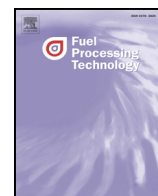




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Research article

On the reduction behavior, structural and mechanical features of iron ore-carbon briquettes

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ABSTRACT

The utilization of Ferro-coke briquettes is increasingly being considered as a process to reduce CO₂ emissions and energy consumption in blast furnace. The briquettes were prepared using iron ore, charcoal, lime, a binder and three different coals of poor coking properties. The coals have Gieseler maximum fluidity below 100 ddpm and are vitrinite-rich with inertinite content close to 30%. The briquettes were carbonized up to 1000 °C in a laboratory-scale oven and in a thermogravimetric analyzer which permitted a detailed evaluation of the weight loss at each stage of carbonization. Iron reduction, strength (both compression and drum tests) and optical properties of the carbon matrix were evaluated in the carbonized briquettes.

The carbonization process caused significant differences in the optical textures of the carbonized materials, in particular in higher rank coals, where there was a greater range of optical texture sizes compared to the cokes from single coals. The best resistance to compression was observed in the briquettes with the larger optical texture, whereas the best resistance in a drum was that of the briquettes having larger proportion of mosaics. Furthermore, the Fe-coke briquettes produced by cold briquetting and carbonization show self-reducing properties of iron oxides.

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1. Introduction

The growing need for a drastic reduction of greenhouse gases emission leads the steel industry to search for innovative solutions to reduce energy consumption and neat CO₂ emissions [1]. A good example is the European ULCOS (Ultra Low CO₂ Steelmaking) project [2] aimed at identifying various routes for CO₂ emissions abatement and the numerous investments of the Japanese industry and government [3]. A long-term research work on a wide spectrum of innovative low-carbon technologies is still required before they can be deployed at an industrial scale. In this scenario over the last decades, technologies categorized as efficiency improvers for existing blast furnaces (BFs) have emerged as green short-term growing technologies in the iron and steel industry [4]. Among the environmental and resource-saving options the improvement of the reaction efficiency in the blast furnace may lead to a decrease of the reduction agent ratio (RAR), decreasing CO₂ emissions [4–13]. The concept of this new technology is based on the reduction of the temperature of the thermal reserve zone (TRZ) of blast furnace, which can be achieved through the use of highly reactive lump coke. Naito et al. [5] showed the potential of highly reactive coke to reduce the TRZ temperature in an adiabatic BF simulator, which lowered the reducing agent consumption rate by approximately 25–35 kg/ton of pig

iron. However, Babich et al. [14] reported some limitations to the reduction of TRZ temperature in modern blast furnaces using highly-reactive lump cokes.

For the viability of reducing TRZ temperature, two different approaches related to the highly reactive coke produced in conventional coke ovens have been reported. The first one is aimed at the addition of iron- or calcium-inorganic additives to the coal blends to be carbonized in coke ovens, while the second approach involves the impregnation of the coke surface by using aqueous solutions of iron- and calcium-salts [6,7,14]. A reduction of 10 kg of reducing agent per ton of pig iron can be attained with the use of such cokes in large scale BF tests.

A third approach is based on the incorporation of nut coke into the iron bearing layers in a BF. Nut coke is recognized as a low-value product generated in cokemaking that improves BF productivity and reduces coke consumption, overall CO₂ emissions of the steel plant and production cost of iron [15]. By mixing nut coke with sinter the increase in BF productivity increases for 1.5–4% and, at the same time, a reduction of the coke rate accounts for 4–8%. This approach has been widely implemented in modern BFs with pulverized coal injection (PCI).

Another different approach to decrease CO₂ emissions and BF coke consumption has been reported by Higuchi et al. [8]. The authors provide the use of the so-called Fe-coke briquettes made up of iron ore and carbon from coal as a novel blast furnace burden material. Green or raw briquettes could be charged to the blast furnace in mixed burden

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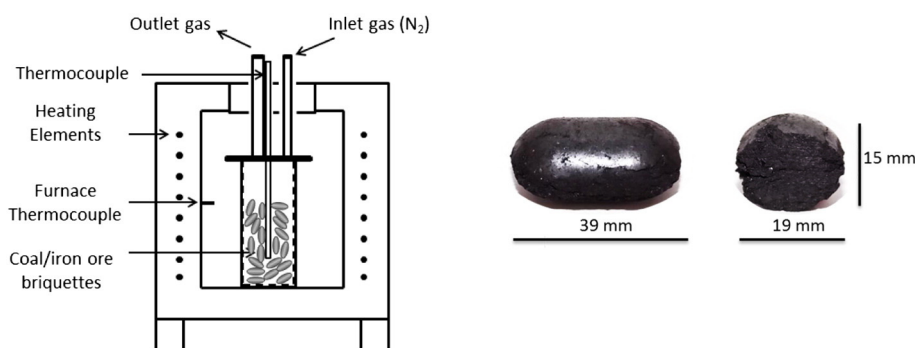


Fig. 1. Experimental device used for the carbonization tests.

layers with conventional iron-ore-bearing burden (sinter and pellets). In the case of raw briquettes, coal will exhibit in situ carbonization and the iron oxides achieve a fast reduction to FeO and metallic Fe. In such situation, the reactivity towards CO_2 of the carbon inside the briquette is enhanced by increasing the ratio of mixed iron ore, due to the catalytic effect of iron on Boudouard reaction and direct iron reduction. Furthermore the authors have proposed that the briquettes manufacture with 43% iron may reduce the TRZ temperature up to 180°C , increasing reduction efficiency by 6.8%. The cold briquetting process of iron ore and carbon sources has emerged as a complementary approach to the sintering process. It is interesting to highlight that Fe-coke briquettes facilitates the introduction of low-grade coal and iron ore resources.

Within this context, this work is aimed to describe the production of cold Fe-coke briquettes from coal/iron ore blends, the in-situ iron-oxides reduction ability inside the briquettes during carbonization and the mechanical properties after carbonization. The importance of coal quality as a carbon source to promote the reduction of iron oxides in raw Fe-coke briquettes, their physical properties and the

transformations that occur during the carbonization of such agglomerates are discussed.

2. Materials and methods

2.1. Manufacture of coal/iron ore briquettes

Three coals of different ranks were used in the preparation of the briquettes: two Polish coals MR and ZF (high- and medium-volatile bituminous, respectively) and one Australian coal (QS). All of them exhibit very weak coking properties as detected by Gieseler plastometry. Additionally, Eucalyptus charcoal of Brazilian production was used as a carbon source and initiator of iron reduction. Ultimate, proximate, petrographic and thermoplastic characteristics of the briquette components were assessed by following the corresponding standard procedures. The ash composition of carbon sources was determined by X-ray fluorescence in a Siemens-Bruker SRS3000 equipment.

Grain size for coal and charcoal was <3 mm and for iron ore <0.150 mm. Due to the relevance of the grain size distribution in

Table 1

Proximate, ultimate, rheological and petrographic analyses of the coals and charcoal.

| | MR | ZF | QS | Ch |
|----------------------------------|-------|-------|-------|-------|
| Proximate analysis | | | | |
| Volatile matter (wt.% db) | 32.7 | 23.4 | 18.9 | 22.4 |
| Ash (wt.% db) | 3.3 | 7.3 | 11.6 | 4.3 |
| Fixed carbon (wt.%) | 64 | 69.3 | 69.5 | 73.4 |
| Ultimate analysis | | | | |
| C (wt.% db) | 82.52 | 82.6 | 79.29 | 78.96 |
| H (wt.% db) | 4.92 | 4.38 | 4.33 | 2.7 |
| N (wt.% db) | 1.35 | 1.31 | 1.89 | 0.64 |
| S (wt.% db) | 0.57 | 0.52 | 2.35 | 0.03 |
| O (wt.% db) | 7.34 | 3.88 | 0.53 | 13.4 |
| Rheological properties | | | | |
| Gieseler maximum fluidity (ddpm) | 8 | 93 | 24 | – |
| Petrographic analyses | | | | |
| Random reflectance, Rr (%) | 0.82 | 1.14 | 1.35 | – |
| Vitrinite (vol.% mf) | 68.9 | 64.5 | 70.6 | – |
| Inertinite (vol.% mf) | 27.5 | 33 | 29.4 | – |
| Liptinite (vol.% mf) | 3.6 | 2.5 | 0 | – |
| Chemical analysis of ash | | | | |
| SiO_2 (%) | 34.90 | 44.72 | 50.65 | 7.83 |
| Al_2O_3 (%) | 22.59 | 26.69 | 26.81 | 1.87 |
| Fe_2O_3 (%) | 15.23 | 9.05 | 12.41 | 0.69 |
| TiO_2 (%) | 0.97 | 1.13 | 1.29 | 0.00 |
| MnO (%) | 0.16 | 0.13 | 0.20 | 2.17 |
| CaO (%) | 8.80 | 4.48 | 2.98 | 47.14 |
| MgO (%) | 4.06 | 2.11 | 1.19 | 9.37 |
| Na_2O (%) | 1.82 | 2.12 | 0.30 | 3.12 |
| K_2O (%) | 3.22 | 4.59 | 1.69 | 16.46 |
| SO_3 (%) | 8.25 | 3.44 | 0.79 | 3.29 |
| P_2O_5 (%) | 0.00 | 1.55 | 1.59 | 8.04 |

db: on a dry basis; mf: on a minerals-free basis;

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