

Despite advances in new technologies, carbon remains essential in metallurgy. It serves both as an energy source and more importantly, as a reducing agent. Modern pyrometallurgical processes still rely on carbon and difficult to effectively eliminate entirely or replace it with another element. As a step toward CO₂ neutrality, the use of pyrolyzed biomass represents a more environmentally friendly alternative.

Introduction

Pyrometallurgical processes have been major contributors to CO₂ emissions, resulting in global warming and adverse environmental impacts. This is primarily attributed to the extensive use of fossil fuels, such as coal and coke, as both reductants and energy sources for metal production. In line with the 2020 EU Green Deal, the adoption of green technologies has become essential for environmental protection while maintaining efficient metal production and advancing sustainable industrial practices.

From a circular economy perspective, the valorisation of biochar in pyrometallurgical processes offers a promising route for the recycling of metallurgical wastes, including slags, sludges, and metal-bearing dusts such as steel mill dust. Replacing fossil fuels with biochar, a sustainable and CO₂-neutral carbon source in metal recycling processes represents an innovative approach that supports sustainability, circular economy principles, and environmentally responsible metal production.

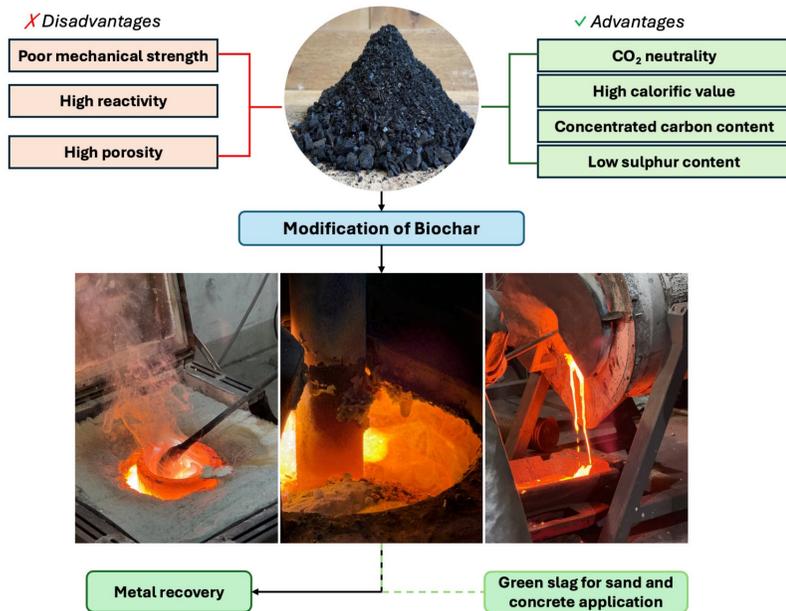


Figure 1: Overview of biochar utilization in pyrometallurgical processes

Surface Modification of Biochar: Microgranulation

However, the effective utilisation of biochar in pyrometallurgical operations requires appropriate pretreatment. Although biochar is a carbonaceous material comparable to coke, it exhibits limitations such as high reactivity, low bulk density, high porosity, and poor mechanical strength. These characteristics hinder its direct substitution for fossil-based reductants and may lead to operational challenges. To overcome these limitations, pretreatment methods such as micro-granulation and briquetting can be employed to enhance the physical and mechanical properties of biochar, thereby improving its compatibility with existing pyrometallurgical technologies.



Figure 2: Microgranulation of biochar with (A) Eirich mixer and (B) Ploughshare mixer

Methodology

Microgranulation

An Eirich EL1 Mixer, Stuttgart, Germany (1 litre capacity) aided in the nucleation growth of the biochar to form granules. The biochar of 200 g weight was dry mixed with a binder for 2 minutes at a 30° mixing angle in a counter-clockwise rotation of the mixing tool. Water was then gradually added in volume range of 150 ml for 8 mins at 15 m/s rotational speed.

The granules were then dried at 106°C for 24 hours.

Modified coke reactivity Index (CRI)

A modified Coke Reactivity Index (CRI) test was performed using a tube furnace. Heating to 950°C took place at a heating rate of 6.3 K/min under a nitrogen atmosphere. After reaching the targeted temperature, holding took place for 15 mins in a CO₂ atmosphere supplied at 5 L/h.

Results and Discussion

Scanning electron microscopy (SEM) analysis

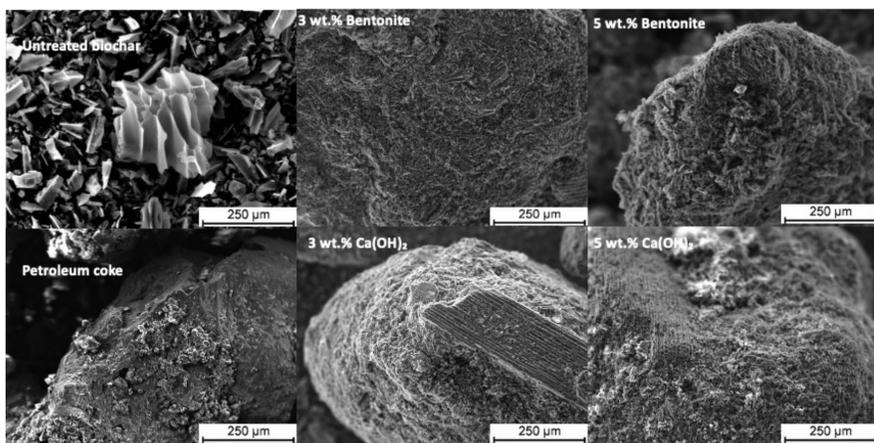


Figure 3: SEM Analysis of biochar with bentonite, biochar with calcium hydroxide binders compared with petroleum coke and untreated biochar

Modified CRI values

$$CRI = \frac{Weight_{initial} - Weight_{final}}{Weight_{initial}} * 100$$



Graph 1: CRI values of the modified biochar

Microgranulation successfully modified the surface of the biochar particles. This is shown by the clogged and closed pores in the biochar structure.

The addition of bentonite binder significantly reduced the reactivity of biochar to the range 20 – 26,1 % at 1, 3 and 5 wt.% binder from 41,7% of untreated biochar.

Conclusion

Surface modification of biochar using binders like bentonite and calcium hydroxide, proved to be effective in optimizing properties of biochar allowing utilization in specific pyrometallurgical processes.

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