Organic binders for the agglomeration of integrated cycle steel plant by-products

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Introduction

In 2022 the world crude steel production was 1878.5 Mt and 70% of it was produced through blast furnaces and basic oxygen furnaces (Anon n.d.). All the steps of steel production release off-gases which must be captured by the filters placed on top of the plants. The gases are then cleaned in an abatement system to reduce global emissions and improve the sustainability of the steelmaking process. The dedusting is achieved with wet scrubbers or dry cleaning, which produce 2 - 22 kg of blast furnace sludge per ton of hot metal, as well as 7 kg of basic oxygen furnace dust and 1 kg of secondary dust per ton of steel (Remus and Europäische Kommission Gemeinsame Forschungsstelle Institut für Technologische Zukunftsforschung n.d.). The elevated concentration of iron oxides and unreacted carbon suggest their recycling in metallurgical processes to recover the iron, but harmful compounds such as Zn and alkalis limit their reutilization in most furnaces. In addition, their fine particle size distribution limits their direct use, hence an agglomeration technique is required. A binder is commonly used to increase the mechanical resistance of the agglomerates, which otherwise fail with a subsequent variation of reduction kinetic and fines dispersion in the furnace. In the proposed work, the above integrated cycle steel plant by-products were cold agglomerated in form of briquettes using corn starch and Arabic gum as binders. The aim was the comparison of mechanical and metallurgical properties given by the two binders to define the best condition in terms of briquette stability and enhanced recyclability of the feedstocks. The choice of an organic binder was driven by the low silica concentration and high carbon content, which enhance the reducibility of briquettes and their compatibility with the furnace (Alsaqoor et al. 2022). In particular, starch is commonly used in literature to agglomerate steelmaking wastes, while Arabic gum is typically used for biomass briquettes.

Materials and methods

The raw materials used are Blast Furnace Sludge (BFS), Basic Oxygen Furnace Dust (BOFD) and Secondary Dust (SD). Their chemical composition has been analyzed by means of X-Ray Fluorescence (XRF), while the mineralogy through X-Ray Diffraction (XRD) and Electronic Scanning Microscope (SEM) equipped with Energy-Dispersive X-Ray Spectroscopy (EDS). Granulometric distribution was analyzed by means of an optical granulometer and the hydrophilic or hydrophobic nature of powder was defined through sessile drop according to BS EN ISO 19403. The binders used are corn starch and Arabic gum. The powders have been agglomerated in pairs and tailored to have a self-reducing mixture. The ratios used are 2.1:1 for BOFD_BFS and 1.2:1 for BOFD_SD. Then, they were mixed with the binder keeping 5 wt% of solid fraction on total dry powders. The first batch (_CS) required the previous starch gelatinization, while the second batch (_AG) used a solution of Arabic gum constituted by a water/natural gum ratio of 2:1. Briquettes of 20 mm in diameter and height of 15 - 17 mm have been produced applying a constant speed of 20 mm/min until the pressure reached 40 MPa and then it was maintained for nearly 2 min. The density of briquettes has been monitored during 15 days of curing and after this period they have been mechanically characterized. Drop test was used to simulate the impact during loading conditions and transportation and was based on the ASTM D440−07 (2019). If the briquette survived to 10 drops, it was then subjected to a compression test according to BS ISO 4700:2015. Briquettes have been heated at 700 °C, 950 °C and 1200 °C to evaluate the degree of reduction (RD), which was inspired by BS ISO 11258:2015, and the swelling inspired by BS ISO 4698:2022.

Results and discussion

Though the mineralogical analysis highlighted hematite and magnetite as the main phases inside all the powders, XRF allowed to consider only BOFD as the iron carrier due to 77.54 wt% of Fe_2O_3 inside. BFS and SD are instead the reducing agents containing a carbon content of 41.81 wt% and 31.13 wt%, respectively. The briquettes were hence produced by mixing BOFD < 125 µm with BFS < 63 µm or SD > 125 µm. The hydrophilic nature of the raw powders has been investigated because the water-powders interaction could affect the mechanical resistance of the agglomerates. The agglomeration of BOFD and SD should result stable being both the powders hydrophobic, while the presence of the hydrophilic BFS should worsen the mechanical stability of the agglomerates (Kanduč et al. 2016).

Figure 1 shows the density, mechanical and metallurgical properties of the briquettes produced. Considering BOFD_BFS, Arabic gum seemed to increase the density of the briquette. In addition, a longer maintenance time during the briquetting process allowed a better arrangement of particles which resulted in the densification of BOFD_BFS_AG. On the contrary, the different binders did not affect the density of BOFD_SD. The Impact Resistance Index (IRI) and the Adjusted Impact Resistance Index (AIRI) were evaluated from drop test to identify the impact resistance of briquettes. The difference between IRI and AIRI highlighted the amount of fines released. BOFD_BFS_CS survived to only 5 drops because the hydrophilic nature of BFS favored the hydration repulsion inside the briquette. The low mechanical resistance of BOFD_BFS could be improved by Arabic gum, which increased the glue power and gave a higher morphological uniformity. BOFD_BFS_AG hence survived to 10 drops and released a lower quantity of fines than BOFD_BFS_CS. The stable cavitation provided by the hydrophobic raw powders instead allowed the survival of BOFD_SD_CS to 10 drops. On the contrary, Arabic gum worsened the resistance of BOFD_SD because it percolated around the big particles of SD and created some clusters of fine particles. The resulting heterogeneous morphology could be the cause for the disintegration of BOFD_SD_AG after 5 drops and the higher amount of fines released than BOFD_SD_CS.

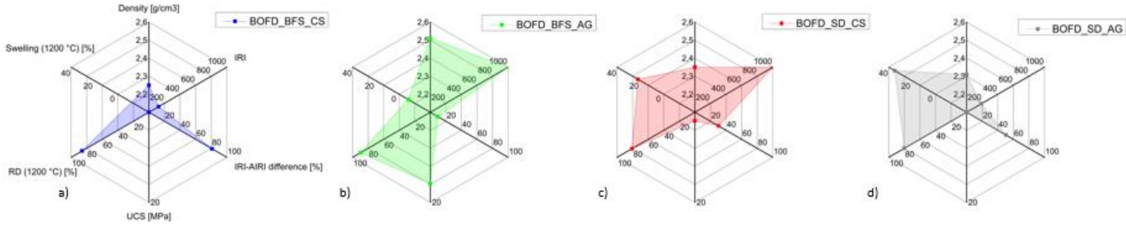

Figure 1 Test results of a) BOFD_BFS_CS; b) BOFD_BFS_AG; c) BOFD_SD_CS; d) BOFD_SD_AG

Though the XRD patterns of the four briquettes highlighted the self-reducing capacity by the presence of iron peaks and the absence of hematite and magnetite peaks, the choice of the right binder is fundamental to assure structural integrity and thermal stability of the briquettes. BOFD_BFS_CS has a degree of reduction of ~86% and broke inside the oven during the thermal treatment. Arabic gum gave instead a better particles arrangement which favored the contact between carbon and iron oxides, improving the carbothermic reaction and resulting in RD of 89.71% for BOFD_BFS_AG. In addition, Arabic gum overcame the disintegrative forces giving the self-stand capacity to BOFD_BFS_AG, which shrank at 1200 °C. RD of BOFD_SD was lower than BOFD_BFS due to the big unreacted carbon particles of SD which drastically reduced the kinetic of the carbothermic reduction. These big particles were also the main cause of the catastrophic swelling shown by BOFD_SD. They indeed tend to popping up leading to the expansion and fragility of the briquettes (Singh and Bjorkman 2004).

Conclusion

In this work, briquettes made combining different integrated cycle steel plant by-products have been pre- and post-heat treatment characterized, to compare the mechanical and metallurgical performances provided by several binders. The main results can be summarized as:

- The briquetting parameters, the density of briquettes and the hydrophilic nature of the raw powders affect the mechanical properties and the stability of the aggregate.
- Coarse reducing agents slow down the reduction kinetic and cause catastrophic swelling.
- The liquid Arabic gum could increase the mechanical properties of fine aggregates and favor their self-stand capacity during the thermal treatment. On the contrary, it worsened the resistance of coarser aggregates.
- As shown in Figure 1, the most promising briquette is BOFD_BFS_AG, thanks to higher mechanical strength both at room temperature and during its smelting, assuring contained swelling while having a high reduction degree.

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