# MANUFACTURING OF FIRED CLAY BRICK WITH IRON ORE TAILING AND STEEL SLAG

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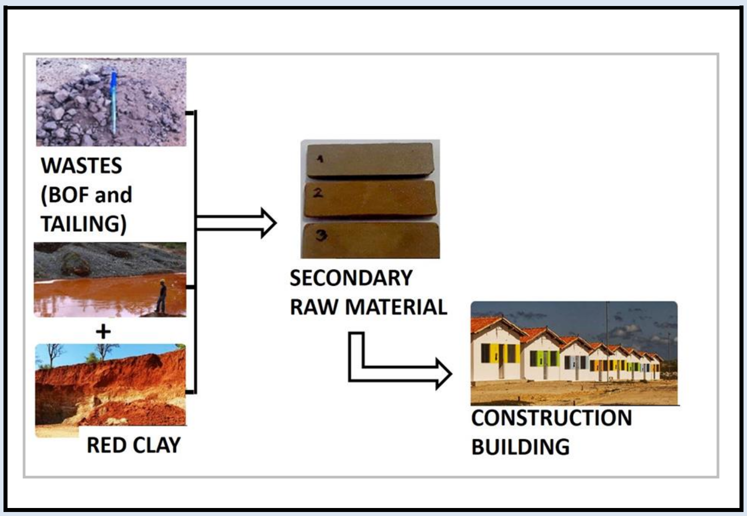


## ABSTRACT

There has been a growing environmental and economic concern about the final destination of industrial waste. This paper aims to evaluate the effect of incorporating iron ore tailing and steel slag on red ceramic bricks. The procedure for producing the fired bricks includes forming the bricks by compressing them into a mold under a specified pressure, and calcination (950 $^{o}$C). In this study, the influence of high substitution (50%) of clay with IOT and BOF slag are investigated using flexural strength and scanning electron microscope (SEM). To the clay mass different proportions of residues were added, being: 25% of slag and 25% of tailing in T25.I25; 50% slag and 0% tailing at T50.I0; 0% slag and 50% tailing at T0.I50; 35% slag and 15% tailing in T35.I15; and, 15% of slag and 35% of tailing in T15.I35. Results show that IOT and BOF slag can be used together to produce fired clay brick with high level substitution, however some adjustments are required depending on the final application. This study contributes to the valorization of the waste, contributing to the planning and management of waste based on sustainability principles and aiming at reducing greenhouse gas emissions.

***Keywords:*** *Red clay, Tailing, Waste, Sustainability.*

# FABRICACIÓN DE LADRILLO DE ARCILLA COCIDA CON RELAVES DE HIERRO Y ESCORIA DE ACERO


## RESUMEN

Ha habido una creciente preocupación ambiental y económica sobre el destino final de los residuos industriales. Este artículo tiene como objetivo evaluar el efecto de incorporar relaves de mineral de hierro (IOT) y escoria de acero en ladrillos de cerámica roja. El procedimiento para producir los ladrillos cocidos incluye formar los ladrillos comprimiéndolos en un molde bajo una presión especificada y calcinación (950 $^{o}$C). En este estudio, se investiga la influencia de la alta sustitución (50%) de arcilla con escoria IOT y BOF utilizando resistencia a la flexión y microscopio electrónico de barrido (SEM). A la masa de arcilla se le agregaron diferentes proporciones de residuos, siendo: 25% de escoria y 25% de relaves en T25.I25; 50% de escoria y 0% de relaves en T50.I0; 0% de escoria y 50% de relaves en T0.I50; 35% de escoria y 15% de relaves en T35.I15; y, 15% de escoria y 35% de relave en T15.I35. Los resultados muestran que las escorias BOF y relaves IOT pueden usarse juntas para producir ladrillos de arcilla cocida con una sustitución de alto nivel, sin embargo, se requieren algunos ajustes dependiendo de la aplicación final. Este estudio contribuye a la valorización de los residuos, contribuyendo a la planificación y gestión de residuos basados en principios de sostenibilidad y con el objetivo de reducir las emisiones de gases de efecto invernadero.


***Palabras Claves****: Arcilla roja, Relaves, Residuos, Sostenibilidad.*

## 1. INTRODUCTION

The metals and mining sectors are extremely important to a country's economy. According to the World Steel Association, in 2017 the world production of crude steel reached 1,691.2 million tons (Mt). At the same time, the world iron ore production was 2.4 billion tons [1]. Although steel is a product of remarkable relevance to human activities, the entire steel production chain (from mining to the final products) generates a large volume of other by-products, such as steel slag and iron ore tailing. Moreover, in 2017, this sector emitted an average of 1.83 tons of $CO_2$ for each ton of steel produced [2].

The rupture of iron ore tailings dams in the municipalities of Mariana (in 2015) and Brumadinho (in 2019), state of Minas Gerais, had major environmental, social and economic consequences. Being these dams one of the results of the accumulation of waste by the industries. They show the need to rethink the waste management model through new system dynamics. In Brazil, much steel slag is intended for use in land/landfill leveling, road bases and sub-base, cement production, concrete aggregate and others [3]. Moreover, despite their inert behavior at room temperature, mining tailings are potentially materials for construction [4–8]. Das, Kumar, and Ramachandrarao (2000) pointed that slag and iron ore tailing are a desirable source to produce fired ceramic brick.

Clay is the conventional natural binder and widely used in brick making. They have been used for years by our society – as early as 14,000 BC at Egypt [10]. However, there is a growing demand for buildings and structures to meet the accelerated growth of the world population [11], and the considerable volume of clay extraction around the world can lead to a depletion of non-renewable resources [12].

In general, the reuse of industrial solid waste as a secondary raw material enables the construction, metals and mining sectors to stay closer and connected to each other within the aim to achieve the challenges of a sustainable development. Thus, stimulate changes in resource exploitation, investment targeting, technology development guidance and institutional transformations.

Thereby, studies have sought different alternatives to produce artifacts to be used mainly in civil construction [13–16], since this sector has strong potential for the incorporation of alternative raw materials as natural aggregates [17] and as binder [18].

Aquino (2015) studied the addition of sludge residue from the textile industry in the production of ceramic sealing blocks. The authors added sludge to the clay mass in several proportions and with firing temperatures of up to 1150 $^{o}$ C. They found positive points for the ceramic bodies with regard to the addition of up to 2% residue. Since, the physical, chemical and mechanical characteristics for this substitution, showed small variations when compared to ceramic masses without sludge [19].

The wide production of waste from the paper industry, added to the proximity to brick manufacturing facilities, spurred a study that aimed to increase the brick's insulation capacity. The results showed that the addition of Kraft cellulose residues to the brick, in the proportions of 2.5 to 5% by weight, were considered effective for the formation of pores in clay bodies with acceptable mechanical properties [20].

Lins et al. [21] tested the production of ecological bricks using the sludge resulting from sewage treatment. The results showed that this residue can be used as an input for pottery, reducing a large percentage in the variable costs of brick production. Areias et al. [22] using this same residue for the production of red ceramics specified that its addition to the clay mass should not be greater than 2.5% by weight, in order not to harm the physical and mechanical properties of the ceramic.

Considering the Civil Construction and Demolition Waste (RCD) generation index in Brazil, Gaspareto & Teixeira [23] evaluated its addition to the ceramic mass for the production of solid bricks. The RCD was used as a non-plastic material, with a pre-established composition of 50/30/20: ceramic, mortar and concrete. The results for mechanical resistance showed that all specimens burned at 900 °C, and with a composition with 40% -weight of RCD, presented a compressive strength higher than 4 MPa, being considered the best composition and firing temperature for the conditions of this job.

In view of these facts, this paper aims to evaluate the effect of incorporating iron ore concentrate tailings (IOT) and BOF steel slag (T365) into solid fired ceramic bricks. This is an attempt to identify an environmentally and technically appropriate destination to large-scale industrial waste produced in the Iron Quadrangle region, state of Minas Gerais, Brazil.

## 2. EXPERIMENTAL PART

Iron ore tailing (IOT), BOF slag (T365) and red clay (RC) were used to develop this research. The BOF slag and the IOT used were previously characterized by Freitas et al., (2018) (Table 1). The iron ore concentration waste are by-products of the steps of flotation and magnetic separation, to obtain the iron concentrate within the requirements of mining companies. The iron ore concentration tailing (IOT) was collected, stored and shipped as soon as it was generated. The clay (C) was supplied by a ceramic company Braúnas Company, located in the municipality of Ribeirão das Neves, MG.

**Table 1**: Chemical composition of raw materials (IOT and BOF slag) (%wt) [24].

| Raw Materials | *Wt%* | | | | | | |
|---|---|---|---|---|---|---|---|
| | $SiO_2$ | MgO | $Al_2O_3$ | $Fe_2O_3$ | CaO | TFe | CaOFree |
| T365[1] | 8.4 | 6.1 | 3.9 | 21.2 | 45.0 | - | 2.3 |
| IOT[1] | 30.2 | - | 2.8 | - | - | 43.1 | - |

1 Measured by inductively coupled plasma–atomic emission spectroscopy (ICP AES).

Thus, the IOT and T365 were dried at 110 ºC for 24 hours to eliminate the excess of water. Clay was used in natural moisture. Subsequently, aiming to eliminate the energy consumption during milling process, the raw materials were manually ground. The density was determined by helium pycnometer to obtain information about the real density of solids. The granulometric distribution of the IOT sample was analyzed using a cyclosizer, and the T365 sample was made by de Freitas et al., 2018.

### 2.1 Samples preparation

The mixture proportions (Table 2) of each sample was chosen in order to evaluate the influence of substitution up to 50% of RC. Materials were homogenized together for 15 minutes. Water was added, about 10% by mass. The brick molding process was made in a hydraulic press, with sample size of 60x20x6mm, and compacted at 100 MPa. Therefore, the total number of bricks was 36.

**Table 2:** Mix proportion of sample bricks (mass content in %).

| Materials | *Mix proportion (wt%)* | | | | | |
|---|---|---|---|---|---|---|
| | RC100 | T25.I25 | T50.I0 | T0.I50 | T35.I15 | T15.I35 |
| T365 | - | 25 | 50 | - | 35 | 15 |
| IOT | - | 25 | - | 50 | 15 | 35 |
| RC | 100 | 50 | 50 | 50 | 50 | 50 |

After molding, the bricks were dried for 24 hours at room temperature, and then dried at 110 ºC for 24 hours. Then the bricks were fired in an electric oven at a temperature of 950 ºC and a heating rate of 3 ºC/min for two hours. Finally, the sintered bricks were obtained after cooling down to the room temperature. Particle size adopted to BOF slag was less than 600 µm.

### 2.2 Mechanical test and microstructure

The mechanical properties were determined by three-point flexural strength, according to ASTM C1161 standard [25]. The results were compared with the recommended limit for solid ceramic bricks: class A < 2.5 MPa [26]. Morphological features were analyzed by scanning electron microscopy (SEM) with an Energy Dispersive Spectroscopy (EDS) system, JEOL JSM 5600 PV model.

## 3. RESULTS AND DISCUSSION

### 3.1 Raw Materials

The IOT and T365 (BOF slag) particle size distribution is given in Fig. 1. IOT has been found to have most particles smaller than 6,3 µm, so there is no need for sieved or grind. BOF slag was sieved to separate particles smaller than 600 µm.

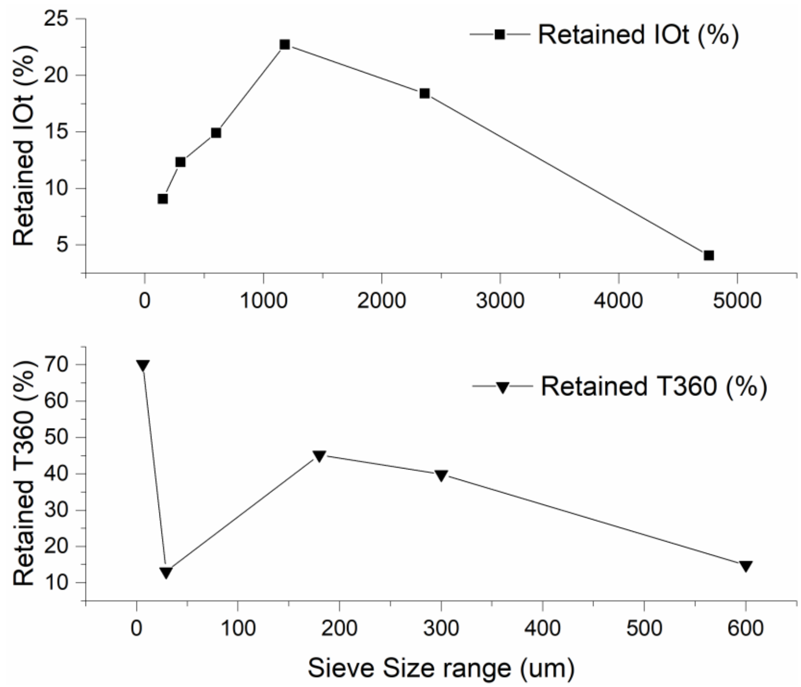


**Figure 1:** Particle size distribution of IOT and T365.

The elements that compounds the red clay are mainly $SiO_2$ and $Al_2O_3$ (Table 3). The true density values found for T365, IOT and RC were 2.75, 3.28 and 2.54 $g.cm^{-3}$, respectively. These values are acceptable if compared with natural gravel (2.7 $g.cm^{-3}$) [27].

**Table 3:** Chemical composition of red clay (%wt).

| *Raw Materials* | *Wt%* | | | | | | |
|---|---|---|---|---|---|---|---|
| | $SiO_2$ | MgO | $Al_2O_3$ | $Fe_2O_3$ | CaO | TFe | CaOFree |
| RC | 43.60 | 0.75 | 31.90 | - | 0.17 | 3.90 | - |

The results about the physical properties and oxide contents found in the IOT (Table 1) and Clay (Table 2) samples are in accordance with those described by da Silva (2014), when compared to the magnetically separated fine tailing sample.

### 3.2 Flexural Strength

In general, when comparing the RC100 sample with the others, it is clear that there is a decrease in flexural strength (Fig. 2). Furthermore, comparing the samples containing wastes (T25.I25, T50.I0, T0.I50, T35.I15 and T15.I35), bricks with IOT lead to improved flexural strength. On the other hand, the increase in T365 tends to reduce this property.

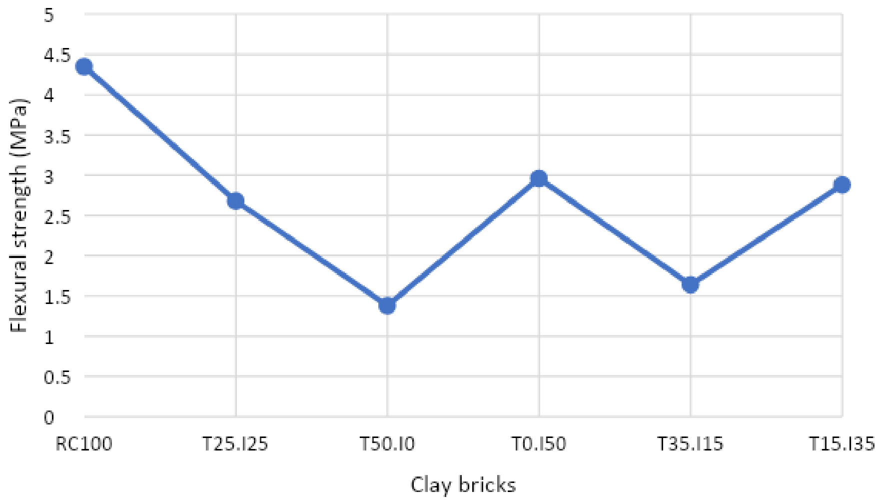


**Figure 2:** Results of the three-point flexural strength test of clay bricks.

T50.I0 and T35.I15 bricks did not meet the minimum technical requirements (2.5 MPa). The behavior of T25.I25 and T15.I35 may be related to interaction between two mechanisms: oxides provided by the raw materials, such as $SiO_2$ and $Al_2O_3$, led to the formation of hydrated aluminum silicates [29], and IOT particle size caused an improvement in sintering rate [30].

Probably reducing the total percentage of wastes (less than 50%) could improve the mechanical behavior of all samples. Behera (2019) pointed that bricks containing up to 40% tailing and fired at 950 $^{o}$C have a worse mechanical behavior comparing with 0% and 20% substitutions.

Moreover, it is important to note that there are superficial cracks in all bricks, except for RC100 and T0.I50, which also impair the mechanical performance. In this case, these cracks may have been caused by the difference in the heating and cooling rate between surface and core during calcination. Or even, caused by the presence of iron and aluminum oxide present in the slag. Fig. 3 shows an example of these surface cracks, on the sample T25.I25.

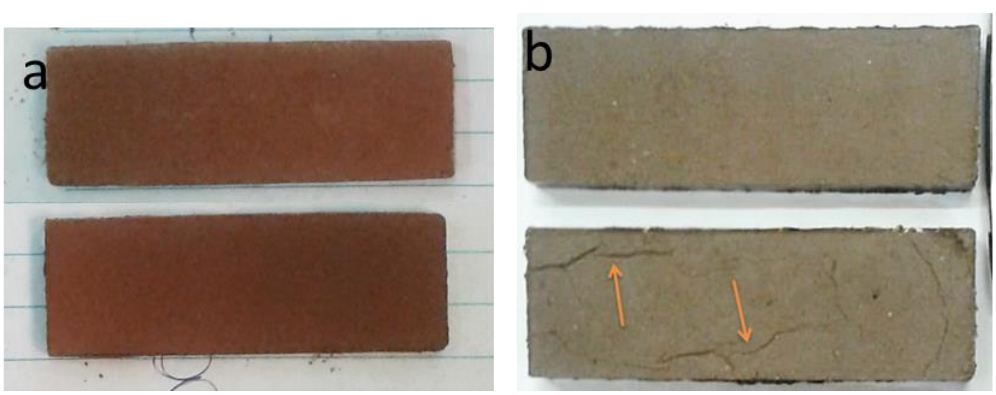


**Figure 3:** Sample surface (a) T0I50, (b) T25.I25.

### 3.3 Microstructure

The experimental data is in accordance with the SEM microstructure (Fig 4.a-e). All brick samples showed high heterogeneity in grain size, texture and grain shape. In general, there are a large number of voids and pores, which can be related to both water evaporation and the release of gases produced during firing [32,33]. The Figure 4. e (01) shows a loose grain, rich in silica and aluminum, with high surface energy (pores) and without neck formation in the contact between particles.

There is no clear evidence of vitrification [12]. It is also observed that clay particle did not strongly react with IOT and/or T365 (Fig 4. b-d). Therefore, the acquired mechanical strength may be related to the high pressure applied to mold the samples, which led to the formation of a dense and compacted matrix. And also, to filling effect of finer unreacted particles, which helps to enhance the mechanical behavior [34]. Comparing bricks T25.I25 and T15.I35 is possible to observe that the increase in IOT content contributed to filling effect. Probably it fills the voids and pores and improve particle hydration and mechanical strength [30].

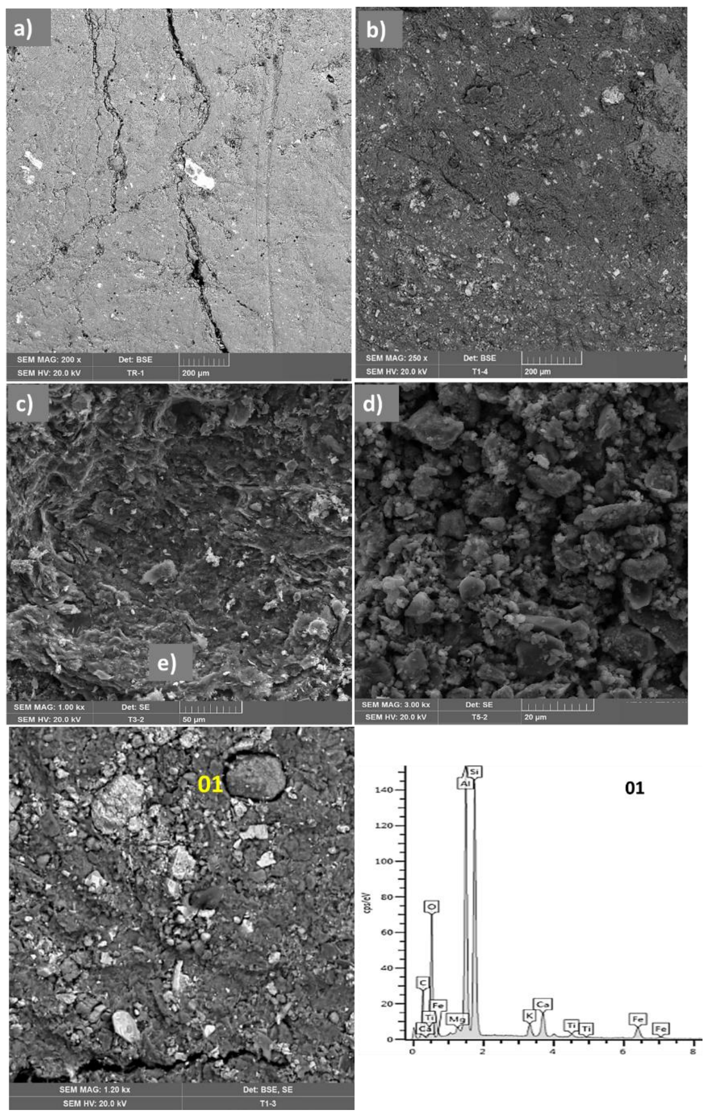


**Figure 4:** SEM images of samples ( a) RC100; b) T25.I25 c) T0.I50 d) T15.I35 e) T25.I25 (with EDS analysis).

## 4. CONCLUSION

The incorporation of IOT and BOF steel slag to make bricks from the mixture with red clay was favorable.

The flexural strength results of samples T25.I25, T0.I50 and T15.I35 met the standard. However, to avoid cracking, adjustments in particle size, and in the firing process (milder heating and cooling levels, e.g.) are suggested.

Smaller particles are believed to collaborate with the reaction between the waste and the clay.

The construction, steel and mining industries lack planning and management models that contemplate mechanisms that provide the best environmental performance of their respective products.

Furthermore, as they are representative industries in the Iron Quadrangle region, the implementation of strategic tools such as the industrial symbiosis model appears to be a viable proposal.

Further studies on the joint use of these two wastes are needed.

This study contributes to the appreciation of the incorporation of BOF and IOT slag in fired bricks, in order to collaborate with sustainable management of the industrial waste with potential to provide important environmental, social and economic benefits.

## 5. ACKNOWLEDGMENT

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