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Incorporation of residues from the minero-metallurgical industry in the production of clay–lime brick

Welington L. Ferreira, Érica L. Reis*, Rosa M.F. Lima

Department of Mining Engineering, Federal University of Ouro Preto, Ouro Preto, MG, Brazil

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ABSTRACT

Industrial processes such as the extraction and processing of building and dimension stone and the manufacturing of ferroalloys generate large amounts of waste, which can cause environmental damage. Therefore, the development of new techniques for recycling and reusing industrial waste would be useful for minimizing the environmental impacts of these activities. This paper presents the incorporation of soapstone powder and Fe–Si–Mn slag in clay–lime brick as a partial substitution for agglomerate (lime) because these residues meet the standard specification for the chemical composition of a pozzolanic material. The results show that brick samples where 25% lime is substituted by waste residues achieved a compressive strength above 2.0 MPa, which is within the standard specification, after 28 days of curing (soapstone powder) or 60 days of curing (soapstone powder and Fe–Si–Mn slag). These materials were classified as class II, non-inert residues.

1. Introduction

The southeastern region of Brazil (the states of São Paulo, Minas Gerais, Rio de Janeiro and Espírito Santo) is the most developed region in the country and has intense mineral–metallurgical activity. Brazilian steel production totalled 35,162 Mt (Jesus, 2012) in 2011, and the state of Minas Gerais is responsible for 53.2% of all Brazilian mineral production (IBRAM, 2012).

The total recovery of dimension stone is very low. Gencel et al. (2012) reported that 20–30% of the marble block extracted in Turkey turns into dust during the cutting process. In Brazil, the total recovery of dimension stone in quartzite and soapstone quarries is approximately 30–40% per extracted volume (Rodrigues and Lima, 2012). It is common practice all over the world to dispose of the waste from dimension stone processing plants in landfills, which creates a high environmental impact.

In the steel industry, 0.7 to 1.7 t of slag is produced for each tonne of steel (WSA, 2013). In Fe–Si–Mn alloys, 0.9 to 2.2 t of slag is produced for each tonne of alloy (Olsen et al., 2007). For actual Brazilian steel production, 35,162 Mt (Jesus, 2012) of steel is produced along with 24,613.4 to 597,757.4 Mt of slag per year. In 2012, the Fe–Si–Mn alloy industry located in Ouro Preto, Minas Gerais produced 48,794.12 t of slag. Part of the produced slag is normally returned to the steel process; however, the majority must be stored.

Recycling has the potential to reduce the amount of waste disposed of in landfills and to preserve natural resources. Construction materials such as brick and concrete that contain waste materials can support construction sustainability and contribute to the development of civil engineering by reusing industrial waste, minimizing the consumption of natural resources and producing more efficient materials (Pelisser et al., 2011; Gencel et al., 2012, 2013). All of the above mentioned factors are important when the Brazilian habitation deficit is taken into account (Nascimento, 2007).

Clay–lime bricks are easy to manufacture and through processes that do not include burning, which avoids the environmental impacts associated with burning manufacturing processes (Figueiredo, 2011). Among other advantages, lime soil bricks reduce the usage of bedding mortar and coatings due to the quality and final appearance of the bricks, which are markedly superior to their counterparts. These advantages stem from the dimensional regularity and facial flatness of lime soil bricks compared to conventional ones. For this reason, lime soil bricks can be easily used in

* Corresponding author. Departamento de Engenharia de Minas, Universidade Federal de Ouro Preto, Campus Universitário, Morro do Cruzeiro, S/N°., CEP.: 35400-000, Ouro Preto, MG, Brazil. Tel.: +55 31 3559 1590; fax: +55 31 3559 1593.
E-mail addresses: erica@demin.ufop.br, ericalreis@hotmail.com (É.L. Reis).

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masonry, requiring only waterproofing and a finishing cover (Marino and Boschi, 1998).

In this paper, slag from Fe–Si–Mn alloy and soapstone powder produced by the alloy industry and soapstone quarries in the Ouro Preto region of Minas Gerais, Brazil, were used as partial replacements of lime for brick manufacturing. Their pozzolanic characteristics and the possibility to decrease the final price of produced bricks were evaluated in order to assess the bricks as building materials, especially for the poorest economic class of the population.

2. Materials and methods

2.1. Materials characterization

The following characteristics of the raw materials used to produce brick mixtures were previously characterized: particle-size distribution, qualitative mineralogical composition, chemical composition, density and specific surface area.

Particle-size analysis was performed by wet sieving (Tyler series–3360 to 37 μm). X-ray diffraction (total powder method) was used to identify the main minerals in slag, clay and lime. For this purpose, a diffractometer with Cu tube (PanAnalytical model Empyrean) was used. Diffraction data were collected from 2° to 72°. An ultrapycnometer (model 1200e, version 4.00) and BET (model 1200e) were used to determine the densities and specific surface areas of the raw materials, respectively. The run conditions of the ultrapycnometer were as follows: analysis temperature of 27.9 °C, target pressure of 19.0 psig, dry Helium gas, and a flow purge of 4 min (the final density was determined as the average of three determinations). The BET measurements were performed using a degasification time of 16 h at 200 °C. The determination was performed in a 30 ml/min nitrogen flux at a temperature of 77.3 K. The chemical compositions were analysed by inductively coupled plasma–optical emission spectroscopy (Spectro model Ciros/CCD). Loss on ignition was determined by gravity method. Clay Alteberg's limits were determined based on ABNT NBR 6459/84 and NBR 7180/84 standards.

2.2. Preparation of brick samples

Raw bricks were produced using one part agglomerate with 10 parts of brick clay (fraction size −4.8 mm in accordance with NBR 6457/86 standard). Clay–lime bricks (no added residue) and bricks with the addition of 25%, 50% and 75% slag from the manufacture of Fe–Si–Mn alloys or thin soapstone replacing part the lime. The amount of added water was determined based on the standard practice of the NBR 7182/86 standard, which specifies the optimum humidity. Table 1 presents the brick mixture generated from the raw materials.

Table 1
The brick mixture prepared from the raw materials.

Sample	Agglomerate			Clay − 4.8 mm	Humidity (%)
	Lime	Soapstone powder	Fe–Si–Mn slag		
RF	1	–	–	10	22
ST1	0.75	0.25	–	10	21
ST2	0.50	0.50	–	10	20.5
ST3	0.75	0.25	–	10	20.0
SL1	0.75	–	0.25	10	21.0
SL2	0.50	–	0.50	10	20.5
SL3	0.25	–	0.75	10	20.0

Obs.: RF – reference; ST – soapstone; SL – slag.

A hydraulic press (Nowak model PM 15 TON) was used to make the cylinder bricks, which were 5.00 × 10.0 cm in size. Fig. 1 depicts the process of brick confection: In the first step, the brick mixture was introduced into a sample holder and then pressed with a pressure of 2.5 MPa (Fig. 1a). After pressing, the excess material was removed, and the brick was finally removed from the sample holder (Fig. 1b). The bricks produced were introduced into a humidity chamber (EQUILAM, model SS600UMe) at a temperature of 23 ± 2 °C and a relative humidity ≥95% in accordance with the standard procedure of confection and cure-cylinder bricks (NBR 12024/92) for 28 and 60 d.

2.3. Characterization of brick samples

After the 28- and 60-day cure periods in the humidity chamber, the physical and mechanical properties of sample bricks, such as water-absorption values and compressive strength, were determined in accordance with the procedure of the NBR 8492/92 standard. For compressive strength, a press (TIME GROUP trademark model YAW-2000D) with a press strength of 500 N (50 kgf/s) was used.

Solid-residue classification was performed with bricks of lime–residue–clay, which yielded better results in terms of physical and mechanical properties, in accordance with the NBR 10.004/04 standard. Both the leaching and solubilized extracts of solid residues were analysed in accordance with the ABNT NBR 10005/04 and NBR 10006/04 standards.

3. Results

3.1. Characterization of raw materials

Fig. 2 presents the size distributions of the raw materials used (clay, soapstone powder and Fe–Si–Mn slag). As can be observed by the size distribution, the soapstone powder (~50% −37 μm) was finer than the clay (~25% −37 μm) followed by the Fe–Si–Mn slag (~3% −37 μm).

Figs. 3–6 show the X-ray powder diffraction patterns of the clay, lime, soapstone powder and Fe–Si–Mn slag. The identified minerals in the clay sample were quartz (SiO_2), kaolinite ($SiO_2Al_2O_5(OH)_4$) and muscovite ($KAl_2(Si_3Al)O_{10}(OH)_2$). The lime sample contained the phases portlandite ($Ca(OH)_2$), calcite ($CaCO_3$) and nacrite ($Al_2Si_2O_5(OH)_4$). In the Fe–Si–Mn slag sample, only the enstantite phase ($Mg_2Si_2O_6$) was identified. The identified minerals in the soapstone sample were talc ($Mg_3Si_4O_{10}(OH)_2$) and chlorite ($H_{16}\ Al_{2.78}\ Fe_{0.94}\ Mg_{11.06}\ O_{36}\ Si_{5.22}$), which is in accordance with Rodrigues and Lima (2012).

Table 2 depicts the physical properties of the raw material. The specific surface area of the clay sample was the highest, followed by the specific surface area of the lime sample. This result is likely related to the sample porosities and the presence of kaolinite in these samples (Figs. 3 and 4) as opposed to the size distribution (Fig. 2) since the soapstone powder was finer than other samples. The low humidity of soapstone compared with the other samples could be related to its natural hydrophobicity. The density of the materials varied from 2.45 g/cm^3 (lime) to 3.22 g/cm^3 (Fe–Si–Mn slag).

The chemical composition and loss on ignition (LOI) of the raw materials are presented in Table 3. The chemical composition of all analysed samples are in accordance with the main minerals identified in the diffraction patterns presented in Figs. 2 to 5. The higher LOI value of lime sample compared with the other raw samples is related to the carbonate (calcite) and hydroxide phases (portlandite and nacrite).