous paste (Table 1). The paste was poured into the wooden mould of size 9" X 5" X 3" and compacted using a vibrating table for making the brick specimens, The final specimen was air-dried for 24 hours, and the dehydrated specimen kept in the kiln for 24 hours at  $115 \pm 10^\circ\text{C}$ . The CS was measured by a universal testing machine (UTM) at CSIR-CIMFR, Dhanbad, India). WA of the bricks was determined following Archimedes method in deionized water<sup>21</sup> after soaking in water for 24 hours to the weight of brick before soaking in water and EFF tests were performed to keep the bricks edges inside the dish, the immersion depth water level is maintained at least 25 mm, the ambient temperature was around 20 – 30°C and the brick absorbs water in which it is immersed and also extra water gets evaporated. The dish is completely covered using a suitable glass cover to avoid extra fading. When bricks absorb all the water completely and look dry, the same amount of water is poured into the dish and wait till evaporate like before. Just after the second sequence of evaporation, the bricks were examined

for EFF. The XRF (X-Fluorescence) (Make: Panalytical Magi X PW 2424) was used to determine the iron tailing chemical compositions and the mineral phase identified through a range of 2θ angles of XRD (X-ray diffraction) (Make: Rigaku, Ultima IV), and finally, SEM (Scanning electron microscope) was used to study the brick's microstructure.

#### Characterization of brick samples

To obtain the optimum conditions for the preparation of bricks, the EFF, CS, WA, and BD tests were conducted. The CS, WA, and EFF tests were conducted as per IS 3495 Part 1, (1992); IS 3495 Part 2, (1992) and IS 3495 Part 3, (1992)<sup>22-24</sup> respectively. The CS and WA and EFF of the bricks were determined from equations 1, 2, and 3 respectively. Whereas the BD test of the specimen was calculated following equation 4.

$$\text{Compressive strength (CS)} = \frac{L}{A} \quad \dots(1)$$

Where L is the maximum load applied on the brick specimen and A is the average surface area of the two faces under compression.

$$\text{Water absorption}(W_A) = \frac{W_f - W_i}{W_i} \quad \dots(2)$$

Where  $W_i$  is the initial weight of brick before soaking in water and

$W_f$  is the final weight of bricks after soaking in water for 24 hours.

Table 1 — Mixing proportion of different components for manufacture of bricks

| Sample ID                                  | Mixing ratios | Additive 1 (g)      | Additive2 (g) | Additive 3 (g)       | Water (ml) |
|--|---------------|---------------------|---------------|----------------------|------------|
| (A) Iron tailings: cement: sand            |               |                     |               |                      |            |
|  |               | Iron tailings (FeT) | OPC           | Sand (S)             | NA         |
| A1   | 10:02:01      | 2769                | 554           | 277                  | 1200       |
| A2   | 09:03:01      | 2492                | 831           | 277                  | 1200       |
| A3   | 08:04:01      | 2215                | 1108          | 277                  | 1200       |
| (B) Iron tailings: sodium silicate: cement |               |                     |               |                      |            |
| NA   | NA            | Iron tailings (FeT) | OPC           | Sodium silicate (SS) | NA         |
| B1   | 09:01:01      | 2946                | 327           | 327                  | 1200       |
| B2   | 18:01:03      | 2864                | 159           | 477                  | 1180       |
| B3   | 18:03:01      | 2864                | 477           | 159                  | 1200       |
| (C) Iron tailings: sodium silicate         |               |                     |               |                      |            |
| NA   | NA            | Iron tailings (FeT) | NA            | Sodium silicate (SS) | NA         |
| C1   | 09:01         | 3150                | NA            | 350                  | 1200       |
| C2   | 17:03         | 2805                | NA            | 495                  | 1200       |
| C3   | 08:02         | 2800                | NA            | 700                  | 1200       |
| (D) Iron tailings: cement                  |               |                     |               |                      |            |
|  |               | Iron tailings (FeT) | OPC           | NA                   | NA         |
| D1   | 09:01         | 3150                | 350           | NA                   | 1210       |
| D2   | 17:03         | 2805                | 495           | NA                   | 1205       |
| D3   | 08:02         | 2800                | 700           | NA                   | 1260       |

$$\begin{aligned} \text{Efflorescence ratios}(\%) \\ = \frac{\text{Total area of efflorescence}}{\text{Total areas of brick side}} \times 100 \end{aligned} \quad \dots (3)$$

$$\text{Bulk density (BD)} = \frac{W_b}{V_b} \quad \dots(4)$$

Where  $W_b$  is the weight of brick before curing and  $V_b$  volume of brick.

Similarly, the plastic limit (PL), liquid limit (LL), and plasticity index (PI) of the waste sample was determined as per IS 2720 Part 5, (1985).<sup>25</sup>

## Result and Discussion

### Characterization of raw material

Results of the assessment of physical properties for specific gravity (SG), fineness modulus (FM), plastic limit (%), liquid limit (%), plasticity index (%), and maximum dry density ( $\text{g/cm}^3$ ) were 3.4, 2.81, 25, 40, 15, and 1.07, respectively (Table 2). Iron tailing is considered plastic (25%) due to the presence of alumina. The obtained results of PL, LL, and PI indicated the presence of kaolinite clay minerals in iron tailing composition<sup>26</sup>. The present study showed a PL value of 15%, which can be termed as medium plasticity.<sup>27</sup>

The chemical composition of the FeT is studied using XRF (X-ray fluorescence) analysis (Table 3).

Chemical composition of OPC indicated (24.98%  $\text{SiO}_2$ , 4.84%  $\text{Al}_2\text{O}_3$ , 3.02%  $\text{Fe}_2\text{O}_3$ , 61.24%  $\text{CaO}$ , and 1.42%  $\text{MgO}$ ) out of which presence of  $\text{CaO}$  is about 61% by weight which leads to a long-term build-up of strength.<sup>28</sup> Manufacturing of bricks requires certain binding materials (OPC and SS). The OPC is utilized due to the presence of suitable oxides of iron, alumina, and magnesia in the raw material. The calcium oxide presence is comparatively more than SS binder. The OPC is used in brick manufacturing as a source of reactive silica and alumina to enhance the pozzolanic reaction which depends on the water content in the binder to form silicate and aluminat

hydrates, this leads to the development of strength.<sup>29</sup> Silica and alumina when mixed with water to stop cracking, shrinkage or wrapping. The presence of silica in range of 17–25% increases the strength further due to the formation of dicalcium and tricalcium silicates. Higher contribution of silica and alumina in composition increases the setting time of cement at the time of formation of bricks.<sup>30</sup> Wherever early setting is required, we need to change the constituents (silica and lime) accordingly. FeT is plastic due to presence of alumina and its plasticity ensures that bricks can be moulded. It's also provides quick setting quality but reduces the strength while  $\text{Fe}_2\text{O}_3$  provides colour and hardness.<sup>30</sup> The results of XRD of the FeT are shown in Fig. 3, visibly shows that the hematite, quartz ( $\text{SiO}_2$ ) and Kaolinite are the major minerals phase, on the other hand Gibbsite and Muscovite are the minor minerals phase (Fig. 3). The high content of  $\text{SiO}_2$  is due to the presence of quartz and the high contents of  $\text{Al}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$  are due to the presence of kaolinite and hematite.<sup>31</sup>

According to Niroumand<sup>32</sup> presence of kaolin enhances the CS and created an exfoliated area for bricks, and it also contains moisture and the role of water act as a lubricant. Quartz and hematite help to increase CS.<sup>18</sup>

### Mechanical properties of the brick

#### Bulk density (BD)

The BD of different brick samples is presented in Table 4 and Fig. 4. The BD exhibited maximum value ( $2.12 \text{ g/cm}^2$ ) for A1 (FeT: C: S, 10:02:01) ratio and minimum value ( $1.88 \text{ g/cm}^2$ ) for A3 (FeT: C: S, 08:04:01) ratio (Fig. 4 a). Present study indicated that the iron tailing per cent in different combination ratio increased linearly with BD ( $R^2=0.96$ ) in all categories (Fig.4a, c, d) except category B ( $R^2=0.89$ ) (6b).

#### Compressive strength (CS)

Compressive strength (CS) is key factor for considering the application of bricks in construction work. In the Table 4 and Fig. 5, the CS of the brick

Table 2 — Physical properties of iron tailing (Mean of 3 samples).

| Property    | Specific gravity | Fineness modulus | Plastic limit (%) | Liquid limit (%) | Plasticity Index (%) | Maximum dry density ( $\text{g/cm}^3$ ) |
|-------------|------------------|------------------|-------------------|------------------|----------------------|---|
| Composition | 3.4              | 2.81             | 25                | 40               | 15                   | 1.07                                    |

Table 3 — Chemical composition (%) of Iron tailing raw materials and OPC

| Composition  | $\text{SiO}_2$ | $\text{Al}_2\text{O}_3$ | $\text{Fe}_2\text{O}_3$ | $\text{CaO}$ | $\text{MgO}$ | $\text{TiO}_2$ | $\text{K}_2\text{O}$ | $\text{Na}_2\text{O}$ | $\text{P}_2\text{O}_5$ | $\text{SO}_3$ | LoI  |
|--------------|----------------|-------------------------|-------------------------|--------------|--------------|----------------|----------------------|-----------------------|------------------------|---------------|------|
| Iron tailing | 49.00          | 23.22                   | 24.76                   | 0.23         | 0.53         | 1.15           | 0.3                  | 0.04                  | 0.15                   | 0.58          | 0.04 |
| OPC          | 24.98          | 4.84                    | 3.02                    | 61.24        | 1.42         | 0.48           | 0.39                 | 0.29                  | 0.8                    | 2.5           | 0.07 |

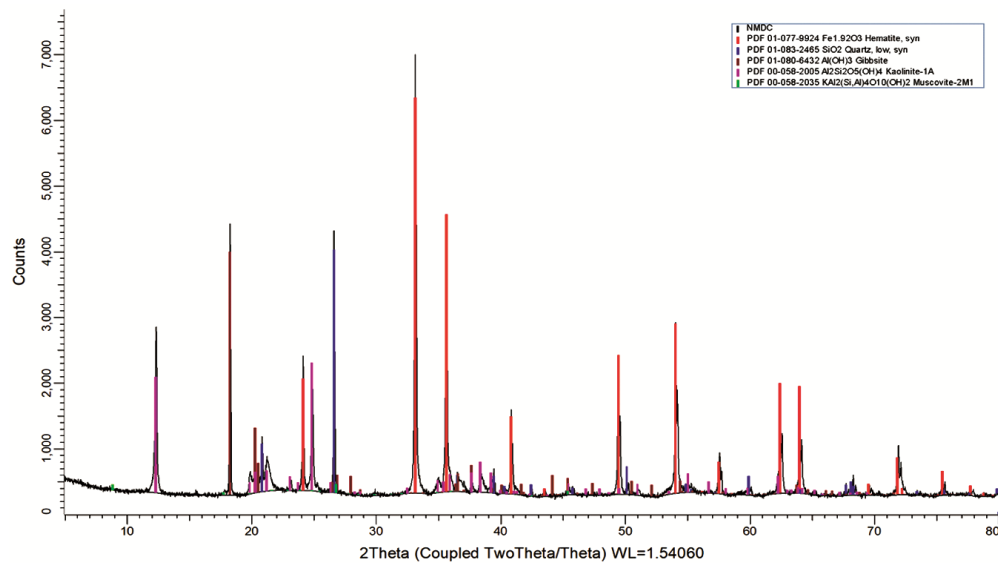


Fig. 3 — XRD pattern of Iron tailing material

Table 4 — Water absorption, compressive strength, and bulk density, efflorescence and cost wise ranking of manufactured bricks

| Sample ID (SID)                            | Ratios   | Water Absorption (WA) (%) | Compressive Strength (CS) (N/mm <sup>2</sup> ) | Heating Duration (hr) | Weight of Bricks (kg) | Bulk Density (BD) (g/cm <sup>3</sup> ) | Efflorescence (EFF) | Cost wise ranking (within category) |
|--|----------|---------------------------|--|-----------------------|-----------------------|--|---------------------|-------------------------------------|
| (A) Iron tailings: cement: sand            |          |                           |  |                       |                       |  |                     |                                     |
| A1   | 10:02:01 | 18.02                     | 4.13   | 24                    | 3.490                 | 2.12                                   | Nil                 | 1                                   |
| A2   | 09:03:01 | 15.21                     | 6.15   | 24                    | 3.210                 | 2.02                                   | Nil                 | 2                                   |
| A3   | 08:04:01 | 10.03                     | 8.43   | 24                    | 3.140                 | 1.88                                   | Nil                 | 3                                   |
| (B) Iron tailings: sodium silicate: cement |          |                           |  |                       |                       |  |                     |                                     |
| B1   | 09:01:01 | 14.5                      | 4.09   | 24                    | 3.500                 | 2.09                                   | Slight              | 2                                   |
| B2   | 18:01:03 | 12.5                      | 6.25   | 24                    | 3.490                 | 2.07                                   | Slight              | 1                                   |
| B3   | 18:03:01 | 10.8                      | 07.95  | 24                    | 3.400                 | 1.99                                   | Slight              | 3                                   |
| (C) Iron tailings: sodium silicate         |          |                           |  |                       |                       |  |                     |                                     |
| C1   | 09:01    | 21                        | 03.43  | 24                    | 3.450                 | 2.06                                   | Heavy               | 1                                   |
| C2   | 17:03    | 19                        | 03.56  | 24                    | 3.380                 | 2.03                                   | Moderate            | 2                                   |
| C3   | 08:02    | 17.5                      | 04.15  | 24                    | 3.350                 | 1.97                                   | Moderate            | 3                                   |
| (D) Iron tailings: cement                  |          |                           |  |                       |                       |  |                     |                                     |
| D1   | 09:01    | 9.05                      | 4.64   | 24                    | 3.400                 | 1.98                                   | Nil                 | 1                                   |
| D2   | 17:03    | 6.08                      | 7.33   | 24                    | 3.250                 | 1.95                                   | Nil                 | 2                                   |
| D3   | 08:02    | 5.50                      | 8.58   | 24                    | 3.200                 | 1.91                                   | Nil                 | 3                                   |
| FCB (IS 1077: 1992)                        |          | =< 20                     | 3.50   | NA                    | NA                    | NA                                     | NA                  | NA                                  |

samples is shown. According to the burnt clay brick standard,<sup>22</sup> the minimum requirement of CS for the burnt clay brick is 3.5 N/mm<sup>2</sup>.

The results of the study shows that the maximum of value of CS was 8.58 N/mm<sup>2</sup> in category D3 in ratios (FeT: OPC, 08:02) on the other hand the minimum value of CS 3.43 N/mm<sup>2</sup> in C1 (FeT: SS, 09:01) shown in Fig. 5c, d. The minimum value was slightly (2%) below the prescribed standard, this may be due to fewer amounts of binding materials used in the

mixtures (SS was 10%). The slightly lower value of C1 pulls down the value of correlation coefficient ( $R^2 = 0.9$ ) in Fig. 5c. In all other categories the data points are quite close to the fitted regression line (Fig. 5). As the OPC with FeT content increases and reached up to 20%, the CS value also increases. This implies that the OPC is directly proportional to the CS up to a certain limit. The relation between OPC content and strength is already studied in the earlier paragraph. The higher content of OPC in bricks also

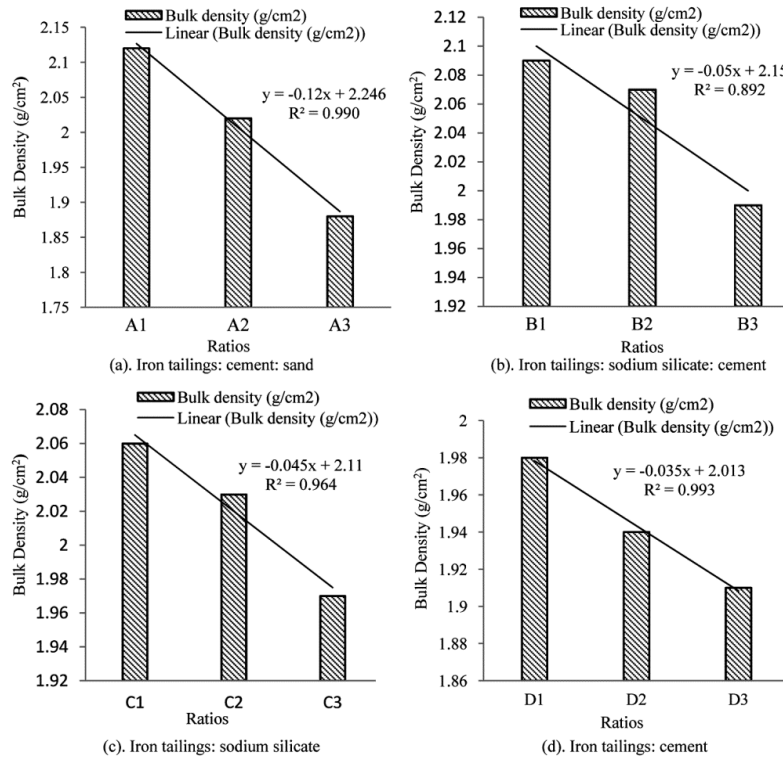


Fig. 4 — Relation between different iron tailing percent (%) combination ratios and bulk density ( $\text{g/cm}^2$ ) of proposed sample of the brick.

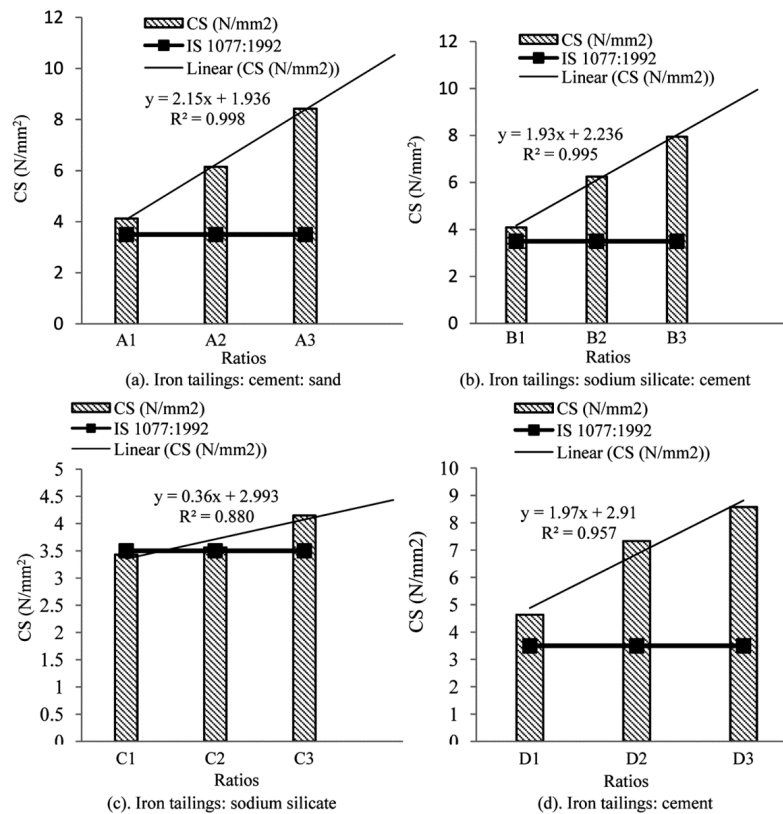


Fig. 5 — Compressive strength (CS) of manufactured brick from iron ore mine wastes

increases the durability of the bricks. According to Chanh *et al.*<sup>33</sup> the curing temperature of bricks in the range of 60 to 90°C, within time span of 24 to 72 h, the CS can be found about 4.0 to 5.0 N/mm<sup>2</sup>. The CS also depends on the fine particles of the FeT.

**Water absorption (WA)**

The WA is an important property of brick to study about mechanical strength and it is showed the permeability of FeT bricks and also an indicator of the degree of the reaction of fired clay bricks. It is also evident in geo-polymerized bricks, meanwhile increased degree of geo-polymerization results in decreased permeability and porosity.<sup>17</sup>

Results indicated a maximum value of (21%) for WA was recorded in category C1 ratios (09:01, FeT:

SS) and minimum value of 5.50% in category D3 (08:02, FeT: OPC) (Table 4 and Fig. 6). The rest of the ratios with different binding materials were not more than 20% which is in accordance with the standard for the common burnt clay brick.<sup>23</sup> The results of WA tests on the different types of bricks prepared in different proportions are shown in Fig. 6. According to the Indian standard,<sup>23</sup> the WA requirement of a common burnt clay brick value is not more than 20%. Present study indicated that the WA was decreased with increase of stabilization (OPC content). Raheem *et al.*<sup>34</sup> stated that cement stabilized interlocking blocks are of better quality. Utilization of hematite tailing and Class F fly ash together with clay produced bricks had WA between 12.5– 15% at 980– 1030°C temperature.<sup>18</sup> A number of studies also

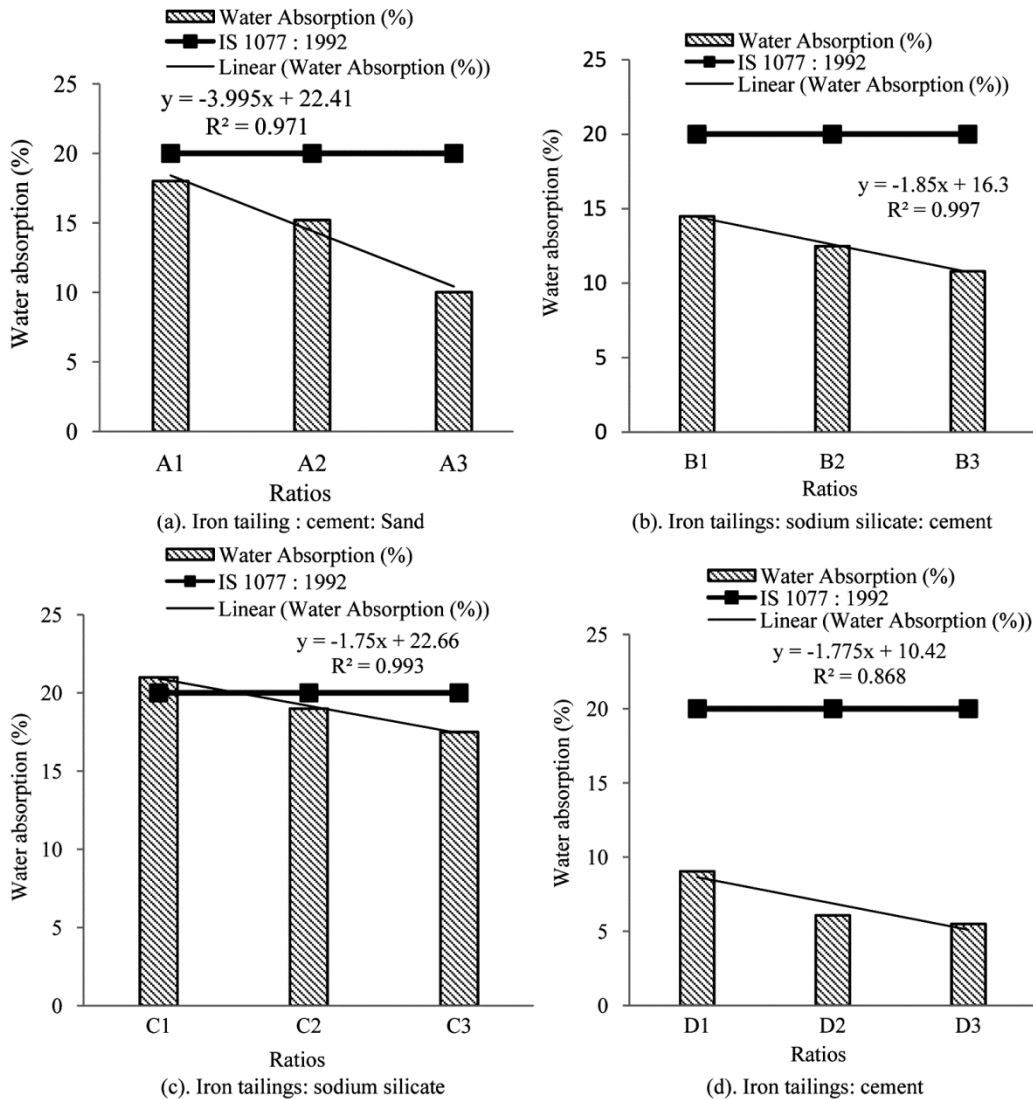


Fig. 6 — Water absorption (%) of manufactured brick from iron ore mine wastes

indicated that the water absorption of proposed bricks sample was less than 20% irrespective of the kiln temperature.<sup>35</sup> The CS was 8.58 N/mm<sup>2</sup> and WA 5.50% in the ratios of FeT and OPC were 8:2 at constant temperature. Similar observation was also reported by Morchhale *et al*<sup>9</sup>. and found opposite relation with OPC content and CS with WA (Table 4). According to Chen *et al*<sup>18</sup>. quality of bricks is affected by the forming water content. High water content results in a higher forming rate and even makes the bricks deformed. Besides, the evaporation of the excessive water in drying and firing leaves more and larger pores, which would make the mechanical strength decreased and the WA increased.<sup>36</sup>

### Efflorescence (EFF)

Efflorescence is one of the important properties to evaluate the quality of bricks. The results of EFF varied from zero to heavy in FeT bricks with various combinations of binding materials (Table 5 and Fig. 7). Out of the four only two categories namely B and C, EFF value varies from slight to heavy (Fig. 7b and 7c). While it is nil in the other two categories A and D. As per IS 1077: 1992 the accepted rating of EFF shall be below or equal to moderate (i.e. 10–50%) for class upto 12.5 and shall be slight (i.e. less than 10%) for higher classes<sup>24</sup>. According to Veinot *et al*<sup>37</sup>. SS has the highest EFF values which increase in environment having high humidity and carbon di oxide.<sup>38</sup>It's also occurred

Table 5 — Efflorescence of manufactured iron ore tailing bricks

| Sample ID | Total Area of Bricks (cm <sup>2</sup> ) | Efflorescence area (cm <sup>2</sup> ) | Efflorescence (%) | Status (IS: 3495 (Part 3) (1992). |
|-----------|---|---------------------------------------|-------------------|-----------------------------------|
| A1        | 1673                                    | 0                                     | 0.00              | Nil                               |
| A2        | 1673                                    | 0                                     | 0.00              | Nil                               |
| A3        | 1673                                    | 0                                     | 0.00              | Nil                               |
| B1        | 1673                                    | 120                                   | 7.17              | Slight                            |
| B2        | 1673                                    | 90                                    | 5.38              | Slight                            |
| B3        | 1673                                    | 45                                    | 2.69              | Slight                            |
| C1        | 1673                                    | 992                                   | 59.29             | Heavy                             |
| C2        | 1673                                    | 562                                   | 33.59             | Moderate                          |
| C3        | 1673                                    | 242                                   | 14.47             | Moderate                          |
| D1        | 1673                                    | 0                                     | 0.00              | Nil                               |
| D2        | 1673                                    | 0                                     | 0.00              | Nil                               |
| D3        | 1673                                    | 0                                     | 0.00              | Nil                               |

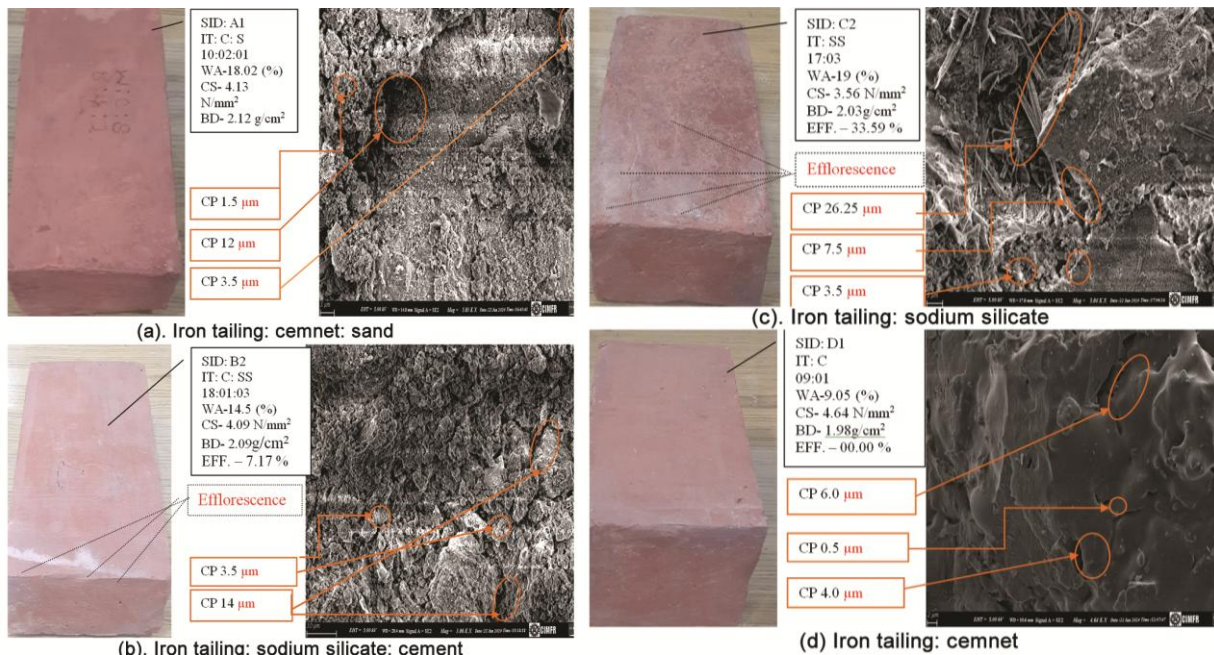


Fig. 7 — Efflorescence observed in the manufactured bricks with microstructure analysis by SEM



because of the reaction between the silicate material and the carbon di oxide present in the surrounding. The silicates of sodium, lithium and potassium were also tested, the results shows that among all the three, lithium silicate formed least rate of EFF. Further, EFF is also reliant on the silica to metal oxide molar ratio and therefore on the alkalinity of the soluble silicate.<sup>37</sup> According to Zhang *et al*<sup>39</sup>.it is seen that there is no significance change in mineralogical characteristics of geopolymer due to occurrence of EFF on the surface of geopolymer bricks. However, the processes like loss of alkalis and sub florescence significantly affect the development of compressive strength and compressive modulus of geopolymer. The test oriented data in Table 5 clearly indicates that when WA is around 21%, it falls in heavy categories which imply that EFF is directly related to WA. The EFF phenomenon is a stubborn problem that creates big trouble for masonry,<sup>14</sup> the most important of which are most of the salts are of alkaline metals or sulphate and alkaline dust potassium, sodium, magnesium, iron and calcium, silicate or carbonate of calcium and sodium or sodium bicarbonate.<sup>11</sup> Although the chlorides sometimes appear with a small amount of EFF and the future effect of these salts is negative on the properties of bricks.<sup>11,40</sup> It resulted cracking and fragmentation of the walls as a result and transforms it into a fragile material. The appearance of the salts on the bricks faces to the destruction of the terminations and the appearance of yellow spots.<sup>11,40</sup>

The details of the best brick in each category are shown in Fig.7.

In category A, (FeT: C: S) three different combination ratios (10:2:1, 9:3:1 and 8:4:1) were prepared and tested. Bricks of the entire three ratios adhere to the limit prescribed by Bureau of Indian Standards regarding WA, EFF and CS requirements (Table 4). Among the A1, A2 and A3; A1 found cheapest with respect to economical point of view (Table 6). In category B, (FeT: SS: C) three different

ratios (09:01:01, 18:01:03 and 18:03:01) were prepared and tested. Bricks of all the three ratios qualify the BIS (Bureau of Indian standard) requirements regarding all the parameters though a slight EFF was observed in all the bricks of this category. Overall B2 found to be most economical compared to others (Table 6). In category C, (FeT: SS) three different combinations (09:01, 17:03 and 8:02) were prepared and tested. C1 bricks could not qualify the BIS requirement but C2 (17:03) and C3 (8:02) fulfilled all the requirements (Table 4). Overall C2 is more economical compared to C3. Similarly in category D, (FeT: C) three different combinations (09:01, 17:03, and 8:02) were prepared and tested. Bricks of all the three combinations adhere to the limits prescribed by the Bureau of Indian Standards regarding WA, EFF and CS (Table 4). D1 shows the best strength and completely adhere to BIS requirements for the manufacturing of common clay bricks (Table 6). SEM was used to observe the microstructure of the economy-wise best bricks in each category after oven dry at  $115 \pm 10$  °C shown in Fig. 7a, b, c, d. The samples A1 and B2 showed less compact with CP size values 12  $\mu\text{m}$  and 14  $\mu\text{m}$ , respectively (Fig. 7a, b). whereas, sample C2 exhibited the largest CP value 26  $\mu\text{m}$  between materials (Fig. 7c), which means the sintered bricks were not consolidated and solidified completely; which leads to lower CS and higher WA rate<sup>41</sup> and higher EFF. Additionally, a large volume of interconnected and irregular CP was formed, it may be due to water evaporation and dehydroxylation in the process of oven drying. Zhang *et al*.<sup>42</sup> analysed the pore structure through SEM and they were found the large pore induces a faster alkali leaching i.e. is one of the causes of the EFF formation. The sample D1 exhibited very high compact with CP sizes value 06  $\mu\text{m}$  indicating a high degree of reaction in the molecules melting and consolidation of the sintered

Table 6 — Overall ranking of bricks across different categories of manufactured bricks.

| Sample ID (SID) | Mixing ratios | Cost wise ranking (within a category)           | Overall Rank |
|-----------------|---------------|---|--------------|
| A1              | 10:02:01      | (A) Iron tailings: cement: sand<br>1            | 3            |
| B2              | 18:01:03      | (B) Iron tailings: sodium silicate: cement<br>1 | 4            |
| C2              | 17:03         | (C) Iron tailings: sodium silicate<br>1         | 2            |
| D1              | 09:01         | (D) Iron tailings: cement<br>1                  | 1            |

bricks leading to the dense structure (Fig. 7d). It indicates the durability of the bricks<sup>43</sup> which means WA is lower and CS is higher. Fig. 7d depicted melting, which were the typical grain and bond microstructure, and crystalline phases were embedded entirely strong formation, which helped in developing the strength of bricks.<sup>18</sup>

Comparing the best bricks across all the categories and ratios namely A1 (10:02:01), B2 (18:01:03), C2 (17:03), and D1 (09:01) we observed that the sample D1 is the best across all categories because of its CS along with low WA, zero EFF and above all it is economical. Further, to the economical consideration, it would also reduce the emission of CO<sub>2</sub> in the ambient environment.<sup>44-46</sup>

### Conclusions

The present study shows that it is feasible to use iron tailing wastes to produce standard quality bricks. The experimental results showed the compressive strength is influenced by the increase in cement/sodium silicate percentage, and or increase in the heating duration of the manufactured bricks and were comparable with the standard prescribed for burnt clay bricks (IS 1077:1992). Furthermore, it is possible to manufacture different types of FeT bricks that can safely be used as load-bearing and non-load bearing units by either using various binding agents along or regulation the heating duration.

This method will not only help to recycle the iron ore wastes but will also produce stronger, energy-efficient, and economically viable alternative building materials (prototype D1). This sample (D1) has better strength and fully satisfies the criterion of the Bureau of Indian standard (IS 1077:1992) for common burnt clay bricks for construction purposes. Finally, this will not only help fulfill the requirements of the burgeoning populace of India but will also aid in conserving the ever precious soil resources.

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