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Pelletization of Fine-Grained Metallurgical and Petroleum Coke

Kholoud Madih[1] and Nehal A. Erfan[1*]

[1]Chemical engineering department, faculty of engineering, Minia university, Minia, Egypt

[*]Corresponding author: n.erfan1@mu.edu.eg

Abstract. Coke powder is a cost-effective material with diverse industrial applications, including ferroalloys, calcium carbide, fertilizer production, and blast furnace injection. However, its low strength, poor crush resistance, and lack of plasticity, combined with the small particle sizes produced during pyrolysis, make it unsuitable for direct use in many processes. Pelletizing coke powder is a widely accepted method to enhance its usability and maximize resource efficiency. By incorporating suitable additives, the strength, crush resistance, and plasticity of the material can be significantly improved. When processed into pellets of specific size and durability, coke powder can be utilized in metallurgy, as industrial or household block fuel, and as a gasification feedstock.
Metallurgical coke is derived from low-ash, low-sulfur bituminous coal through the coking process, while petroleum coke (pet coke) is produced as a byproduct of crude oil refining. Fine metallurgical and petroleum coke particles (under 200 μm) have been successfully pelletized using a rotating disc pelletizer, with sodium silicate (Na_2SiO_3) serving as an inorganic binder which may be used as carburizers, e.g. in steel manufacturing. The impact of binder concentration and pelletizer rotational speed on the crushing strength and average pellet size was analyzed. Experimental results confirmed that the pelletization process effectively produced coke pellets with satisfactory particle size distribution and compressive strength

Keywords: Pelletizing; Metallurgical coke; Petroleum coke

1. Introduction

Metallurgical coke is a solid carbon-rich material that is generated by the pyrolysis of high-volatile coal at moderate to low temperatures (450°C to 900°C). This procedure entails the combustion of coal in an oxygen-free or air-isolated environment, which induces intricate chemical reactions and physical transformations at varying temperatures. Petroleum coke, or petcoke, is generated from the thermal cracking of heavy oil following the separation of light and heavy fractions during crude oil distillation. Its primary component is carbon, making up over 80 $_{wt}$%, with the remainder consisting of hydrogen, oxygen, nitrogen, sulfur, and trace metals. It appears as irregularly shaped, dark gray to black solid particles with a metallic luster and a highly porous structure.
Coke powder is widely used in industries such as ferroalloys, calcium carbide, fertilizer production, and blast furnace injection. However, its low strength, poor crush resistance, and limited plasticity, along with the fine particle sizes resulting from pyrolysis, often make it unsuitable for direct industrial use.
Pelletizing plays a crucial role in the metallurgical and energy industries by enhancing coke material performance through the aggregation of fine particles into larger, mechanically robust structures. This

process not only minimizes material loss from dust generation but also improves the mechanical strength, combustion efficiency, and calorific value of coke materials.

The selection of a binder is essential for shaping coke powder. During processing, the binder breaks down under heat into viscous liquid substances (colloids), which help bond coke particles and contribute to forming a carbon skeleton, thereby strengthening the final product. Binders are generally categorized into three types: inorganic, organic, and composite binders. The inorganic components of these binders influence the ash fusion point, adhesion properties, and slagging behavior of the formed coke.

Organic binders include emulsified asphalt, starch, tar, tar pitch, humic acid, calcium lignosulfonate, biomass, wood cellulose, and paper pulp waste liquid. They exhibit strong adhesion properties, requiring only small amounts to bind coke powder effectively, and generate minimal residual ash when combusted. Once dried and cured under external pressure, organic binders provide the formed coke with a certain degree of cold compressive strength. However, they are relatively expensive, decompose easily at high temperatures, leading to weak carbonized products, and hydrophobic varieties like tar and asphalt can produce excessive smoke during combustion. Additionally, petroleum asphalt's high sulfur content poses environmental concerns.

Inorganic binders, such as bentonite, slaked lime, and clay, are typically mixed with water and coke powder. The hydration reaction between water and the binder facilitates particle adhesion. These binders are widely available, cost-effective, and yield coke with high thermal strength. However, they do not contribute to combustion, increasing the ash content of briquettes and reducing their overall adhesiveness. Additionally, their weak cold-state adhesion limits their usability in some applications. Recent advancements have established a comprehensive framework for enhancing coke performance across various operational conditions by integrating experimental and computational approaches to better understand and optimize pellet characteristics. Experimental research on pelletized coke materials has primarily focused on improving mechanical strength through binder selection, compaction parameters, and structural modifications. For instance, studies by Mochizuki et al. [1- 4] indicate that tar impregnation and vapor deposition methods effectively eliminate micro-pores (~2 nm), significantly increasing compressive strength. These techniques consistently produce crushing strengths of up to 10 daN, comparable to commercial metallurgical coke, highlighting the crucial role of binder distribution in reinforcing the microstructure. Additional research has explored the use of CaO and resin-based binders to enhance pellet strength, yielding carbonation-consolidated briquettes with compressive strengths exceeding 1256 N/a [5] and demonstrating superior performance with resin and pitch-based formulations [6,7].

Beyond strength, combustion efficiency has been a key research focus, as denser pellets and improved pore structures facilitate controlled combustion and reactivity. Studies utilizing thermogravimetric analysis (TGA) have assessed reactivity and thermal behavior, showing that tar-derived binders can enhance oxygen transport and heat transfer properties [3- 5]. However, excessive densification has been found to hinder gas diffusion, underscoring the necessity of balancing density and pore structure for optimal performance [1,8].

Calorific value is another critical aspect of coke pellet performance, which has been a focal point of pelletization methods. Tar impregnation has demonstrated the ability to stabilize carbon content within the pellet structure, leading to controlled energy yields and higher heating values (HHVs) [1,4]. Studies also indicate that binder selection directly influences calorific performance, with some materials enhancing carbon-based energy contributions, while others, such as inorganic binders, inadvertently increase ash content [5,9]. Despite these experimental advances, research on computational optimization of calorific value remains limited. While experimental studies dominate the literature, computational techniques have recently been explored to complement empirical findings. Finite element modeling (FEM) [10] and discrete element modeling (DEM) [11] have been used to simulate the effects of porosity on mechanical strength, providing insights into briquetting mechanics [11]. However, these computational efforts often lack integration with experimental data, and few studies systematically apply computational methods to analyze combustion kinetics or optimize calorific value.

Current research highlights significant experimental progress in improving the mechanical strength, combustion efficiency, and calorific value of pelletized coke materials, with studies focusing on binder formulations [1-6, 8, 12], structural modifications [1,2,10], and reactivity adjustments [9, 13]. However, computational approaches remain in the early stages, particularly regarding combustion dynamics modeling and multi-objective optimization frameworks. The integration of experimental and computational methods presents promising opportunities for advancing coke material development for industrial applications. This study examines the influence of operational parameters in a laboratory disc pelletizer on the pellet size and strength of two types of coke—metallurgical and petroleum coke—given that pelletization has been shown to enhance coke properties.

2. Materials and methods

2.1 Materials

2.1.1 Petroleum coke

It is considered a crucial raw material in many metallurgical industries. The petroleum coke in the current study was brought from the Suez Oil Processing Company with the following specifications:

Table 1. Specifications for petroleum coke

Apparent specific gravity	1.0-1.15
True specific gravity	1.1-1.2
Moisture %	0.3-0.4
Sulfur %	5.0-5.3
Volatile matter %	1.2-14.5
Fixed carbon %	83-87
Ash%	0.2-0.5
Vanadium%	0.035-0.077
Calorific value, kJ/kg	35581

2.1.2 Metallurgical coke

The met coke feedstock had the following specifications

Table 2. Specifications for metallurgical coke

Moisture %	6-9
Sulfur %	0.8
Volatile matter %	0.5
Fixed carbon %	85-89
Ash%	8-10

2.1.3 Binder

The binder used in this study is sodium silicate (Na_2SiO_3). It is a highly vise-caused compound. It has a high density and is soluble in water with high adhering power. It is used in pelletizing with different concentrations of 20 $_{wt}$%,25 $_{wt}$%.33 $_{wt}$%,50 $_{wt}$%

2.2 Methods

The pelletizer designed for this research's experimental work is a laboratory disc pelletizer, shown schematically in **Figure 1**. It consists of an aluminum pan with an inner diameter of 490mm and a depth of 105 mm connected to a steel rod attached to a gearbox and motor with 0.34 hp and 1400 rpm. This set is fixed on a movable plate to control the inclination angle. The effect of rotation velocity was studied at different values ranging from 17 rpm to 31 rpm at a fixed inclination angle of 45°.

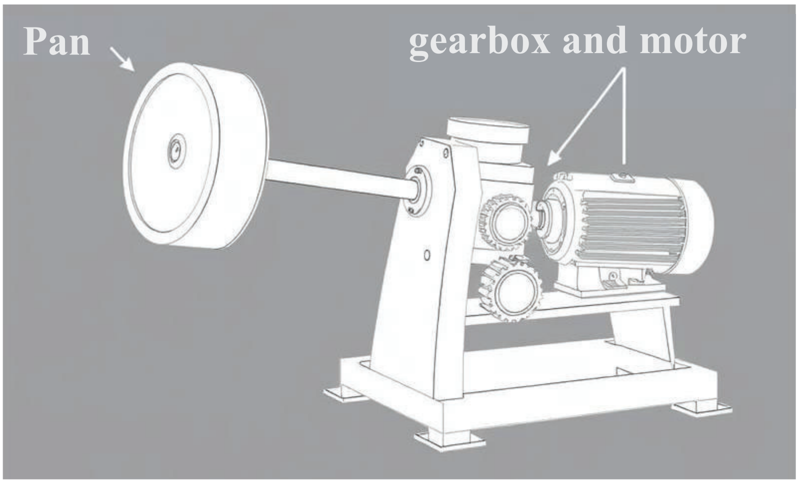

Figure 1. laboratory disc pelletizer (schematic)

The hydraulic press was used to measure the crushing strength of the prepared samples of pellets after being sun-dried according to the ASTM D4179 technique. A set of trials has been designed with the two types of coke mentioned in the materials section to determine the effect of the pelletizer's rotating speed and binder concentration on the mean diameter of the produced pellets and the crushing strength.

3. Results and discussion

Figure 2 represents the effect of binder (Na_2SiO_3) concentration on the average diameter of formed pellets and compressive strength for both metallurgical and petroleum coke. Increasing binder percentage results in a considerable increase in the average diameter of formed pellets and compressive strength. This can be due to the increase in the degree of molecular interconnections between the matrix and the load by increasing the binder content. For metallurgical coke, the maximum pellet diameter and compressive strength were 14 mm and 210 kPa, respectively, which are enhanced results compared to petroleum coke (12 mm and 130 kPa). The enhancement in pellets diameter and compressive strength for metallurgical coke can be due to the larger carbon content for metallurgical coke compared to petroleum coke as presented in tables 1 and 2. Figure 3 shows the effect of disc pelletizer rotational speed on average diameter and compressive strength of both metallurgical and petroleum coke at $50_{wt}\%$ binder concentration. Increasing disc rotational speed decreases the average diameter of the formed pellets for both metallurgical and petroleum coke. Furthermore, metallurgical and petroleum coke pellets exhibited better compressive strength at lower disc rotational speeds, which is economically preferable.

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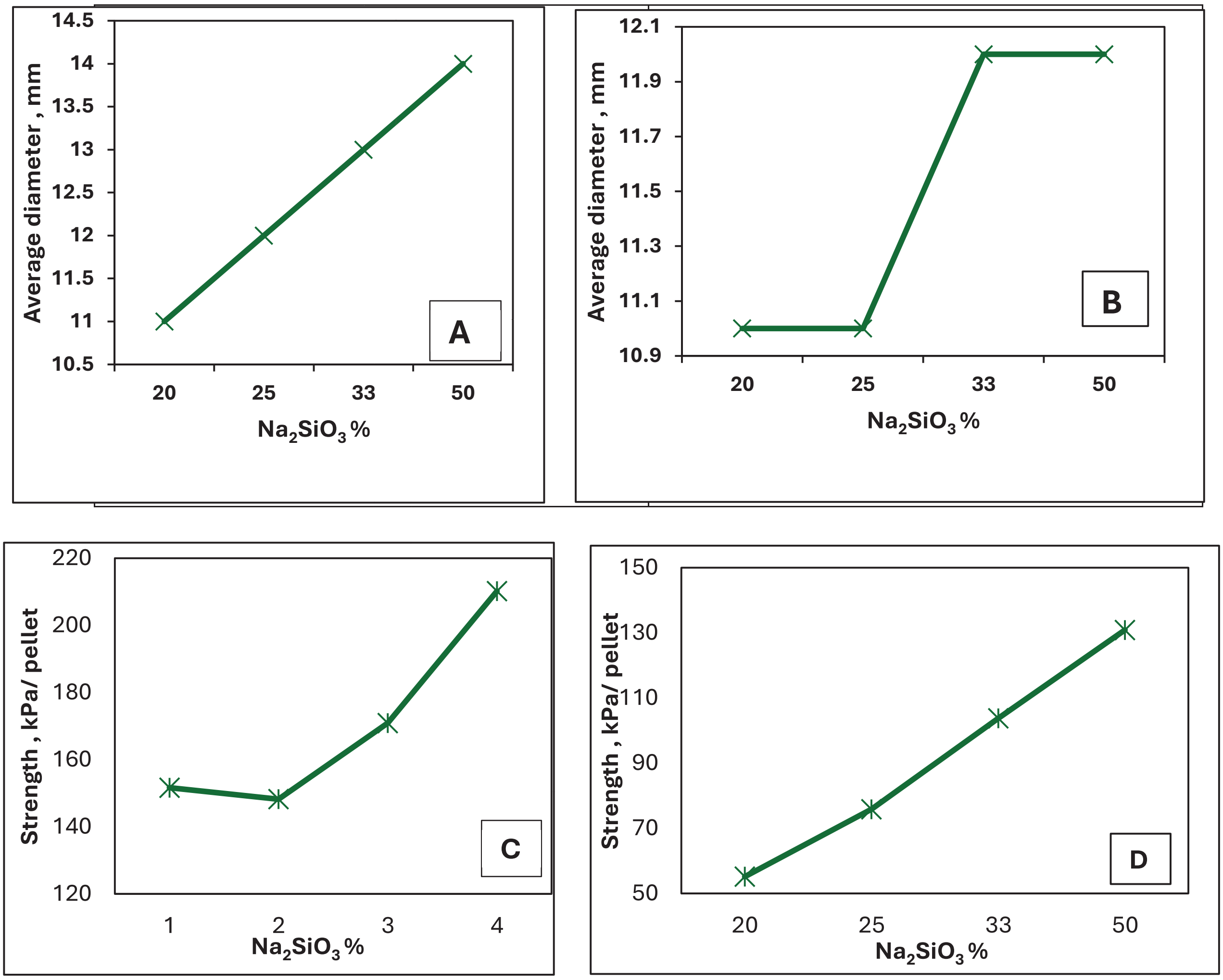

Figure 3. Effect of Na_2SiO_3 concentration on average diameter and compressive strength of (A, C) metallurgical coke and (B, D) petroleum coke at 24 rpm pelletizer rotational speed.

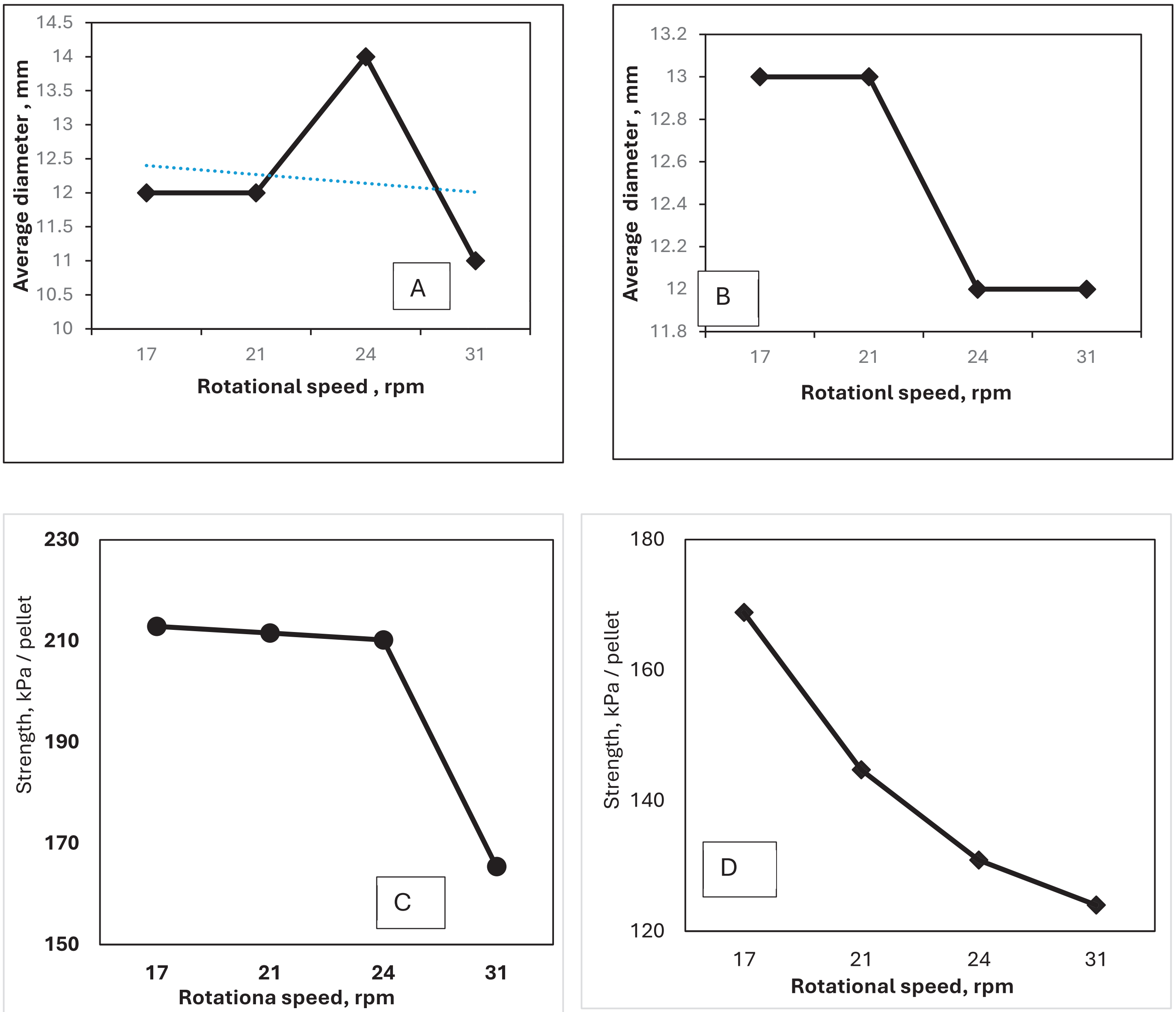

Figure 4. Effect of pelletizer rotational speed on average diameter and compressive strength of (A,C) metallurgical coke and (B, D) petroleum coke at 24 rpm pelletizer rotational speed.

4. Conclusions

In this work the influence of the operating parameters of a handmade laboratory disc pelletizer on the pellet size and compressive strength of two types of coke, metallurgical and petroleum coke was studied. Coke pelletizing has been demonstrated to improve its properties. For metallurgical coke the maximum pellets diameter and compressive strength were 14 mm and 210 kPa consequently which are an enhanced results compared to petroleum coke (12 mm and 130 kPa). Coke pellets examined a better compressive strength at lower disc rotational speeds which's economically preferable.

References

[1] Y. Mochizuki, M. Nishio, N. Tsubouchi, and T. Akiyama, "Preparation of a Carbon-Containing Pellet with High Strength and High Reactivity by Vapor Deposition of Tar to a Cold-Bonded Pellet," Energy & Fuels, vol. 31, pp. 8877-8885-8877–8885, 2017, doi: 10.1021/ACS.ENERGYFUELS.7B00680.

[2] Y. Mochizuki, M. Nishio, J. Ma, N. Tsubouchi, and T. Akiyama, "Preparation of Carbon-containing Iron Ore with Enhanced Crushing Strength from Limonite by Impregnation and Vapor Deposition of Tar Recovered from Coke Oven Gas," Energy & Fuels, vol. 30, pp. 6233-6239-6233–6239, 2016, doi: 10.1021/ACS.ENERGYFUELS.6B00651.

[3] Y. Mochizuki, M. Nishio, N. Tsubouchi, and T. Akiyama, "Reduction behavior and crushing strength of carbon-containing composites prepared from a limonite-based pellet and COG tar," vol. 6, pp. 446-453-446–453, 2016.

[4] Y. Mochizuki, M. Nishio, N. Tsubouchi, and T. Akiyama, "Reduction Rate and Crushing Strength of a Carbon-Containing Pellet Prepared by the Impregnation Method of COG Tar," Energy & Fuels, vol. 30, pp. 2102-2110-2102–2110, 2016, doi: 10.1021/ACS.ENERGYFUELS.5B03009.

[5] Z. Guo, X. Xu, D. Zhu, J. Pan, C. Yang, and S. Li, "Clean Preparation of Formed Coke from Semi-coke by the Carbonated Consolidation Process," ACS Omega, vol. 8, pp. 27398-27409-27398–27409, 2023, doi: 10.1021/acsomega.3c02519.

[6] A. Suresh et al., "Utilisation of low-grade raw materials for preparation of reactive catalysed-coke for blast furnace application," Ironmaking & Steelmaking, vol. 46, pp. 491-497-491–497, 2019, doi: 10.1080/03019233.2017.1405152.

[7] R. Sah and S. Dutta, "Effects of Binder on the Properties of Iron Ore-Coal Composite Pellets," Mineral Processing and Extractive Metallurgy Review, vol. 31, pp. 73-85-73–85, 2010, doi: 10.1080/08827500903404732.

[8] Y. Mochizuki, M. Nishio, N. Tsubouchi, and T. Akiyama, "Reduction behavior and crushing strength of carbon-containing pellet prepared from COG tar," Fuel Processing Technology, vol. 142, pp. 287-295-287–295, 2016, doi: 10.1016/J.FUPROC.2015.10.025.

[9] Y. Mochizuki, M. Takahashi, J. Bud, Y. Wang, and N. Tsubouchi, "Strength and Gasification Reactivity of Coke Prepared by Blending a Ca/C Composite and Coal," ISIJ International, 2021, doi: 10.2355/isijinternational.isijint-2020-622.

[10] J. Oda, J. Sakamoto, S. Kimura, S. Itagaki, and K. Hukada, "On Relationship between the Mechanical Properties and Structural Topology in the 3-Dimensional Porosity Model of Coke," 2004, doi: 10.1299/kikaia.70.177.

[11]Y. Ono, M. Ramdzuanny, Y. Matsushita, H. Aoki, S. Wada, and T. Shishido, "Numerical Simulation of Coal Briquetting Process Using Discrete Element Method," ISIJ International, 2021, doi: 10.2355/isijinternational.isijint-2021-272.

[12] R. Xu et al., "Effect of Binders on the Crushing Strength of Ferro-Coke," Materials, vol. 14, 2021, doi: 10.3390/ma14040850.

[13] S. Nomura, H. Terashima, E. Sato, and M. Naito, "Some Fundamental Aspects of Highly Reactive Iron Coke Production," Isij International, vol. 47, pp. 823-830-823–830, 2006, doi: 10.2355/ISIJINTERNATIONAL.47.823.