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Chapter 2

Recycling of Steelmaking Plant Wastes in Clay Bricks

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Additional information is available at the end of the chapter

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Abstract

The steelmaking industrial sector generates a wide variety of solid wastes, predominantly composed of slag, dust, sludge, and scrap. The need to find a correct environmental alternative to recycle steelmaking wastes, as well as the possibility to bring some technical advantageous to clay bricks for civil construction, makes this industrial segment present itself as an excellent alternative for the reuse of these residues. In this way, some studies were presented in this chapter that evaluated the effect of incorporation of different steelmaking plant wastes such as blast furnace sludge, sludge, and slag from oxygen steel-refining process in the physical and mechanical properties of clay bricks for civil construction. As final considerations, the most investigated wastes present a particle size distribution compatible to clay brick processing. Although the wastes display different chemical and mineralogical composition, low amounts are well tolerated by the ceramic, not impairing the physical and mechanical properties. Furthermore, the presence of determined constituent, as, for example, fine coke in blast furnace sludge, can contribute significantly to save energy during the firing stage.

Keywords: residue, ceramic, incorporation, environmental

1. Introduction

The steelmaking industry plays an important role in economy and in a modern society development. As a provider of employment and essential materials, this sector is connected to a huge variety of industrial productive chains. However, a clearer related view on how to manage this key industry with greater sustainability could positively impact the economy and the environment globally. To provide a more sustainable productive chain, besides avoiding

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generating residue, the solid residues may be managed through a more noble and environmentally correct destination.

There are basically two main routes for steel production; they are the integrated route and the semi-integrated route. At the first route, the reduction of ore, including iron ore, coal or charcoal, and fluxing agents, occurs in the blast furnace to generate pig iron, in which it is then refined to produce steel, while in the second route the steel is directly produced in electric arc furnace [1].

During the steelmaking at both routes and also at the reefing step, the main residues generated can be divided into categories such as slag, sludge, and dust [2]. The mineralogical and chemical compositions of each of these wastes vary according to the raw materials employed in the process and to what they have as common elements, mostly composed of iron, carbon, calcium, magnesium, silicon, and manganese and still containing smaller proportions of aluminum, zinc, alkaline earth metals, and traces of other elements [3].

It is preferable that the valorization of the solid wastes is carried out on the steelmaking route itself; however, if this practice is not possible, it is necessary to look for other productive processes capable of incorporating this waste as raw material. In association with this practice, it is desired that these wastes, when hazardous or not inert, are inertized in order to reduce their toxicity. In this sense, it is verified that much of this waste is still disposed in landfills or sent for incineration; even if this constitutes an environmentally correct practice, it is considered the least noble practice according to solid waste management [2].

The ceramic industry for civil construction has gained prominence in recent years due to its potential for incorporation of solid waste generated in the most diverse industrial activities. This potential is based primarily on the characteristics of the raw material and the high production volume in this industrial sector [4].

The basic raw material for the bricks and roofing tiles manufacturing is clay, and due to the nature of its formation, it has natural variability in its chemical and mineralogical composition. This variation, coupled with the low technical performance required for its products, allows residues of different compositions to be incorporated into the ceramic clayey body. In addition to direct environmental benefit, technical improvements in processing or product quality may occur, and even energy savings can be generated when certain wastes are incorporated with combustibility characteristics. Another notorious benefit is the possibility of inertization, in the ceramic matrix, toxic metals contained in these residues [5]. Dondi, Marsigli, and Fabbri [6] still emphasize the function of improving sustainable development by providing the economy of clay, which is a natural nonrenewable resource.

The purpose of this book chapter was to provide a summary based on existing scientific references on the environmental, technical, and economic benefits of using the waste generated in the steelmaking process as a raw material for the ceramic industry, seeking, whenever possible, to correlate the characteristics of the residues and their influence on the properties and microstructure of the ceramics.

2. Steelmaking plant wastes as raw materials for clay brick production

2.1. The ceramic industry as an active agent for the improvement of sustainable development

The industrial segment of red clay-based ceramics, also known as structural ceramics, is part of the nonmetallic mineral sector of the mineral processing industry, sharing the entire production chain of civil construction. The following products make up this segment, bricks, roofing tiles, blocks, and paving ceramic floors, among others.

Several researches have reported on the state of the art of using various wastes to red clay-based ceramic products, such as red mud of Bayer process [7], fluorescent lamp glass waste [8], granite waste [9], effluent sludge from paper industry [10], blast furnace sludge [11], and sugarcane bagasse ash [12], among others. This potential is based on basically two particularities of this industrial sector, the characteristics of the raw material and the high production volume [4].

Dondi, Marsigli, and Fabbri [6] elaborated a classification in order to organize different types of industrial solid wastes as to their main influence when incorporated to the clayey bodies for ceramic production. Through extensive bibliographical research, these authors categorized the residues into combustible residues, fly ash, flux residues, and plasticity-modifying residues.

More recently, Vieira and Monteiro [13] presented a new classification for industrial solid waste aiming its application as raw material for ceramic production for civil construction. In this classification, the authors propose only three categories, being combustible residues, flux residues, and property-modifying residues. Thus, fly ash was excluded from the old classification and should now be classified as combustible waste, and the category of plasticity-modifying waste was renamed as property-modifying waste, since not only plasticity but also other properties could be altered by waste that did not fit the other categories of classification.

2.2. Characteristics of steelmaking wastes and their influence on clay brick properties

The steel industry generates a huge variety of wastes in the course of its process, mainly in the case of integrated mills. In relation to the solid wastes generated, the transformation of iron ore into steel can be classified into slags, sludges, and dusts, which together represent between 2 and 4 tons per ton of steel produced. The composition of these wastes varies according to the source of generation but usually contains iron, carbon, calcium, magnesium, silicon, manganese, zinc, and lead. Besides that, some slag and sludge contain a notable amount of heavy metals, and their improper deposition can negatively impact the environment [3, 14–19].

So, the disposals of these wastes in landfills are becoming less attractive which not only occupy plenty of land but also increase the costs. Therefore, it is desirable to identify productive cycles capable of using the steelmaking wastes as raw material. In this way, this will lead to a better evolution of sustainable development. The following will be analyzed as to how the

incorporation of these wastes in clayey bodies for production of ceramics for civil construction affects the properties and microstructure of these products.

2.2.1. Slag

The slag originated at the steelmaking refining process, denoted as steel slag (SS), may vary in chemical composition as a function of the raw materials used and the technology and equipments employed. Currently, this residue is recycled in cement production as well as a base for pavements and composition for aggregates.

The difficulty of using the steel slag as raw material for construction products is its capability to enlarge. This is a consequence of the presence of free CaO and MgO as well as the polymorphism of the dicalcium silicate combined with the oxidation and corrosion of the metallic iron [20].

In relation to the characterization of this waste, the particle sizes with no crush processing present a wide distribution range varying from 20 to 30 × 10^3 μm and mean particle sizes of 7.860 μm. This is an undesirable feature for traditional ceramic production, in which it typically uses raw material with particles having sizes lower than 2.000 μm. Aiming its application in an industrial way, it would be necessary to comminute this residue before it is added to the ceramic clayey body [14].

Table 1 presents the chemical composition and the loss on ignition (LoI) of the steel slag, which is predominantly composed of Ca, Fe, Mg, and Si. Ca is present in the form of silicates as well as carbonate. Mg occurs mainly as free oxide and Fe as reduced oxides such as wustite and magnetite. Si occurs as silica and also as complex silicates. The loss on ignition may be attributed to carbonate decomposition and also to the dehydration of hydroxides such as brucite ($Mg(OH)_2$). The chemical composition results also in identified traces of K, V, Ni, Cu, Zn, Nb, Rh, and I.

The incorporations of 0 (C0SS), 5 (C5SS), 10 (C10SS), 20 (C20SS), and 30 (C30SS) wt.% of SS into clayey body, sieved at 20 mesh (0.840 μm), were evaluated by `Vieira and Monteiro (2010) [14]. The specimens were sintered at 700, 900, and 1000°C at heating rate of 3°C/min.

The extrusion prognostic is an important parameter to production of ceramics for civil construction, since this property is related to the workability and productivity of the pieces. In **Figure 1**, it can be observed that the clayey body without waste incorporation is located within the limits of the acceptable and non-recommended regions, and in practice, the results indicate that the incorporation of SS did not practically present significant variation at the workability of the clay.

CaO	Fe_{total}	SiO_2	MnO	SO_3	TiO_2	Al_2O_3	P_2O_5	MgO	LoI*
45.10	23.62	10.29	5.40	0.54	0.34	2.90	1.81	10.33	12.96

*Loss on ignition.

Table 1. Chemical composition of the SS (wt.%) and loss on ignition (LoI) [14].

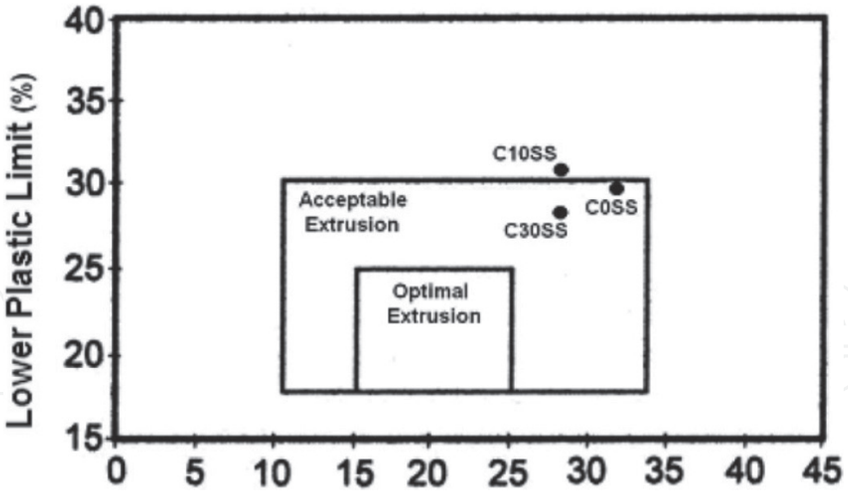


Figure 1. Extrusion prognostic through Atterberg limits [14].

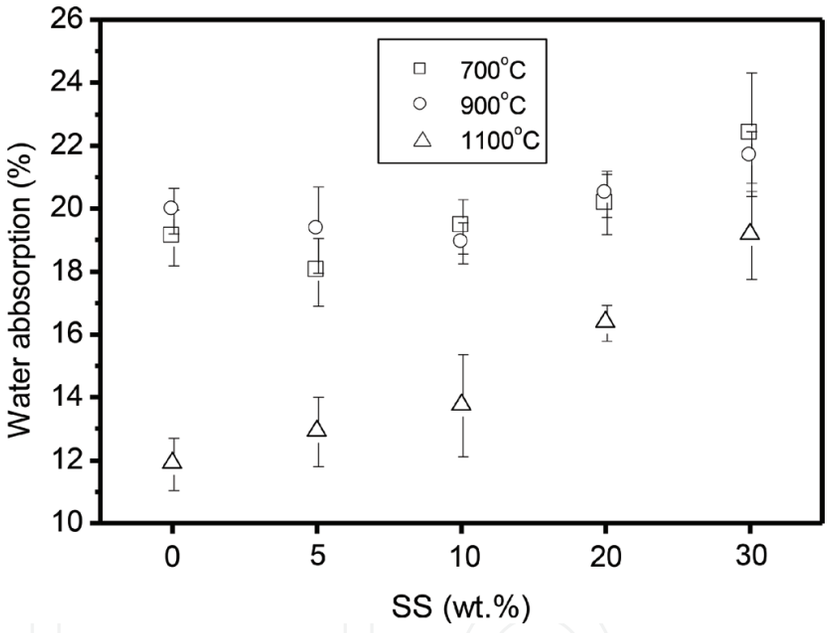


Figure 2. Water absorption of the clay as a function the amount of the SS incorporated [14].

The results of the technological properties evaluated are represented in **Figures 2–4**. In relation to the influence of the steel slag incorporation, the incorporation of higher up to 10 wt.% impairs the water absorption (**Figure 2**), while adding up to 5% has improved this property. This slight improvement in water absorption may be due to the better packaging provided by the addition of the residue. It may be noted that the temperature elevation of 700–900°C increased the water absorption; this can be explained by the combustion of coke fines at temperatures close to 800°C. The linear shrinkage (**Figure 3**) almost does not change with SS incorporation at sintering temperatures of 700 and 900°C. From another point of view, at temperature of 1100°C, the linear shrinkage significantly decreases with the SS incorporation. The flexural rupture strength is represented in **Figure 4**, and the results suggest that the incorporation

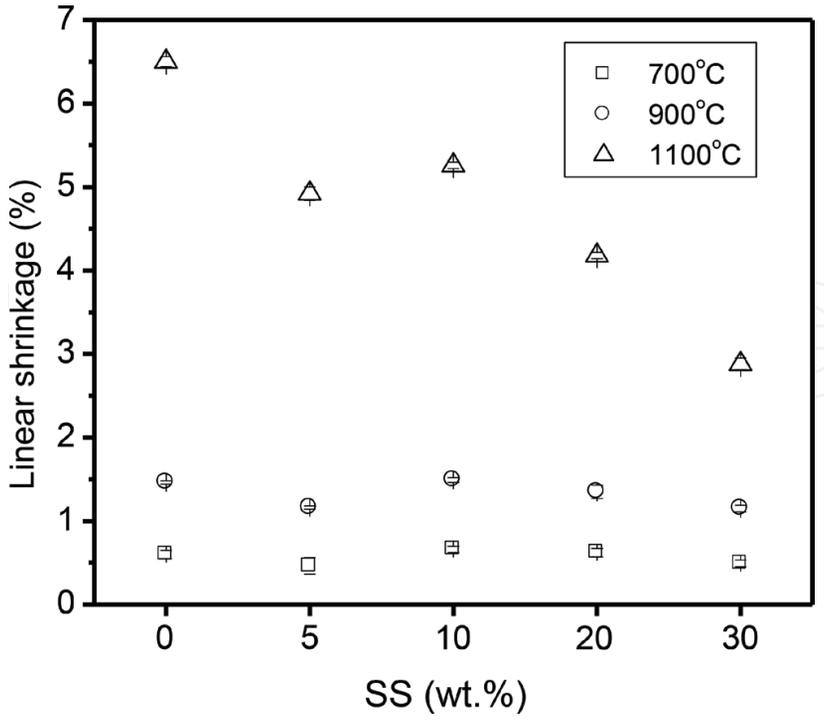


Figure 3. Linear shrinkage of the clay as a function the amount of the SS incorporated [14].

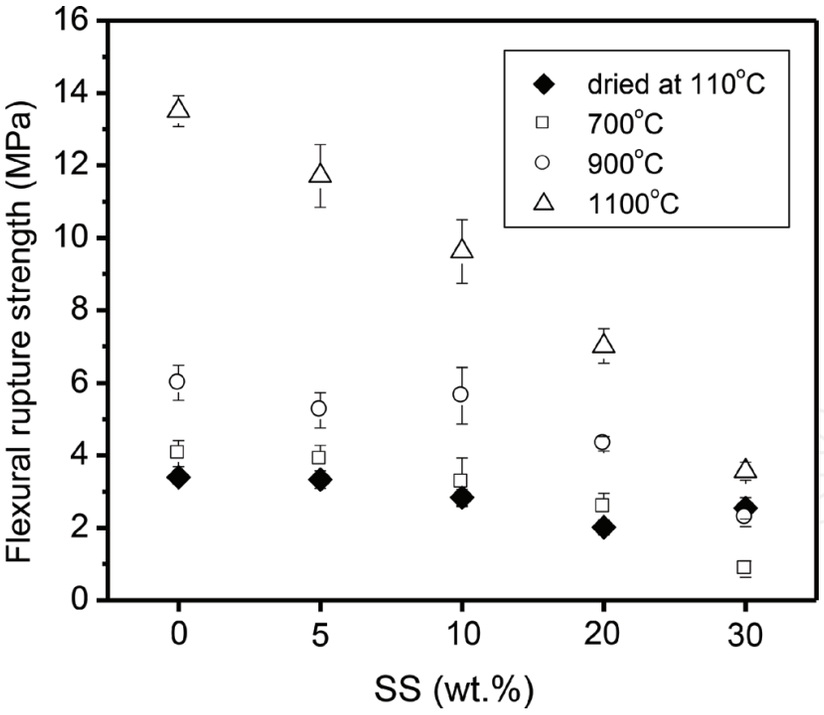


Figure 4. Flexural rupture strength of the clay as a function the amount of the SS incorporated [14].

of 10% SS (C0SS) sintered at 900°C is feasible for the reddish ceramic production since the values for this property are compatible with the products containing 0% of residue. At the lower temperatures investigated, 700 and 900°C, the clayey body (with no SS incorporation) supports SS addition up to 10 wt.% without significant changes on its properties.

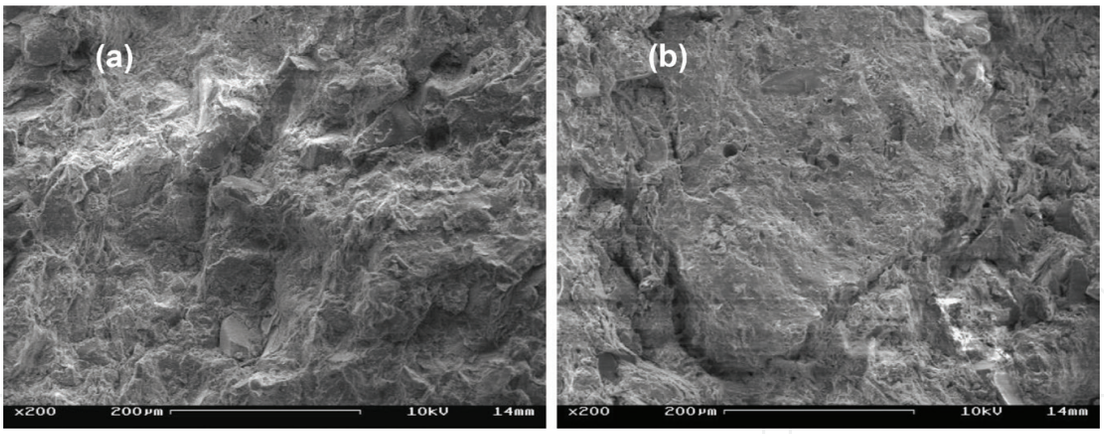


Figure 5. SEM micrographs of the fractured region of the clay (a) fired at 700°C; (b) fired at 1100°C [14].

At temperature of 1.100°C, the mechanical strength suddenly decreases with the amount of SS incorporation. At this temperature, the sintering mechanisms are highly intensified; in this sense, the clay minerals are extremely reactive during the sintering stages in temperatures higher than 950°C due to their morphology, constitution, and particle size [17], promoting both solid-state and liquid-state sintering. Thus, the reduction in the content of clay minerals due to the incorporation of residue reduces the reactivity of the ceramic clayey body; therefore, there will be fewer points of contact formed during the sintering, and as a consequence, the mechanical strength of the product will be impaired. For this reason, the deleterious effect of the SS addition on the open porosity and mechanical strength of the clay is more pronounced.

The microstructure of the fracture region of the ceramics containing 0 and 30% of residue is shown in **Figures 5** and **6**, respectively. At these micrographs, it may be noted that the two ceramics presented rougher texture. As expected, the ceramics sintered at higher temperatures produced samples with finer texture, but the cracks and voids are still present. It can be noted that the C30SS ceramic has typical regions in which the materials were plucked out at the moment of the mechanical resistance tests.

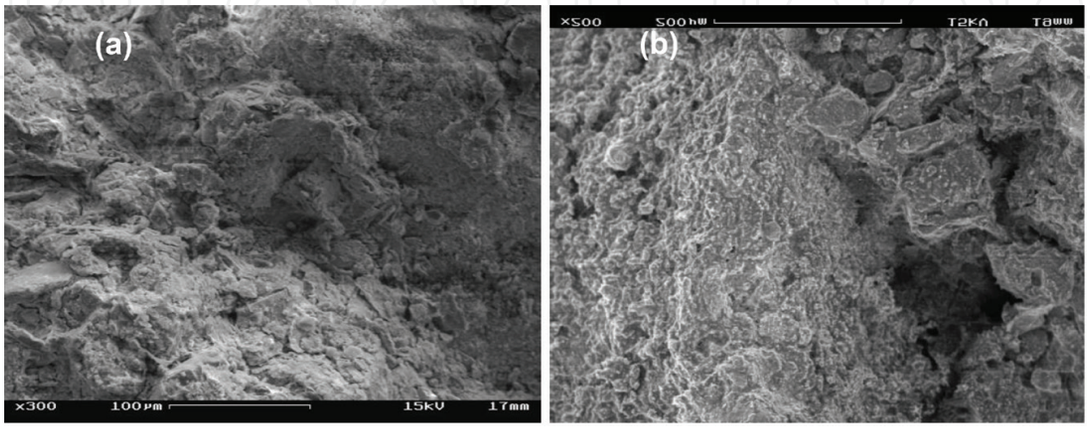


Figure 6. SEM micrographs of the fractured region of the clay with 30% of SS incorporated (a) fired at 700°C; (b) fired at 1100°C [14].

In this context, it is possible to predict that the SS particles do not react with the clay compounds. The insufficient level of chemical bonding leads the SS particles to stay loose from matrix and therefore generates defects such as voids and cracks in the product.

2.2.2. Sludge

As a result of the gas treatment, sludge from wet dedusting systems, which have a high iron content with the order of 75 to 80%, is obtained from the implantation of the dedusting systems in the steelworks. Companies that have not developed ways to recycle this waste end up destining them to the landfills, excessively increasing the cost of production, since its volume generation is considerable, reaching values of the order of 36 $kg.t^{-1}$ of steel produced. One of the main problems for the recycling of steel slurry in the steelmaking process itself is its high moisture content [3].

According to **Figure 7**, the steel sludge has a particle size distribution that the equivalent spherical diameter varies from 1 to 800 μm and mean particle sizes with 35.6 μm. For reddish ceramic production, this is an appropriate characteristic, in which these industries use materials with particles having sizes lower than 2000 μm.

In relation to the chemical composition (**Table 2**), the steel sludge is composed mainly by Fe, with 74.03%. The CaO comes from calcite introduced in the process to convert pig iron into steel. The small MgO content is associated with the desulfurizing agent also used in the steel process, which also contributes with CaO. The content of SiO_2 can be derived from the oxidation of silicon present in pig iron, while the ZnO content is associated with the use of galvanized scrap.

The influence of steel sludge incorporation into clayey ceramic products was evaluated by Vieira et al. (2007) [16]. In this paper, the authors evaluated the influence of incorporation of

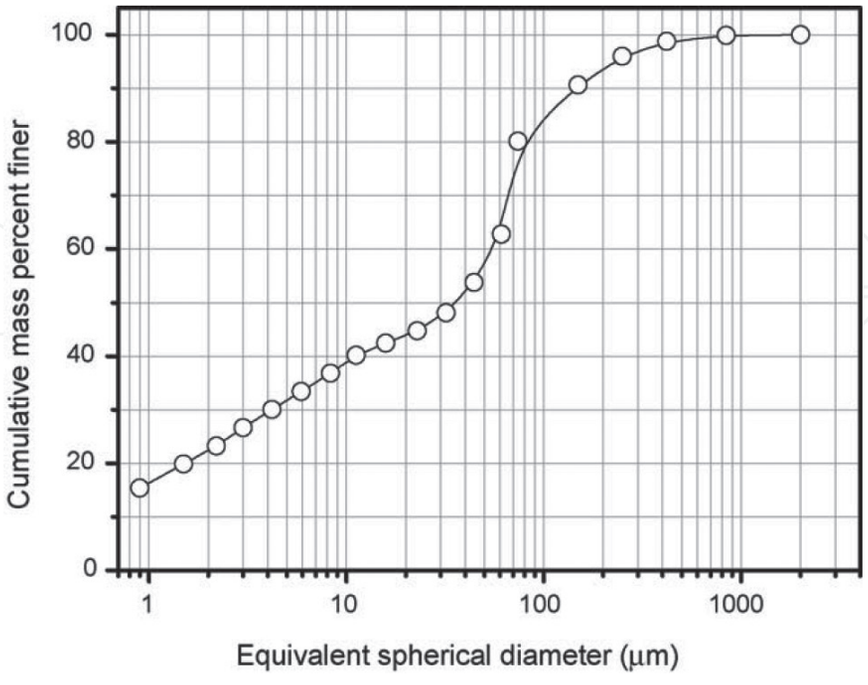


Figure 7. Steel sludge particle size distribution [15].

SiO_2	Al_2O_3	Fe_{total}	TiO_2	CaO	MgO	K_2O	Na_2O	ZnO	LoI*
1.86	0.12	74.03	0.90	16.50	3.42	0.16	0.33	2.78	—

*Loss on ignition.

Table 2. Steel sludge chemical composition (wt.%) [15].

up to 20 wt.% of fine steel sludge generated at an integrated siderurgic plant on the properties of a kaolinitic clay-based ceramic used to the produce bricks and tiles. Other authors [17] also focused on evaluating the microstructure and the inertization of potentially toxic elements through ceramic matrix by performing solution and leaching test in the ceramics with residue incorporation sintered at 900°C.

Figure 8 shows the fracture surface micrographs of the ceramic with 5% of waste incorporated. A very rough microstructure is observed with the presence of well-distributed porous particles. These particles are associated with fine steel sludge and are not adhered to the ceramic matrix. This may lead to a reduction in the mechanical strength of products incorporating higher residue content.

Figure 9 shows the fracture surface micrographs of the clay with 20% of waste incorporated. It is possible to observe that the steel sludge is relatively well distributed in the clay matrix. However, with the increase of its quantity, more regions appear with fails. In addition, increasing the waste amount, which exhibits an inert behavior during firing, reduces the amount of clay, the main material responsible for the consolidation of the ceramic particles.

In **Table 3** the leaching and solubilization results are presented, indicating the values obtained and the acceptable limit, according to the Brazilian legislation of potentially toxic metals of the formulation containing 5% of steel sludge. It is possible to observe that in the leached standard parameters, Ba, Cd, Cr, and Pb are present in quantities well below the limit values. Already solubilized, Al is present in a quantity nine times higher than the limit acceptable by norm. Al present in clay is one of its natural constituents and therefore apparently lies in equilibrium in nature. In this way its content above the stipulated limit by norm is questionable from the point of view of environmental problems. Other elements such as Cd, Cu, Fe, Mn, and Pb are in very small concentrations, being below the detection limit of the equipment.

To evaluate the effect of steel sludge incorporation on the properties of ceramics for civil construction, Vieira et al. [15] prepared specimens with additions of 0, 5, 10, and 20 wt.% of fine steel sludge into a kaolinitic clay from Brazil.

It can be seen in **Figure 10** the dried bulk density and the sintered bulk density of the formulations. One should notice that steel sludge waste (SSW) additions tend to increase the dried bulk density, mainly for the 20 wt.% addition. This behavior is probably due to the higher real density of the SSW particles compared with the clay particles and also the coarser particles of the SSW as compared with the clay, which may favor the packaging.

In **Figure 11**, the results of the analyzed properties of the sintered ceramics as function of residue incorporation are represented. An interesting result can be noted for water absorption;

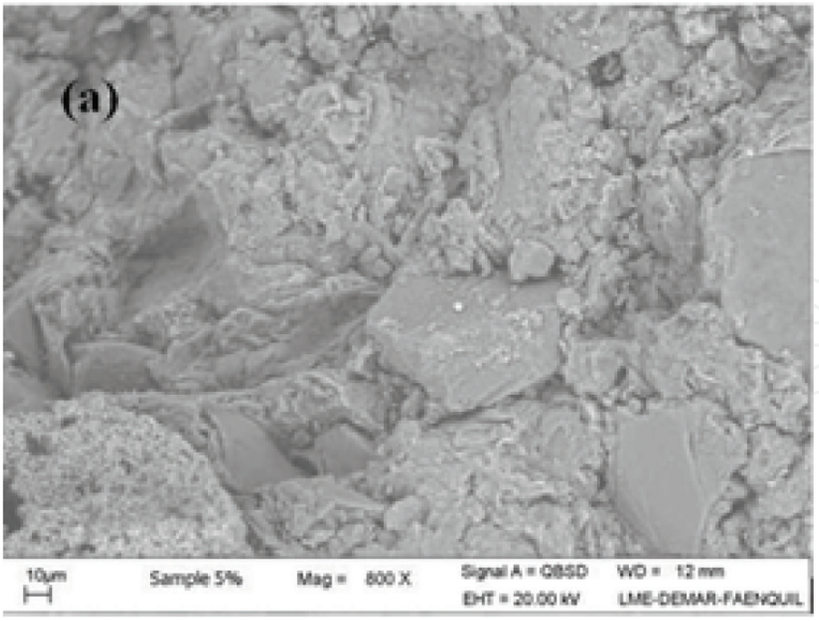


Figure 8. Micrograph obtained by SEM of the ceramic incorporated with 5% of steel sludge and sintered at 900° C in magnification of 800× [17].

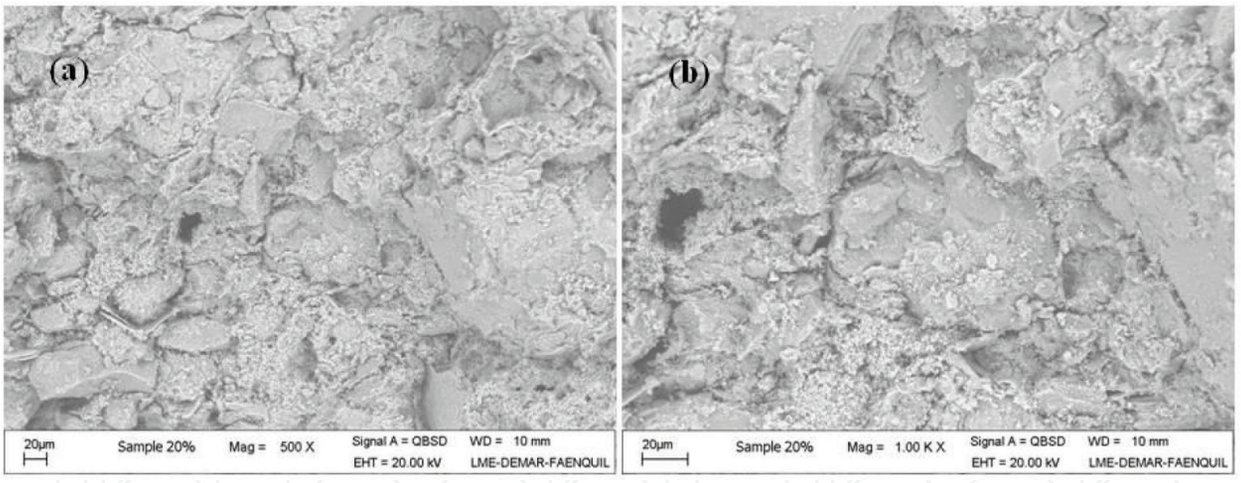


Figure 9. Micrograph obtained by SEM of the ceramic incorporated with 20% of steel sludge and sintered at 900° C in magnification of 500× (a) and 1000× (b) [17].

considering the error bars, this property is little affected by the residue amount increasing. Therefore, as the open porosity of the ceramics containing residue is practically unchanged, it is correct to affirm that the partial substitution of the clay by the residue aided in the reduction of the loss on ignition. It is known that the loss on fire caused by clay is due to dehydroxylation of kaolinite to form metakaolinite; in this way, this mechanism is responsible for leaving porosity in the ceramic. When the clay is replaced by the residue, although it is reducing the content of clay minerals which are the most reactive particles and contribute most to the consolidation mechanisms during the sintering, it is also reducing the loss to fire; for this reason, this property is little changed.

Element	Solubilized (mg/L)	Limits (mg/L)	Leached (mg/L)	Limits (mg/L)
Al	1.8	0.2	19	Not required
Ba	0.06	0.7	0.7	7.0
Cd	<0.003	0.005	0.04	0.5
Cr (total)	<0.02	0.05	<0.05	5.0
Cu	0.004	2.0	0.13	Not required
Fe	0.02	0.3	0.22	Not required
Mn	0.02	0.1	0.9	Not required
Na	10	200	—	Not required
Pb	<0.06	0.1	0.14	1.0
Zn	0.02	5.0	1.3	Not required

Table 3. Potentially toxic metals in the leaching and solubilization extracts of the ceramic with 5% of incorporated steel sludge [17].

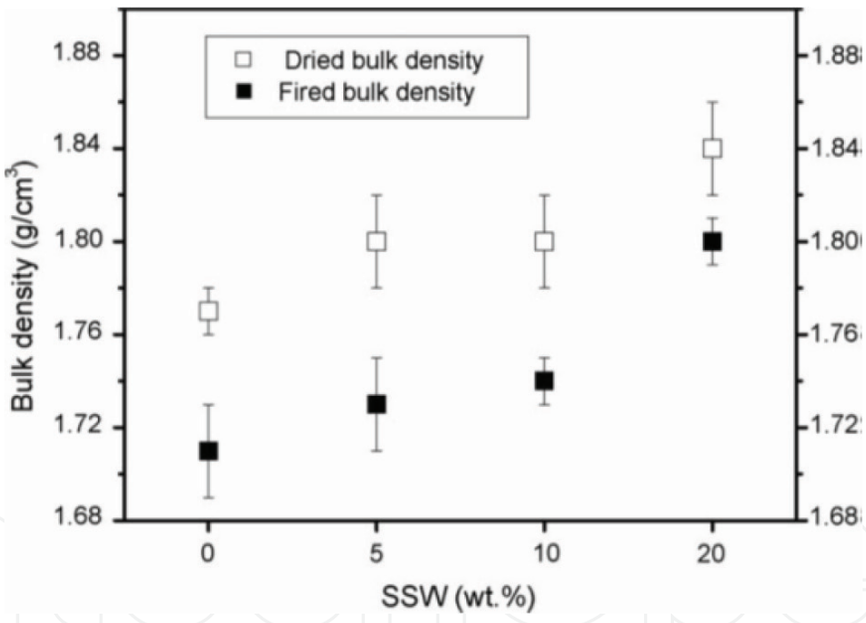


Figure 10. Dried and sintered bulk density of formulations containing steel sludge waste [15].

This same explanation helps in the understanding of the linear shrinkage behavior. The loss on fire reduction with the SSW incorporation consequently causes the reduction of the firing linear shrinkage. This behavior assists in the ceramic production favoring the better control of the dimensions of the products, besides, of course, to avoid defects during the drying and sintering stages.

The flexural rupture strength is also represented in **Figure 11**. Although the residue incorporation does not greatly affect the open porosity of the sintered ceramics, the mechanical

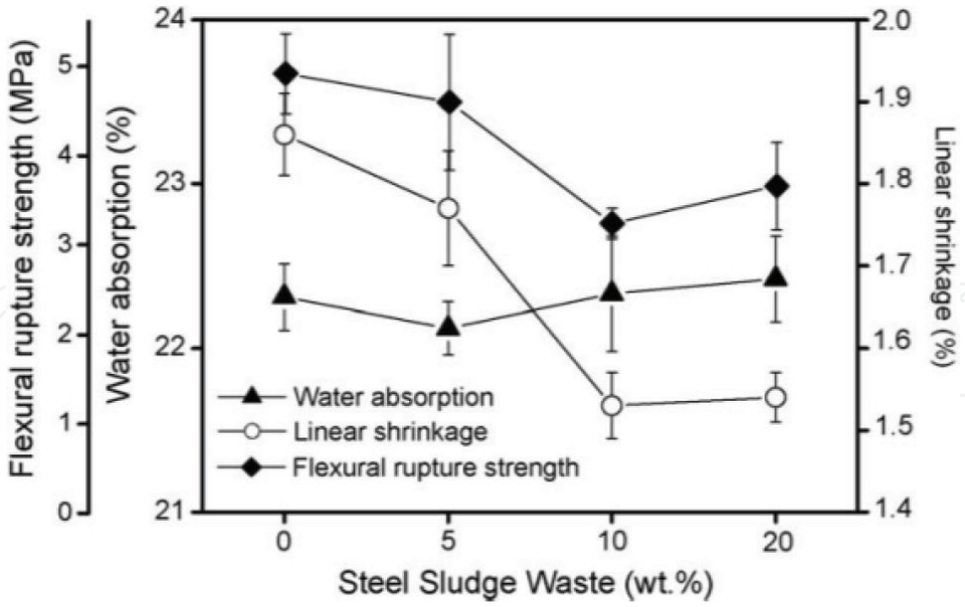


Figure 11. Sintered technical properties of formulations containing steel sludge waste [15].

strength is a property that is highly dependent on the particle consolidation during the sintering step. As seen, the mineralogical composition of this residue does not favor the sintering mechanism in these temperatures evaluated. In this way, additions of up to 5% by weight of waste are acceptable so that there is no too much reduction at the product resistance.

2.2.3. Dust

Dusts are obtained in the dry cleaning systems of process gases from the sintering stage of an integrated steelmaking plant, here denoted as PMW (particulate material waste). **Table 4** shows the chemical composition of the PMW, which is predominantly formed by iron compounds such as hematite and magnetite. CaO and SiO_2 also present relatively high amounts. The loss on ignition is predominantly associated with the combustion of coke fines and the decomposition of both calcite and dolomite. The amount of 2.28% of SO_3 suggests the presence of sulfates, possible of Ca, such as gypsum.

In **Figure 12**, the particle size distributions of the PMW with no crush processing are represented. It should be emphasized that this particle size distribution prevents its reuse in the process to which it originated. However, for reddish ceramic industry, this characteristic is ideal, since this residue can be used directly without undergoing any other crush processing.

Figures 13–15 show the graphs corresponding to the results of the technological properties after firing. A remarkable behavior can be noted with the water absorption (**Figure 13**) reduction due

Fe_{total}	SiO_2	MnO	SO_3	Al_2O_3	K_2O	MgO	CaO	ZnO	C	LoI*
70.70	6.82	0.82	2.28	1.20	1.81	10.33	9.70	0.72	3.30	10.70

*Loss on ignition.

Table 4. Chemical composition of the particulate material waste (wt.%) [18].

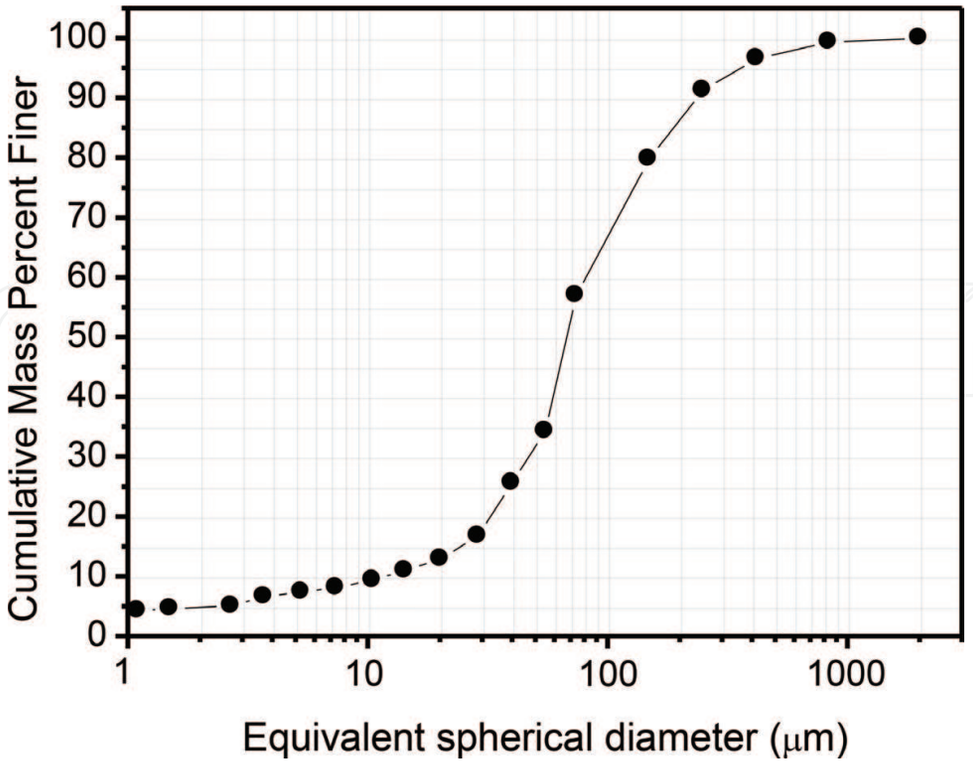


Figure 12. Particle size distribution of the PMW [19].

to the residue content increasing, principally at 1050°C. Although the ceramic clayey body was composed of highly refractory clay, the incorporation of 20% of the residue allowed the brick production at sintering temperature of 750°C and tiles at 900°C.

The firing linear shrinkage, represented at **Figure 14**, shows that the PMW addition doesn't contribute to the increasing of this property; it is therefore a residue capable of assisting in the dimensional control of the products.

In **Figure 15**, the mechanical resistance of the ceramics with PMW addition is represented. This residue with content lower than 20% was able to improve this property at all sintering temperatures investigated.

The mineralogical constitution of the PMW, which contains high amount of iron compounds, suggests an inert behavior during the sintering stage of red clay-based ceramics. Therefore, the explanation of how the residue may have acted to improve the properties may be based on dry bulk density. Probably the combination of these two raw materials helps in the better packaging at conformation stage favoring greater points of contact between the grains. Thus, there will be less void spaces which are responsible for the water absorption reduction and mechanical resistance increasing.

Figure 16 represents the SEM micrograph of ceramic with 0% of residue content and fired at 1050°C. The points located at this figure are derived from EDS analysis. The micrograph shows the intrinsic porosity probably related with void spaces left after the conformation step and consolidated as pores after sintering. The presence of pores can be associated with the dehydroxylation of some hydroxides and clay minerals and also with the different expansion

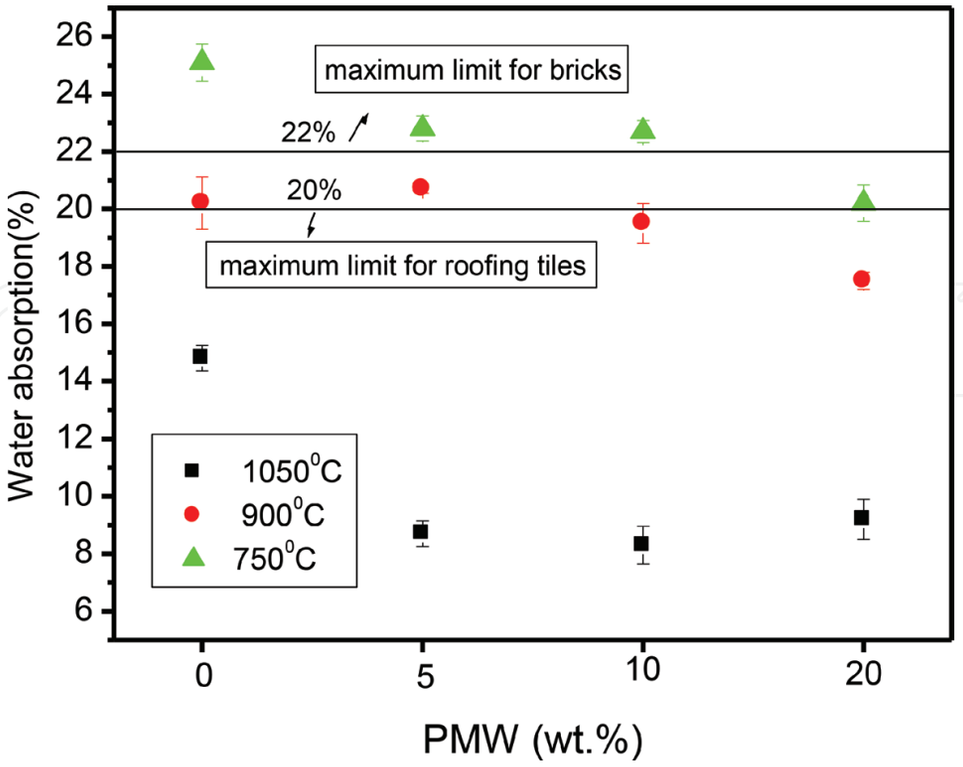


Figure 13. Water absorption of the clayey body as a function the amount of the PMW incorporated [19].

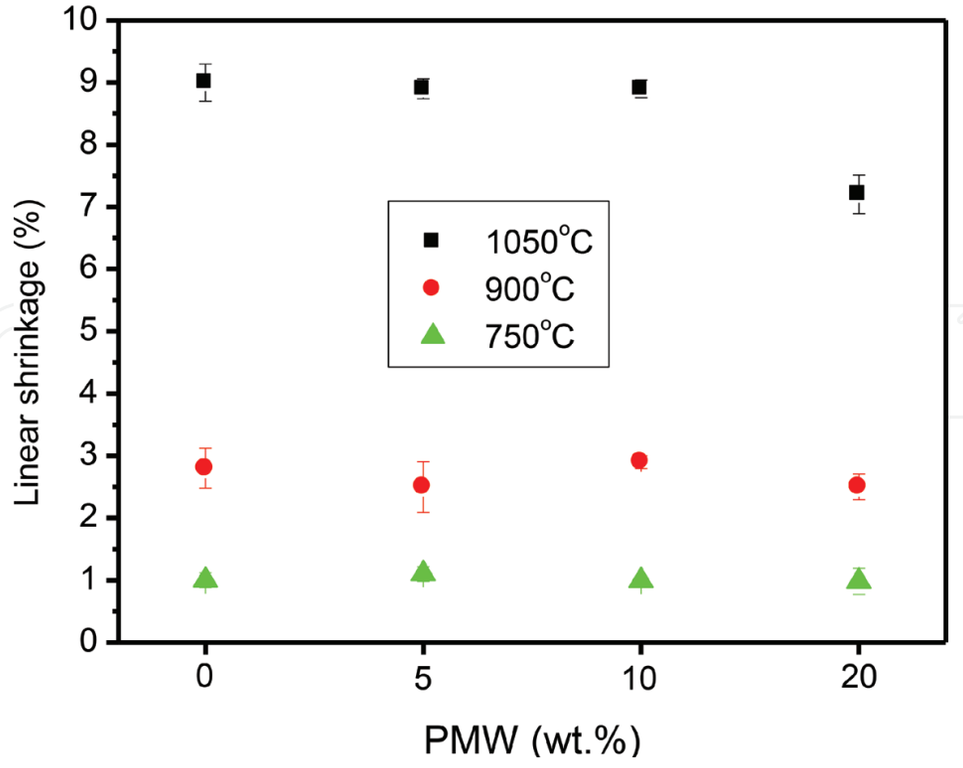


Figure 14. Linear shrinkage of the clayey body as a function the amount of the PMW incorporated [19].

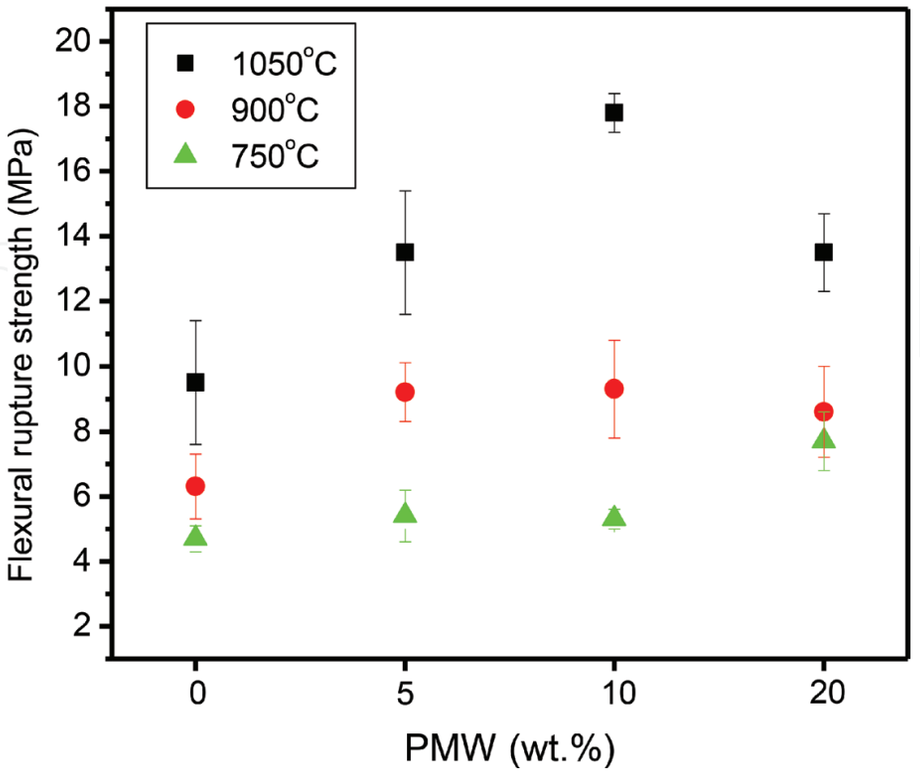


Figure 15. Flexural rupture strength of the clayey body as a function the amount of the PMW incorporated [19].

coefficients among the ceramic phases during the sintering stage. Due to the refractory nature of this clay, the sintering is impaired as well as the reduction of pores, event at temperatures around 1050°C.

The EDS spectrum of point 1 indicates the existence of Zr and Si that can correspond to zircon silicate. Punctual regions 2 and 3 are basically composed of Si, Al, and Fe, i.e., the basic constituents

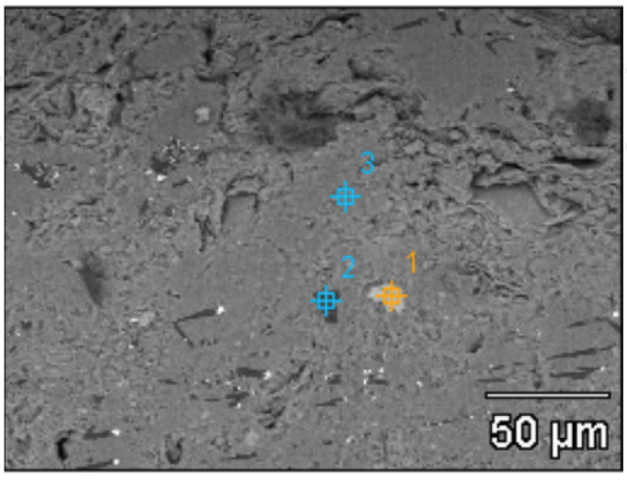


Figure 16. SEM micrograph of ceramic with 0 wt.% of steel dust incorporated and sintered at 1050°C, including EDS spectra of selected points [18].

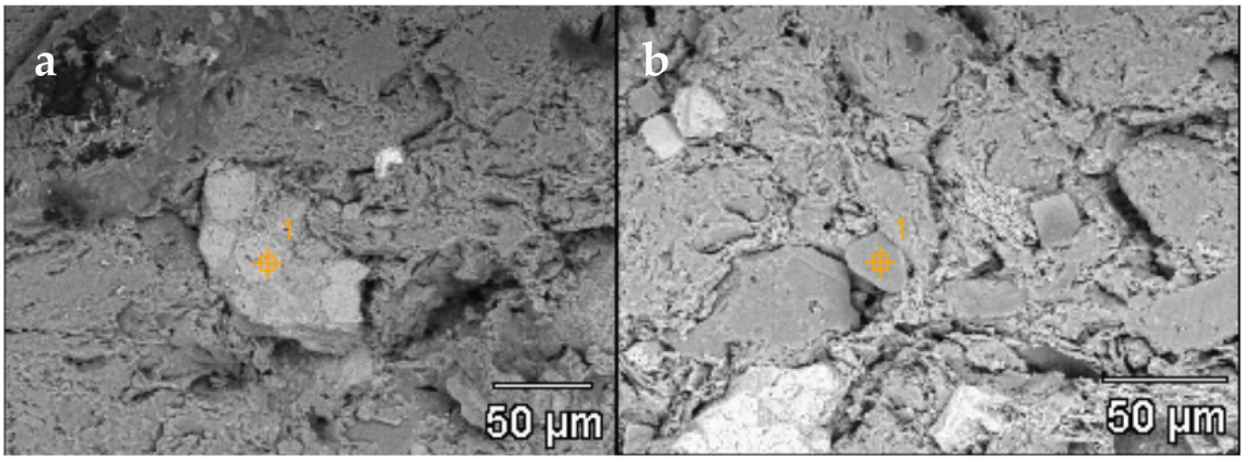


Figure 17. SEM micrographs of ceramic with 20 wt.% of steel dust incorporated and sintered at 1050°C, including EDS spectra of selected points [18].

of a kaolinitic clay. In this case, the Si and al predominantly constitute the aluminosilicate amorphous clayey matrix.

Figure 17 shows two SEM micrographs of ceramic specimen with 20 wt.% of dust steel waste incorporated, sintered at 1050°C. In this figure selected punctual regions, marked in the micrographs, were analyzed by EDS. In both micrographs of **Figure 17**, defects associated with microcracks and pores can be observed.

As already mentioned for the microstructure of ceramics with no dust waste addition (**Figure 16**), these defects are associated with the conformation step and further consolidation on sintering. It is important to notice in relation to **Figure 17** that the main microstructural distinction between the ceramics with residue addition and those with no waste (**Figure 16**) is the relatively larger particles apparently belonging to the waste. In fact, the EDS spectrum of the large particle in **Figure 17** (a) indicates the presence of Ca and Fe that are, as listed in **Table 4**, characteristics of the PMW. Moreover, the microcracks that surround the particles indicate that this residue can lead to occasional defects in ceramics.

It is correct mentioning that, in spite of the defects observed, this waste acts as an inert material and assists on the plasticity control of the clayey body. Despite the inert character of the residue particles, the observed microcracks (**Figure 16(a)**) may be associated due their different expansion coefficient at sintering stage, more pronounced at 1050°C. The particle analyzed in **Figure 16(b)** is relatively small and by its EDS spectrum, with Si and O, corresponds to a quartz particle, which already exists in the natural clay.

3. Final considerations

At this sense, it is technically possible to recycle steel slag by incorporating into clayey ceramic. However, the incorporation of this waste into clayey ceramics must be done in amounts of up to 10 wt.%. An elevated amount of steel slag can increase the porosity of the fired ceramic and decrease its mechanical strength due to its inert action and elevated weight loss.

It can be concluded by the influence investigation of the steel sludge as raw material for ceramic production in that its incorporation is technically feasible. The porous agglomerate constituents of the steel sludge do not adhere to the clayey matrix, creating regions of failure that contribute to the reduction of the mechanical strength of the final products with incorporations of residue above 5% by weight. The environmental evaluation shows excess of Al in the solubilization extract, coming from the clay. The other evaluated elements are within the limits required for both the solubilization tests and the leaching test. The fine steel sludge is a waste predominantly composed of Fe metallic, Fe oxides (magnetite and wustite), and calcium carbonate (calcite). This waste shows a fine particle size, average of 35.6 μm that is appropriate for red clay-based ceramic production. This waste contributes to increase the dried bulk density of the ceramic. Incorporations of 5 wt.% of the waste are beneficial to the ceramic since it decreased the fired linear shrinkage and does not increase the water absorption. And also, the mechanical strength does not decrease which is also a convenient result for this level of incorporation.

The incorporation of a particulate, PMW, waste generated in the sintering stage of an integrated steelmaking plant, caused significant changes in a kaolinitic clay-based ceramic sintered at 1050°C. Relatively large dark phases associated with Fe and Ca compounds in the waste were formed in the clayey ceramic matrix. These phases showed evidences of microcracks- and pores-induced defects. The PMW incorporation results not only in an increased amount of porosity but also pores with relatively larger sizes. It is suggested that the inert nature of the waste, as well as its different coefficient of thermal expansion with respect to the aluminum silicate matrix, is responsible for the additional defects produced in the clayey ceramic. It was found that the particulate material waste from the sintering stage of an integrated steelmaking plant has an elevated amount of Fe and Ca compounds. The incorporation of this waste, in amounts of up to 20 wt.%, into a clayey body did not change its workability and enhanced the evaluated physical and mechanical properties such as water absorption and flexural rupture strength. The results indicated that this type of waste has a potential to be used into red ceramics with real benefits both in the processing and in the quality of the products.

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