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ORIGINAL PAPER

Steel slag and iron ore tailings to produce solid brick

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Abstract
The main goals of this work were to verify the potential of reuse of steel slag and iron ore tailings as secondary raw materials to produce solid brick and to evaluate whether this application can consume the amount of slag generated in Brazil. The feasibility of this application was verified through a comparative study. The mechanical behavior of concrete artifacts and pressed bricks made from residues was compared with others described in the literature. The residues were initially characterized using chemical and granulometric analysis. The bricks were produced by mixing different compositions of the residues with the addition of cement in the contents of 0 and 5%. The bricks were pressed in a manual mechanical press and sent to curing. The values of flexural strength of the bricks were higher than 2.0 MPa, and the average weight of the bricks was like those found in the ecological bricks. The simulation with the construction of houses showed that the proposed application can consume the amount of slag generated in Brazil. The generation of the income from carbon credits associated with CO_2 reduction is an incentive to implement environmental management tools in Quadrilátero Ferrífero territory, specifically, industrial symbiosis and the carbon market.

Keywords Steel slag · Iron ore tailings · Solid brick · Low carbon · Construction

Introduction

The society, represented by consumers, suppliers and governments, among other members, aware of global trends that point to the growth in industrial production, consumption and waste generated, values initiatives related to sustainable development.

There is an environmental and economic concern with the destination of these wastes, which if improperly discarded may contaminate the environment and create a risk to public health. It stimulates the growth of studies that seek alternatives for reuse of these materials.

Thus, organizations interested in practices that achieve sustainable development and minimize environmental problems have adopted the most diverse models and tools of environmental management. The carbon price is valuable tool for the private sector in terms of the development of competitive advantages.

Likewise the adoption of environmental management tools and market instruments makes possible the adequate practice of industrial solid waste (ISW) management, justifying the conduct of this work.

Initially, it is proposed here to present to industries ways to implement more sustainable projects, considering international policy and goals and then to assess the potential of reuse of residues for the manufacture of solid bricks, prioritizing a manufacturing process with lower greenhouse gas (GHG) emission and with lower energy consumption. The production chain was not considered as a whole, that is, suppliers and customers are not the focus of this preliminary study.

The theme gains relevance when considering high-impact activities in the environment and high representation in the territory, as in the steel, mining and civil construction sectors, especially in Brazil.

According to the World Steel Association, in 2015 world crude steel production reached 1.62 billion metric tons, with

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1.20 thousand Mt using oxygen converters. In Brazil, using this productive process, this amount was 26 Mt. Considering that 120 kg of basic oxygen furnace (BOF) slag (Wimmer et al. 2014) is produced for each ton of steel, the high production of this waste, 3.12 Mt, is evident. In Brazil, the generation of iron ore concentrate exceeds 120 Mt per year (IPEA 2010).

The environment impact generated by a given activity can be measured considering the emission of CO_2. In 2010, production of iron, steel and non-metallic minerals alone resulted in 44% of all the industry's CO_2 emissions, accounting for 30% of total global GHG emissions. Constructions accounted for 19% of the emissions of these gases related to energy, including electricity (IPCC 2014).

Moreover, the world's urban population is expected to reach between 5.6 and 7.1 billion people by 2050, making human settlements gain importance in this scenario. By 2016, the world population living in urban areas was approximately 4 billion people.

The reuse of waste from iron mining and steel as secondary raw materials favors the development of new production standards. In view of that, the following hypotheses were assumed to delineate the second part of this study, the brick manufacturing process:

1. The residues generated in the territory can be reused as an alternative raw material to the natural aggregates, mainly considering their physical characteristics, as described in the works of Netinger et al. (2011) and of Silva et al. (2014);
2. The production of brick for structural masonry, used in the reference territory, can consume the amount of steel slag generated in Brazil, as simulated in the present study;
3. The addition of iron ore tailings rich in SiO_2 could reduce the Ca/Si ratio of the steel slag and improve its hydraulic activity. This hypothesis was tested by comparing the mechanical resistance of the bricks produced;
4. A brick totally produced with residues would imply the reduction in the extraction of natural aggregates and preservation of the water resources. In Brazil, sand is mostly extracted from river beds (MME 2009);
5. This is an ecological brick, since the manufacturing process tested does not use cement in its composition and is not burned. This implies a production of low carbon and low energy consumption. We used the QE-CO_2 method to calculate the CO_2 emission for the construction of popular houses with T2 brick (manufactured in this study). The work showed that there was reduction in the emission of CO_2 (Assis et al. 2017).

Espuelas et al. (2017) mentioned that the production of unburned bricks can be an effective way to reduce the environmental footprint of the construction industry, since this manufacturing process not only requires less energy and natural resources, but also generates less waste.

Thus, the main aim of this article is to evaluate the reuse of BOF slag and iron ore tailings as secondary raw materials for the manufacture of massive brick. The secondary goals were: (1) to estimate whether the application of the brick in the structural masonry would be able to consume the amount of slag generated; (2) to present environmental management tools with the potential to generate income for the private sector; and (3) to estimate whether the reduction in CO_2 emission is capable of stimulating the adoption of economic instruments as a solid waste management strategy.

This study innovates a new method to produce bricks by mixing aged slags (365 days exposed to the weather) and the iron ore concentration tailings. It contributes to the regional strategic planning by bringing to light relevant elements and identifying considerable potentialities and territorial demands. In addition to presenting data and information that can stimulate partnerships between government institutions, research, government and business, it also articulates regional strategic planning with politics and with international agreements.

The joint action among the different members of the society encourages the most diverse applications of the ISW, considering the aggregation of value to the product and the local demands. Tanimoto (2004) reported that partnerships thus contribute to both commercialization and legalization of waste exchange (environmental licenses) (cost × benefit).

We highlight that the innovative nature of this study makes it important to carry out additional research that guarantees the technical and environmental reliability of the brick produced. Also, the impact/ long-term usage of this brick has not yet been considered. These studies are already ongoing.

Pathways for the implementation of more sustainable projects in Quadrilátero Ferrífero

The Quadrilátero Ferrífero (QF)—located in the state of Minas Gerais, Brazil—is worldwide recognized for its mineral wealth. And consequently, there is a strong presence of several companies in the steel and mining sectors. Recognizing its importance, the dynamics of this region were chosen to reflect some aspects, such as the feasibility of the potential use of management tools and the applicability of projects focused on low carbon production processes.

The expressiveness of the mineral wealth can be estimated by considering the state of Minas Gerais, which holds 34.5% of the country's steel production and represents 67.0% of the iron ore reserve in Brazil (DNPM 2016).

Consequently, approximately 606 Mt of mining waste (FEAM 2016) was inventoried, 40.0% representing iron ore tailings (Silva et al. 2011).

Considering the state in question, we highlight the housing deficit of approximately 529 thousand dwellings in 2014 and the consumption of aggregates, 71.1 Mt in 2011 (ANEPAC 2012).

The reuse of waste and tailings reduces energy consumption, gas emissions and the consumption of natural raw materials (Quijorna et al. 2014). In Brazil, the valorization of the reuse of solid waste and of production processes that adopt sustainable standards is expressed in Law No. 12,305, of August 2, 2010. This law establishes the National Solid Waste Policy and an order of priority for the management of solid waste. The order of priority is “non-generation, reduction, reuse, recycling, treatment of solid waste and environmentally adequate final disposal of waste” (Brasil 2010).

The valuation of low carbon production processes is also supported by the commitment established by the Brazilian Nationally Determined Contribution (NDC). The NDC was presented in September 2015 at the UN General Assembly with the goal to reduce national GHG emissions by 37% by 2025 (CEBDS 2016).

It is evident that low carbon production processes and solid waste management are of interests of public government. The adoption of environmental management tools that prioritize the exchange of solid waste appears as a path toward the sustainable development of the QF. Considering the characteristics of this territory added to the public interest, it becomes relevant to present tools that present the potential to generate income for the private sector.

The industrial ecology comes from the metaphor of nature to analyze and optimize the industrial complexes, logistics and consumption, as well as your energy and material flows (Costa et al. 2010).

Industrial symbiosis (IS) is defined as a multi-company network to foster eco-innovation and long-term culture change. It represents a complex of interactions that makes it possible to develop and share knowledge, generate mutually profitable transactions and processes (Lombardi and Laybourn 2012) and reduce production costs (Yuan and Shi 2009).

Dong et al. (2013) evaluated and compared the environmental and economic gains related to IS activities in industrial iron and steel areas in Liuzhou and Jinan in China and Kawasaki in Japan. The results show that in Liuzhou, there are three symbiosis activities among industries, including reuse of blast furnace slag in the cement and construction industries. The annual by-product/waste exchange exceeded 2.0 Mt/year, earning economic revenue of more than US$ 36.55 million for the iron/steel company.

In Brazil, actions of this kind are observed in the Camaçari Petrochemical Complex, Bahia, with economic benefits totaling gains of US$ 900 thousand per year (Tanimoto 2004). In the state of Minas Gerais, the promotion of the Brazilian Industrial Symbiosis Program resulted, in the period from 2009 to 2012, in 139,793 tons of waste diverted from landfills, 194,815 tons of saved raw materials, 87,476 tons of carbon emissions reduction and cost reductions of R$ 8,768,683.00 for participating companies (FIEMG 2017).

The concept of cleaner production, defined as the continued application of a preventive and integrated environmental strategy to processes, products and services, emerged to increase the eco-efficiency of the production process and reduce risks to health and the environment (Pereira and Sant’anna 2012).

According to the MMA (2017), the evolution of this concept led to the idea of “Sustainable Production and Consumption.” Besides the classic variables (reduction in the consumption of raw materials, water and energy) the cleaner production incorporats the idea of reducing GHG emissions, i.e. “low carbon production”. Besides the already classic variables (reduction in the consumption of raw materials, water and energy) incorporates the idea that a cleaner production is a standard that emits less GHG, is “low carbon production.”

Based on a quantitative comparison of CO_2 emissions with both existing and hypothetical data, Ammenberg et al. (2015) studied different production systems and cement products. The authors found that, with the incorporation of by-products from local industries replacing clinker, such as granulated blast furnace slag (GBFS), CO_2 emissions reduced by almost half, per ton of cement.

Ferreira et al. (2016) analyzed the environmental impact of the use of electric arc furnace slag replacing natural aggregates in highway construction. The results of the life cycle assessment revealed that the environmental impact of said construction can be reduced by using slags. Technically the slag fulfilled the legal requirements for such application.

When the outlook is based on consumption, data show that many imported products incorporate high flows of non-recycled waste—even though a country’s national economy may have high rates of recycling and waste recovery (Tissérant et al. 2017).

Global concern about reducing CO_2 emissions is clear in the economic carbon pricing instrument. By mid-2016, there were already 64 international jurisdictions that taxed carbon or operated emissions trading systems (CEBDS 2016). Brazilian NDC is one of those that considered the use of market mechanisms (World Bank 2016).

The Clean Development Mechanism (CDM) and the United Nations Conference on Climate Change (COP 22) emerge as alternatives for partnerships between countries and institutions. These partnerships facilitate the implementation of sustainable projects through innovative, low-cost technologies that reduce GHG emissions in developing countries. And, in addition to CO_2 reduction goals, they generate carbon credits from these reductions (Thiesen 2010), directly or indirectly.

The CDM Executive Board recorded 7690 project activities by January 31, 2016. China leads the way with 3764 project activities and 3.8 billion tons of carbon dioxide equivalent (tCO_2eq) being reduced. Brazil ranks third with 339 registered project activities and is responsible for the reduction of 399 million tCO_2eq, which corresponds to 5% of the world total (MCT 2016).

Mauthoor (2017) mentioned the benefits of the recycling of electric arc furnace slag as concrete aggregates, which results in reduced dependence on imported raw materials. In addition, when combined with recycling options and technology, partnerships lead to local sustainability.

Galán-Arboledas et al. (2017) used this type of slag for the manufacture of ceramic bricks. Their results show that the incorporation of 30% by weight of the slag generally leads to adequate technological properties, thus providing a potential economy of up to 17% on natural gas consumption and reduction in CO_2 emissions of up to 24%.

Reuse of steelworks slag and iron ore tailings

The metallurgical sector is concerned with adding value to its waste, transforming it into inputs for other sectors. An example of value-added products is ferrous sulfate, produced through these residues (Maia et al. 2017). Engstroma et al. (2013) noted that the accumulation of minor elements in the slag often limits the possibility of reusing it in the process. Thus, to avoid landfill, steelmakers often try to process the slag into useful materials.

According to Instituto Aço Brasil, in the biennium of 2014–2015, companies in the steel sector invested R$ 2.5 billion to improve the environmental performance of its operations. By 2015, the destination of steel slag and other slag was as follows: 2.0% for final disposal, 14.0% for inventory, 37.0% for sale, 26.0% for internal reuse and 21.0% for donation. The application of this slag is distributed through base and sub-bases sectors, cement production (2.0%), agronomic use (1.0%), land leveling (41.0%) and others (11.0%) (IABr 2016).

On the other hand, when analyzing the current mining waste management scenario, it is possible to verify that forms of waste disposal are not prioritized to reduce and/or reuse and/or recycle them. These tailings present chemical compositions and granulometries distinct from the original soil, requiring adequate disposal to reduce their impact on the environment (Yellishetty et al. 2008).

It should be noted that the main destination is still disposal in tailings dams (92.68%) (FEAM 2016). This type of disposal represents an excessive cost of capital and operation, thus reducing the profit margin of the companies (Gomes 2009).

Therefore, in view of the need to reuse waste in general and to add value to the product, many studies have sought different alternatives to the production of artifacts for use mainly in civil construction.

The problem inherent to the recycling of steel slag is mainly due to its volumetric instability. However, when properly treated, it does not expand (Liu and Yan 2008). According to Brazilian Standard NBR 10.004 (ABNT 2004), this waste falls within class II-A, non-hazardous and non-inert waste (Junior 2012).

Andrade et al. (2014) pointed out that mining tailings are potentially interesting materials for civil construction. For this application, the chemical composition is not very strict and the granulometry and strength of the material are of greater relevance.

Silva et al. (2014) studied the feasibility of adding 5% of the iron ore tailings to the production of ceramic brick. The results indicated that the addition of the waste contributed to the mechanical resistance to the flexion of the brick, which reached 6.5 MPa.

The suitability of waste from iron mining was analyzed by Yellishetty et al. (2008) for use in civil construction. The authors concluded that particles with granulometry of 12.5–20.0 mm are suitable for use in the manufacture of concrete. And particles smaller than 0.475 mm proved to be very suitable for the manufacture of bricks.

Sezer and Gülderen (2015) studied the use of steel slag as an aggregate in concrete. Blends containing steel slag as fine and coarse aggregate simultaneously segregated. The mixtures, with 7 days of curing, containing only the substitution as fine aggregate had flexural strength varying from 4.19 to 2.84 MPa.

Da Silva et al. (2016), using BOF steel slag as aggregate in concrete pavers for paving, found flexural strength values greater than 10 MPa for all tested curing ages. The authors processed the slag to remove the metallic constituents of the sample.

Netinger et al. (2011) studied the use of steel slag as aggregate in concrete and compared the results obtained with concrete made from dolomitic natural aggregates. The authors considered that the mechanical results of volumetric expansion and susceptibility to corrosion were satisfactory.

Naganathan et al. (2015) studied the performance of brick produced from fly ash, bottom ash and cement. Mechanical results of this type of bricks were satisfactory compared to conventional bricks. Toffolo et al. (2014) compared the physical and mechanical characteristics of

Table 1 Chemical composition of the raw materials

Material	wt%						
	Fe^{a}_{total}	SiO_2	MgO	Al_2O_3	Fe_2O_3	CaO	CaO free
T365	24.3	8.4	6.1	3.9	21.2	45.0	2.3
IOT	43.1	30.2	–	2.8	–	–	–
C	–	33.6	4.1	13.2	3.0	39.7	–

[a] Measured by inductively coupled plasma–atomic emission spectroscopy (ICP AES)

concrete paving blocks, manufactured with iron mining residue and with natural aggregates. The results of compressive strength, expandability and water absorption were satisfactory.

Experiment

Materials

The slag and tailings samples were supplied by companies located in Quadrilátero Ferrífero, Minas Gerais, Brazil. The cement (C) acquired was the CP IV-32 RS, material popularly used in civil construction.

The slag generated during the refining of steel in oxygen converters is called BOF (basic oxygen furnace) slag. In the company, it was abruptly cooled by sprinkling of water, then benefited and stored in open courtyard for 365 days, hence called (T365).

The iron ore concentration residues 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.

Methods

Phase 1: Bibliographic research on the following topics: environmental management tools and case studies; national policy and the international scenario in the context of climate change and the depletion of natural resources; and reuse of solid waste.

Phase 2: Waste characterization and experimental procedures.

The chemical composition of the samples was determined by energy dispersive X-ray spectroscopy (EDS-720)—Shimadzu (Table 1). The expansibility test was carried according to Brazilian Standard ABNT NBR NM 13 (2004). The method is based on the evaluation of free calcium oxide by dissolution in ethylene glycol and subsequent titration in standard solution of hydrochloric acid (HCl).

For the manufacture of the bricks the residues were properly dried, disaggregated and sifted. The particle size adopted was less than 0.15 mm. The components were mixed until the color was uniform. Thereafter, 10% of water was added, based on the weight of the dried mass, and again homogenization was carried out, until the blend became flour-like. For each composition, 10 specimens were cast in stainless steel mold. The specimens were pressed in a manual mechanical press with a pressure of 20 MPa.

Table 2 shows the mix ratios chosen for the manufacturing of the bricks, molded in accordance with the ABNT Brazilian Standard 10833 (ABNT 2013).

The 30 pressed specimens were stored for 14 days in the shade and moistened with a frequency of three times a day for the first 7 days.

After curing, the bricks were weighed and analyzed visually for possible surface defects (Fig. 1). The flexural strength with three supports was obtained according to

Table 2 Mix ratio for each sample group (wt%)

Material	Mix ratios (wt%)		
	T1(100/0/0)	T2(85/15/0)	T3(85/10/5)
T365 (BOF slag)	100	85	85
IOT (iron ore tailing)	–	15	10
C (cement)	–	–	5

Fig. 1 Bricks made from waste steel (T365) and iron mining (IOT) and cement. T1, T2 and T3 are the respective proportions of raw materials: T1 (100/0/0), T2 (85/15/0) and T3 (85/10/5)

ASTM C1161:1990 and was tested with 6 specimens of each composition.

Before performing an extensive set of mechanical tests, we consider it is necessary to evaluate the mechanical behavior of the combination of wastes and also the method of processing the bricks. A comparative evaluation was made with other studies described in the literature. For this purpose, the types of waste, the mode of production (whether burned or cured) and the mechanical results were considered. The recommended flexural strength limit for ceramic bricks is 2.0 MPa (ISO 13006: 2012), and it was also used as reference.

Phase 3: In order to know whether the production of brick for structural masonry can consume the amount of steel slag generated in Brazil, the construction of a popular house with 10 thousand bricks was simulated. For this scenario, brick T2 (85/15/0) (Table 2) and the number of households built annually in the state of Minas Gerais, Brazil, were used.

Results and discussion

Mechanical testing and properties

The visual analysis allowed to verify that the solid bricks produced did not present surface cracks. This result indicates that there was a good synergy between the mixed residues. Fine aggregates were used in this research; in this way the granulometry adopted for the residues was adequate for the manufacture brick, as shown by Yellishetty et al. (2008).

Table 3 shows the average values of the mechanical test, the average weights of the bricks produced and those commercially available for comparison.

In general, the produced bricks have satisfactory average weights when compared to the ecological brick. However, the bricks tested are heavier than the solid brick and concrete block, most commonly used products on the market. As expected, the weight of the bricks increased with the IOT content, rich in iron oxide.

Table 3 Brick parameters measured

Material	Size (10^{-2} m)	Weight (kg/m^3)	Strength (MPa)
T1(100/0/0)	20 × 10 × 5	2220	4.04
T2(85/15/0)	20 × 10 × 5	2430	3.07
T3(85/10/5)	20 × 10 × 5	2400	3.61
Common solid brick[a]	23 × 11 × 5.5	1070	–
Green brick[a]	25 × 12.5 × 6.25	2690	–
Concrete block[a]	39 × 19 × 19	1910	–

[a] These data were obtained from the company website which commercializes such products (http://www.leroymerlin.com.br/, accessed in: 10/09/2016)

All the compositions evaluated met the minimum mechanical strength, 2.0 MPa for manufacturing solid bricks (ISO 13006: 2012). The free CaO content of the aged slag (Table 1—T365) and the absence of cracks reinforce the good mechanical performance of T1 brick (100/0/0). It is important to note that this compound, one of those responsible for the deterioration and fragmentation of concrete built with steel slag (Guo et al. 2014), was hydrated.

The mechanical behavior of the brick containing only steel slag (T365) was like that found by Sezer and Gülderen (2017), when studying concrete mixtures containing steel slag as a fine aggregate. When compared to the concrete paver produced by Da Silva et al. (2016), the deleterious effect of iron oxide on the mechanical performance of the brick is clear. The authors removed the metallic constituents of the slag and obtained better mechanical performance.

The higher content of iron oxide in T2 brick (85/15/0) had a negative effect on mechanical strength when compared to T1 brick. The reduction in the resistance can be the result of the low hydraulic activity of BOF slag, favored by the inert phases of iron oxide in contact with water (Belhadj et al. 2012). This result indicates that the addition of SiO_2-rich iron ore tailings did not contribute to improvement in the hydraulic activity of the steel slag.

Although it is a matter of different production processes, it is worth comparing the mechanical behavior of T2 brick with that produced by Silva et al. (2014). This one content 5% by weight of the IOT and T2 15% of this waste. The chemical composition of the steel slag (Table 1—T365) showed that the sum of the magnesium, iron and calcium oxides corresponded to more than 72% by weight. As solid phases of these oxides played a negative role in the cementitious properties of the BOF slag (Guo and Shi 2013), the addition of iron oxide contributes to the lower values of flexural strength of T2 in relation to the ceramic brick of the author.

The addition of cement increased the resistance of brick T3 (85/10/5), compared to T2, indicating that the cement contributed to the reactivity of the steel slag.

T1 and T3 bricks stand out because they are lighter and have the best results of flexural strength. However, it is observed that products that do not use this binder are environmentally more advantageous. The cement is one of the elements mainly responsible for CO_2 emissions in the atmosphere (Li et al. 2016).

Souza et al. (2015), using life cycle analysis, concluded that the concrete manufacturing process has a major impact on climate change and resource depletion when compared to ceramic products. Oliveira et al. (2016), applying the same methodology in blocks of concrete of the Brazilian market, found that the cement is responsible for a significant portion of the CO_2 emission. They pointed out that this indicator is not related to the amount of cement clinker, but to the amount of cement used in the block.

The results described in the literature using life cycle analysis reinforce the importance of the selection and combination of raw materials to minimize the consumption of cement.

Simulation of the consumption of steel slag in civil construction

The consumption of steel slag in the production of brick for structural masonry was simulated considering the factors: the construction of a popular house with 10,000 bricks and the use of T2 brick (85/15/0). According to the censuses carried out by Instituto Brasileiro de Geografia e Estatística between 2000 and 2010, approximately 126 thousand households were built in Minas Gerais.

The T2 brick has 2.07 kg of steel slag. For these constructions, approximately 2.6 Mt/year of steel slag and 454.7 thousand tons of iron ore tailings would be consumed.

Considering the BOF slag generation ratio per ton of steel (Wimmer et al. 2014), the total amount of BOF steel slag produced in Brazil in 2015 was 3.1 Mt. In doing so, the commercialization of the said brick would consume approximately 84% (2.6/3.1) of the annual production of this residue.

This result indicates that the application of steel slag to brick production has the potential to generate economic gains for steel mills (Dong et al. 2013), to promote social benefits and environmental advantages. The social sphere would benefit from the provision of deposit areas for other purposes, as well as access to lower-cost housing. The environmental gain is reflected in the reduction in GHG emissions (Assis et al. 2017).

Assis et al. (2017) used the QE-CO_2 method to calculate the CO_2 emission for the construction of 1000 popular houses. The houses were hypothetically constructed using the T2 brick, the concrete block and the ceramic brick. The values found with the use of the respective products were: 58.45 tCO_2, 3753.6 tCO_2 and 1415.2 tCO_2. In this scenario, the construction of the 126,000 households using the T2 brick would generate a reduction of 465,588.9 tons of CO_2, when compared to the concrete block.

In the European market, carbon credits are traded at around US$ 9.25 per ton. That is, the carbon credits related to CO_2 reduction in the simulated venture could be traded for US$ 4.3 million.

That said, the author suggests that the exchange of residues and the production of bricks could be subsidized with the implementation of the industrial symbiosis in Quadrilátero Ferrífero, favored by the proximity between the source area, the productive sector and the consumer centers (Gibbs and Deutz 2007). It also suggests that this management tool should be applied to integrate the use of economic instruments, such as the carbon market.

Conclusions

The use of BOF slag and iron ore concentrate tailings as secondary raw materials in the manufacture of solid brick was considered technically feasible, with reference to the minimum mechanical requirement of 2.0 MPa. The comparison of the mechanical behavior of the proposed bricks with other civil construction artifacts indicated that for better results, it is necessary to process the slag to remove the metallic constituents.

The simulation to evaluate the consumption of steel slag in civil construction showed that the proposed application is capable of consuming 84% of the amount of slag generated in Brazil.

The generation of the income from carbon credits associated with CO_2 reduction is an incentive to implement environmental management tools in Quadrilátero Ferrífero territory, specifically, industrial symbiosis and the carbon market.

Thus, it is concluded that this study contributed to the valorization of BOF slag and to the management of solid waste generated in Quadrilátero Ferrífero, based on the principles of sustainable development. It should be clarified that the details of this study are in progress, contemplating the analysis of the life cycle of the product, the compressive strength and the leaching.

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