

# Influence of biocoke on iron ore sintering performance and strength properties of sinter

Lina Kieush<sup>1,2\*</sup>, Andrii Koveria<sup>3</sup>, Maksym Boyko<sup>4</sup>, Maksym Yaholnyk<sup>4</sup>,  
Andrii Hrubciak<sup>5</sup>, Lavr Molchanov<sup>6</sup>, Volodymyr Moklyak<sup>5</sup>

<sup>1</sup> National Metallurgical Academy of Ukraine, Dnipro, Ukraine

<sup>2</sup> Montanuniversität Leoben, Leoben, Austria

<sup>3</sup> Dnipro University of Technology, Dnipro, Ukraine

<sup>4</sup> Ukrainian State University of Science and Technologies, Dnipro, Ukraine

<sup>5</sup> G.V. Kurdyumov Institute for Metal Physics of the National Academy of Sciences of Ukraine, Kyiv, Ukraine

<sup>6</sup> Iron and Steel Institute of Z.I. Nekrasov of the National Academy of Sciences of Ukraine, Dnipro, Ukraine

\*Corresponding author: e-mail [lina.kieush@stud.unileoben.ac.at](mailto:lina.kieush@stud.unileoben.ac.at)

## Abstract

**Purpose.** The research purpose is to substantiate the use of biocoke as a fuel in the iron ore sintering, as well as its influence on the performance and properties of the resulting sinter. To completely replace conventional coke breeze, biocoke is produced using 5 wt.% biomass wood pellets at different carbonization temperatures of 950 or 1100°C. Further, the influence of biocoke on the sintering process and the sinter quality is studied at a high proportion of biomass pellets of 10, 15, 30, 45 wt.% and a carbonization temperature of 950°C.

**Methods.** Carbonization is performed in shaft-type electric furnaces to produce laboratory coke or biocoke. Afterward, the sintering of iron ores is conducted on a sinter plant. To assess the sintering process and the quality of the resulting sinter, the filtration rate is determined on a laboratory sinter plant using a vane anemometer designed to measure the directional flow average velocity under industrial conditions. The sinter reducibility is studied using a vertical heating furnace to assess the effect of coke and biocoke on the sinter's physical-chemical properties.

**Findings.** It has been determined that biocoke, carbonized at a temperature of 950°C, has good prospects and potential for a shift to a sustainable process of iron ore sintering.

**Originality.** It has been proven that biocoke with a biomass pellet ratio of up to 15 wt.%, obtained at a temperature of 950°C, does not affect the parameters characterizing the sintering process. The sinter strength indicators correspond to the use of 100 wt.% conventional coke breeze. Biocoke used with a high proportion of biomass pellets of 30 and 45 wt.% causes a deterioration in the sinter quality.

**Practical implications.** The results of using biocoke with the addition of 5-15 wt.% biomass pellets and at a temperature of 950°C are within the standard deviation, which makes it possible to use biocoke with 15 wt.% biomass pellets instead of industrial coke breeze.

**Keywords:** biocoke, coke breeze, iron ore sinter, sintering process, sintering performance, strength, wood pellets

## 1. Introduction

Iron ore sintering is an energy-intensive metallurgical process [1]. This complex metallurgical process remains the most widely used sintering process worldwide for preparing ferrous burden for the blast furnace (BF). As a result of the sintering process, a partially reduced and porous iron sinter is obtained, comparable to lump iron ore. This partially reduced ore mass can be 40–60% of the iron content in the blast furnace feedstock [2]. However, the iron ores sintering process also poses a significant environmental hazard. Among all the processes involved in steel production, sintering is the primary source of emissions, accounting for approximately 45% of the total steel industry emissions [3], [4]. Additionally, coke breeze is used as a fuel for sintering, which is accompanied

by pollutant emissions. Therefore, the use of raw biomass or biomass after carbonization to partially replace coal in the production of coke, which is then used as a fuel in sintering, can be advocated for mitigating the environmental burden.

The use of renewable materials to produce biofuels [5]-[8] for various purposes [9]-[13] is relevant for solving global climate problems [14]-[16]. However, the peculiarities of technological processes using carbon materials are limiting factors. Therefore, obtaining biomaterials with properties no worse than conventional ones allows for expanding the possibilities of using renewable raw materials. In addition to knowing the biomass properties and the specifics of the processes of its application [17]-[20], it is important to use technological solutions that improve the

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biomass properties, such as torrefaction [21], [22] pyrolysis [23], [24], and compaction [25]-[28].

Metallurgical processes are difficult to change, but it is practically feasible to replace conventional fuels with alternative ones. When using renewable fuel in iron ore sintering, it is necessary to find the optimal ratio [29]-[35], since replacement can deteriorate the strength of the iron ore sinter. Another disadvantage is conditioned by the thermal conditions of the sintering process, namely the low input of biomass fixed carbon and the excessive combustion rate.

Zhou et al. [36] used straw charcoal from 5 to 80% instead of coke breeze in the sintering process. The result shows that the use of straw charcoal does not affect the technical performance of the sinter ore, including the chemical composition and metallurgical properties. When using straw charcoal for sintering at 80% replacement, the SO<sub>2</sub> concentration is reduced by about 18% compared to that without replacement, and the NO<sub>x</sub> and CO<sub>2</sub> content are about 46% and 14%, respectively.

Lovel et al. [37] conclude that there are no obvious technical obstacles to replacing coke with charcoal in iron ore sintering. The authors used conventional metallurgical coke, hardwood charcoal, and woody weed prickly acacia charcoal as fuel in their studies. Sintering has been studied to replace coke with 50 and 100% char. The more reactive coke component significantly reduces sintering time, resulting in increased productivity despite a decrease in bulk density. Sintering with coke results in performance increases of 10 and 19% compared to the reference cokes. The use of charcoal had a negative effect on the sinter strength, and it has been noted that the increased charcoal addition reduces the tumble index.

Abreu et al. [38] studied charcoal as an additional fuel in the iron ore sintering. The main fuel was coke breeze and anthracite with 10, 25, 50, and 100% replacement of energy input with charcoal to produce sinter. Experimental results have shown that fuel blending where 50% of the heat input is provided by charcoal can be compared to 100% coke blending under normal sintering conditions and can result in a 50% reduction in greenhouse gas emissions. In turn, Cheng et al. [39] studied the use of coke breeze with the 20, 40, 60, 80, and 100% replacement of fixed carbon input with charcoal. Duration time, melting temperature and melting quantity index reached their maximum values at a degree of 60% charcoal replacement. When the degree of replacement exceeded 60%, the melting time duration and the melting point

index sharply decreased, indicating a substantial deterioration in the sinter strength.

Jha et al. [2] succeeded in replacing coke with 10% sawdust, 30% charcoal, and 30% sawdust-charcoal combination in the iron ore sintering. The temperature-time profile indicates the ability of charcoal to generate the maximum temperature in the shortest amount of time. The opposite reaction was noticed in the case of using sawdust. It has been found that coke creates a relatively lower temperature for a sufficiently long time period than charcoal.

A number of studies have concluded that replacing conventional coke with biomass or charcoal is important for finding the optimal proportion that allows obtaining sinter with quality and reducibility indicators at the level of sintering process parameters using 100% coke breeze. The effect of adding biomass or charcoal to coke and/or anthracite on the sintering process has been previously proven. The paper aims to study the impact of biocoke obtained with the addition of biomass pellets at different carbonization temperatures of 950 or 1100°C on the sintering process performance and the resulting sinter quality. It is worth noting that biocoke is an independent fuel that can replace the use of coke. The advantage of using biocoke can also be its production at certain carbonization temperatures, for instance, 950°C. In this case, the required physical-chemical and physical-mechanical properties are achieved as fuel for iron ore sintering, as well as for use in the blast furnace (BF) and submerged arc furnace (SAF) [40].

## 2. Materials and methods

### 2.1. Characteristics of materials

To obtain biocoke, hard coals from Dnipro Metallurgical Plant and industrial wood biomass pellets are used, the characteristics of which are presented in Table 1. The conventional laboratory coke breeze used as the reference is obtained from the hard coals listed in Table 1. The coal blend composition for obtaining laboratory coke is as follows, wt.%: coal A is 32.5; coal B is 30; coal C is 25; coal D is 12.5.

Industrial coke breeze, which also serves as a reference, is taken from Dnipro Metallurgical Plant and obtained from the hard coals shown in Table 1. However, the authors do not know the composition of the industrial coal blend. The proximate and ultimate analyses are carried out according to [41], [42].

Table 1. Proximate and ultimate analyses of raw biomass, hard coals and coal blend

Sample	$M^a$ , wt.%	$A^d$ , wt.%	$VM^d$ , wt.%	$S_t^d$ , wt.%	$C^d$ , wt.%	$H^d$ , wt.%	$N^d$ , wt.%	Fixed carbon, wt.%	Higher heating value (HHV), MJ kg <sup>-1</sup>
Wood biomass pellets	8.6	5.4	74.2	0.07	44.21	5.92	0.60	20.4	17.76
Coal A	1.6	9.6	32.5	1.62	75.23	5.02	1.55	57.9	31.08
Coal B	1.4	8.1	28.9	0.82	77.42	4.86	1.47	63.0	31.88
Coal C	2.1	8.8	24.4	0.64	81.98	4.17	1.40	66.8	33.08
Coal D	1.5	9.0	18.6	1.02	83.15	3.92	1.35	72.4	33.38
Coal Blend	1.6	8.9	27.7	1.06	78.56	4.62	1.46	63.4	32.21

$M^a$  is moisture (air-dried basis);  $A^d$  is ash (dry basis);  $VM^d$  is volatile matter (dry basis);  $S_t^d$  is total sulphur (dry basis);  $C^d$  is carbon (dry basis);  $H^d$  is hydrogen (dry basis);  $N^d$  is nitrogen (dry basis); calculated by difference,  $O^d$ , % = 100 -  $C^d$  -  $H^d$  -  $N^d$  -  $S^d$  -  $A^d$ ; calculated by fixed carbon, % = 100 - ( $V^d$  -  $A^d$ ); calculated by HHV, MJ kg<sup>-1</sup> = 0.3491·C + 1.1783·H + 0.1005·S - 0.0151·N - 0.1034·O - 0.0211·Ash

Iron ore and iron ore concentrate are used to produce the sinter. The chemical composition of blend materials is shown in Table 2.

The other constituents used for this investigation are lime and limestone. The chemical composition of these constituents is presented in Table 3.

**Table 2. Chemical composition of the iron ore and iron ore concentrate (wt.%)**

Content	Sample	
	Iron ore concentrate	Iron ore
TFe	65.88	57.75
FeO	28.27	1.76
Fe <sub>2</sub> O <sub>3</sub>	62.71	80.54
SiO <sub>2</sub>	6.44	12.71
Al <sub>2</sub> O <sub>3</sub>	0.30	1.60
CaO	0.17	1.72
MgO	0.26	0.62
LOI	1.85	1.82
Other oxides	–	0.47

TFe is total iron content; LOI is loss on ignition at a temperature of 950°C in air

**Table 3. Characteristics of fluxing agents (wt.%)**

Content	Sample	
	Limestone	Lime
TFe	0.28	12.66
FeO	–	–
Fe <sub>2</sub> O <sub>3</sub>	0.40	18.09
SiO <sub>2</sub>	1.50	1.80
Al <sub>2</sub> O <sub>3</sub>	0.56	26.61
CaO	48.50	86.80
MgO	0.92	1.40
LOI	43.56	–
Other oxides	–	–

Table 4 gives the sinter blend composition, which corresponds to the industrial one. The blend composition is the same for all sintering; only the fuel type changes. The blend basicity is 1.4.

**Table 4. Composition of the sintering blend**

Components	Content, wt.%	Sizes, mm
Concentrate	46.75	< 0.1
Iron ore	10.5	0-10
Lime	1.5	0-3
Limestone	10.25	0-3
Fuel	6	0-3
Return fines	25	5-10

## 2.2. Carbonization

Carbonization of laboratory coke and biocoke at temperatures of 950 or 1100°C is carried out in a shaft-type electric furnace. Detailed information regarding the carbonization process is presented in [40], [43]. The amount of wood pellet additives is 5, 10, 15, 30, and 45 wt.%. The granulometric composition of the coal blend is constant, which ensures the content of particles less than 3 mm at the level of 82%. The diameter of the wood pellets is 8 mm, and the length is in the range of 4 to 22 mm. The weight of the coal blend for carbonization is 2 kg. Afterward, the resulting coke or biocoke is cooled to room temperature and ground to a particle size of less than 3 mm, used in the sintering process.

## 2.3. Determining the sintering process main parameters and the sinter strength characterization

The sintering process, determination of specific capacity, sintering velocity, and method for determining the strength properties of the sinter are described in detail in [44], [45]. The experiments are conducted on a sinter plant used for the preparation and sintering of the blend under the control of the

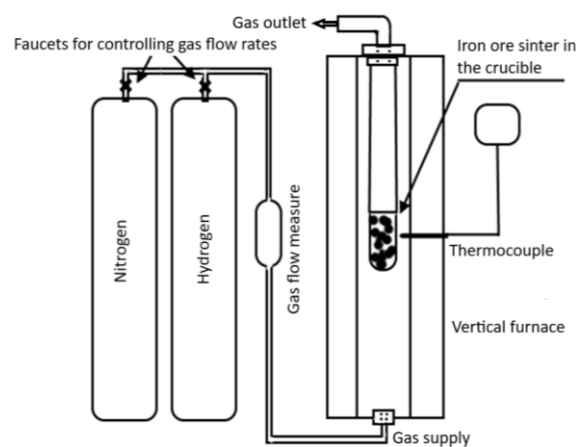
sintering process parameters. The plant consists of three main units: blend preparation unit, sintering process unit, and sinter mechanical testing unit. The preparation unit includes mass measuring equipment for weighting the blend components and determining their initial moisture content, as well as the moisture content of the resulting blend. It also includes a mixer-granulator with special equipment for a uniform supply of fluid under a pressure of 147 kPa. Water consumption of 8% is applied for each sintering test. The drum type mixer-granulator, 0.8 m long and 0.53 m in diameter, is positioned horizontally and has a velocity of 30 rpm.

## 2.4. Determining the filtration rate

The filtration rate is determined on a laboratory sinter plant using a vane anemometer designed to measure the directional flow average velocity under industrial conditions. The rate of the gas flow passing through the sintered layer is measured before the blend ignition and after the end of the sintering process. Before starting measurements, the transmission mechanism is turned off through the lock and the initial data of the counter is recorded. Then the anemometer is set in the airflow above the sinter pot with a wind inlet towards the flow and the impeller axis along the flow direction. After 10-15 seconds, the anemometer and stopwatch are simultaneously turned on. The anemometer is in the air stream for one to two minutes. Afterward, the anemometer and stopwatch are turned off. The final data and time in seconds are recorded. The number of divisions per second is determined by dividing the difference between the final and initial data by the time.

## 2.5. Determining the iron ore sinter reducibility

To assess the effect of coke and biocoke on the physical-chemical properties of the sinter, the reducibility of the obtained sinter is studied. The experimental system is used; the schematic diagram is shown in Figure 1. The experimental system has a vertical heating furnace in the reaction zone, from which the test sample is placed in a crucible with a perforated bottom and walls. The weight of the sample is 0.1 kg and the sinter size is 10-12 mm. The test temperature for reducibility is 800°C. Hydrogen is used as the reducing gas. The hydrogen flow rate is 6 l/min and the holding time is 60 minutes.

**Figure 1. Schematic diagram of the experimental system to determine the sinter reducibility**

The furnace is heated to 800°C, and at the end of the experiment, the sample is cooled in a nitrogen atmosphere. The degree of reducibility is calculated based on the weight loss of the sample.

### 3. Results and discussions

Proximate and ultimate analyses of cokes and biocokes are shown in Table 5. With an increase in carbonization temperature, the readiness of cokes and biocokes increases, as evidenced by a decrease in volatile matters. Consequently, the carbon content increases, while the content of sulfur, hydrogen and nitrogen decreases.

At the same time, the proportion of the mineral part also increases. However, the decrease in the ash content of bio-

coke is facilitated by an increase in the amount of biomass pellets. The presence of biomass pellets leads to some reduction in coke readiness while reducing the content of carbon, sulfur, nitrogen and increasing the content of hydrogen. The amount of fixed carbon increases with an increase in the amount of biomass additive due to a decrease in the ash content of the biocoke. The HHV decreases as biomass addition increases and the carbonization temperature decreases.

Table 5. Proximate and ultimate analyses of fuels after carbonization

Fuel (carbonization temperature, °C)	Amount of biomass pellets	$W^a$ , wt. %	$A^d$ , wt. %	$VM^d$ , wt. %	$S^d$ , wt. %	$H^d$ , wt. %	$C^d$ , wt. %	$N^d$ , wt. %	Fixed carbon, wt. %	HHV, MJ kg <sup>-1</sup>
Industrial coke breeze (1100)	0	1.20	13.3	1.15	0.30	0.32	84.48	1.03	85.55	29.54
Laboratory coke (1100)	0	0.88	13.6	1.22	0.32	0.29	84.50	0.96	85.18	29.54
Laboratory coke (950)	0	1.54	13.1	1.62	0.34	0.32	84.28	1.06	85.28	29.45
Biocoke (1100)	5	0.95	13.4	1.30	0.29	0.34	84.46	0.95	85.30	29.56
Biocoke (950)	5	1.67	13.0	1.66	0.33	0.36	84.35	1.01	85.34	29.52
Biocoke (950)	10	1.51	12.9	1.64	0.30	0.37	84.15	0.92	85.46	29.39
Biocoke (950)	15	1.66	12.8	1.71	0.27	0.40	83.97	0.84	85.49	29.35
Biocoke (950)	30	1.80	12.4	1.73	0.23	0.46	83.57	0.77	85.87	29.20
Biocoke (950)	45	1.88	12.1	1.85	0.18	0.49	83.06	0.65	86.05	28.96

Figure 2a shows the microstructure of wood biomass, which is used to replace coal and produce biocoke. It can be seen that the biomass is characterized by high porosity and wrinkles. After co-carbonization with a coal blend, the resulting charcoal retains its structure with increased porosity and wrinkling, as evidenced by Figure 2b. In biocoke, charcoal occurs as separate inclusions, as shown in Figure 2c for a biocoke produced using 5 wt.% biomass pellets. The microstructure of a conventional laboratory coke produced at 1100 °C is shown in Figure 2d. As previously studied and concluded in [39], charcoal has more pores and wrinkles than coke, which increases the specific surface area (SSA).

In turn, biomass/charcoal increases the SSA of the biocoke [43]. This affects the quality of biocoke as a fuel and the course of the sintering process in which it is used.

Table 6 summarizes the sintering process results and the quality parameters of the sinter obtained by using industrial coke, laboratory coke, and biocoke (5 wt.% wood pellet additive) as a fuel with different carbonization temperatures. An increase in the carbonization temperature of the fuel improves the strength characteristics of the sinter. Additionally, the sinter yield is increased by +10 mm, and the impact of the sinter strength is increased. Thus, at a carbonization temperature of 950°C, the impact of the resulting sinter strength reaches 80.1%. At a carbonization temperature of 1100°C, it is 81.2%, which corresponds to the strength obtained using laboratory coke, 81.3%, but remains lower than for industrial coke, 82.4%.

Figure 3 shows the effect of using biocoke with 5 wt.% biomass pellets produced at different pyrolysis temperatures on sinter yield +10 mm, impact and abrasion strength of iron ore sinter, as well as reducibility compared to using other conventional types of fuel.

The best sinter yield values of +10 mm are obtained when using industrial coke, then laboratory coke at a temperature of 1100°C, and biocoke at a temperature of 1100°C. Changes in the values of the sinter reducibility index are within the standard deviation, but tend to increase when using coke and biocoke obtained at a temperature of 950°C. This indicates that the lower readiness of the fuel and, as a result, its higher reactivity contribute to the intensity of the reduction reactions of the iron ore sinter. The sinter impact strength is within the standard deviation, but increases with increasing readiness of fuels, as well as with the HHV.

Figure 4 shows the effect of using biocoke with 5 wt.% biomass pellets produced at different carbonization temperatures on the sintering process parameters compared to conventional fuel types.

No significant effect of biocokes obtained at temperatures of 950 and 1100°C on the sintering velocity and specific capacity parameters is observed.

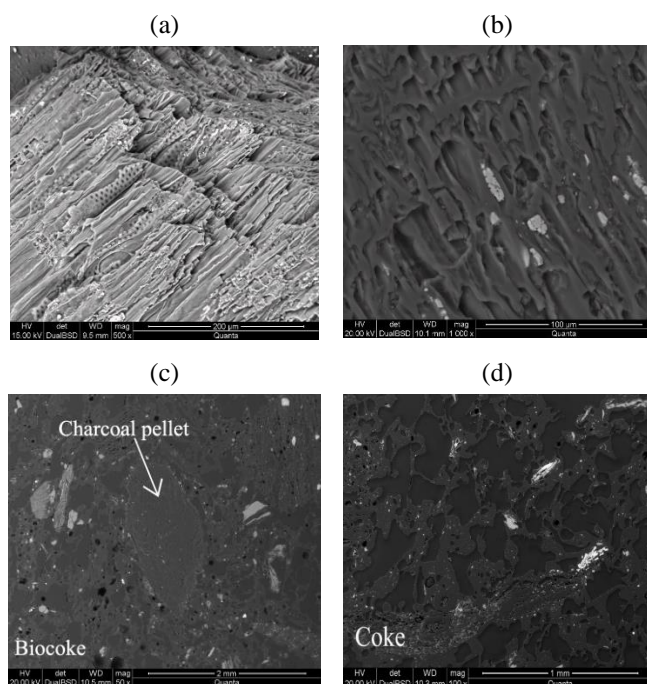
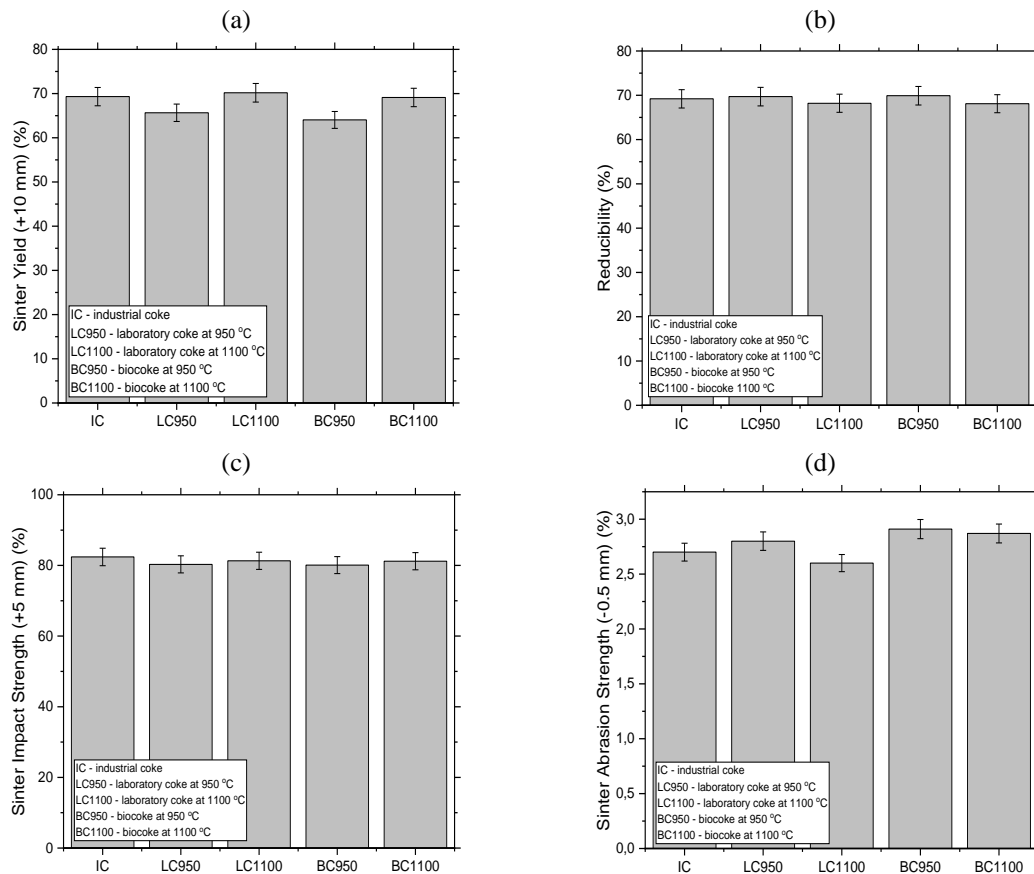


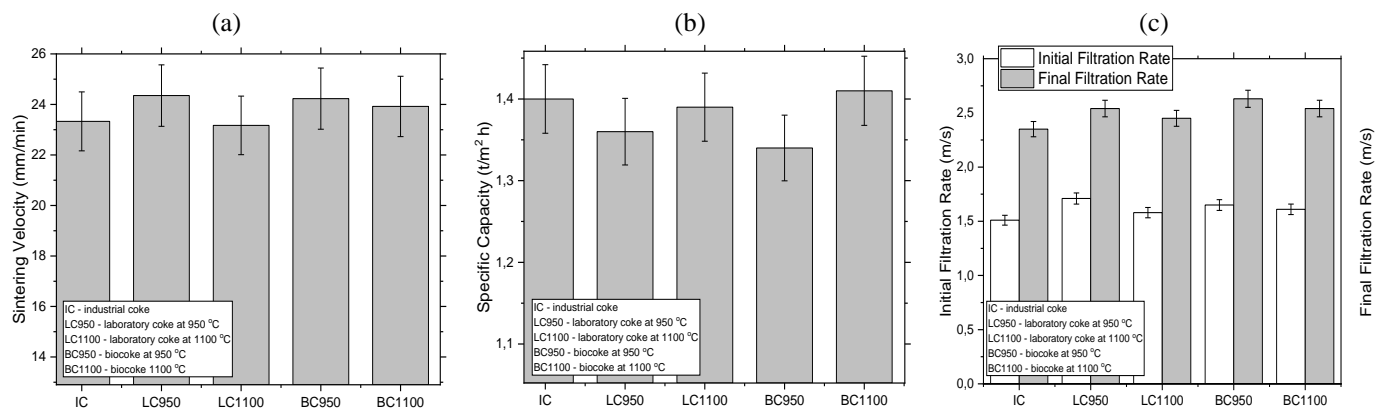
Figure 2. Microstructure image of the wood biomass used to produce biocoke (a); charcoal microstructure image (b); biocoke microstructure image (c); conventional laboratory coke microstructure image (d), data from [43]

**Table 6. Parameters of the iron ore sintering process and the quality of the sinter obtained using industrial coke, laboratory cokes, and biocokes as a sintering fuel**

Sintering process and resulting sinter parameters	Fuel type (carbonization temperature, °C)				
	Industrial coke breeze	Laboratory coke (950)	Laboratory coke (1100)	Biocoke 5 wt.% 950	Biocoke 5 wt.% (1100)
Sinter yield (+10 mm), %	69.31	65.66	70.18	64.04	69.12
Sintering velocity, mm/min	23.33	24.35	23.17	24.23	23.92
Specific capacity, t/m <sup>2</sup> ·h	1.40	1.36	1.39	1.34	1.41
Initial filtration rate, m/s	1.51	1.71	1.58	1.65	1.61
Final filtration rate, m/s	2.35	2.54	2.45	2.63	2.54
Sinter abrasion strength, % (-0.5 mm)	2.70	2.80	2.60	2.91	2.87
Sinter impact strength, % (+5 mm)	82.40	80.30	81.30	80.10	81.20
Reducibility, %	69.20	69.70	68.20	69.90	68.10



**Figure 3. Effect of using biocoke with 5 wt.% biomass pellets produced at different carbonization temperatures on the sinter properties: (a) impact on sinter yield (+10 mm); (b) impact on sinter reducibility; (c) impact on sinter strength (+5 mm); (d) impact on sinter abrasion strength (-0.5 mm)**



**Figure 4. Effect of using biocoke with 5 wt.% biomass pellets produced at different carbonization temperatures on the sintering process parameters: (a) impact on sintering velocity; (b) impact on specific capacity; (c) impact on initial and final filtration rates**

However, the initial filtration rate is characterized by a high value when using biocokes with 5 wt.% biomass pellets at a temperature of 950°C. The value of the final filtration rate is also the highest for biocoke with the addition of 5 wt.% biomass pellets at a temperature of 950°C. It can be concluded that the use of biocoke with the addition of 5 wt.% biomass pellets affects the increase in the filtration rate of the blend during the sintering process. The sintering velocity and specific capacity remain approximately at the same level, making it possible to recommend biocoke obtained at a temperature of 950°C as a fuel for iron ore sintering. Based on this conclusion, subsequent study is performed on the use of biocoke in the iron ore sintering, which is obtained at a temperature of 950°C with a high proportion of wood pellets of 10, 15, 30, and 45 wt.%.

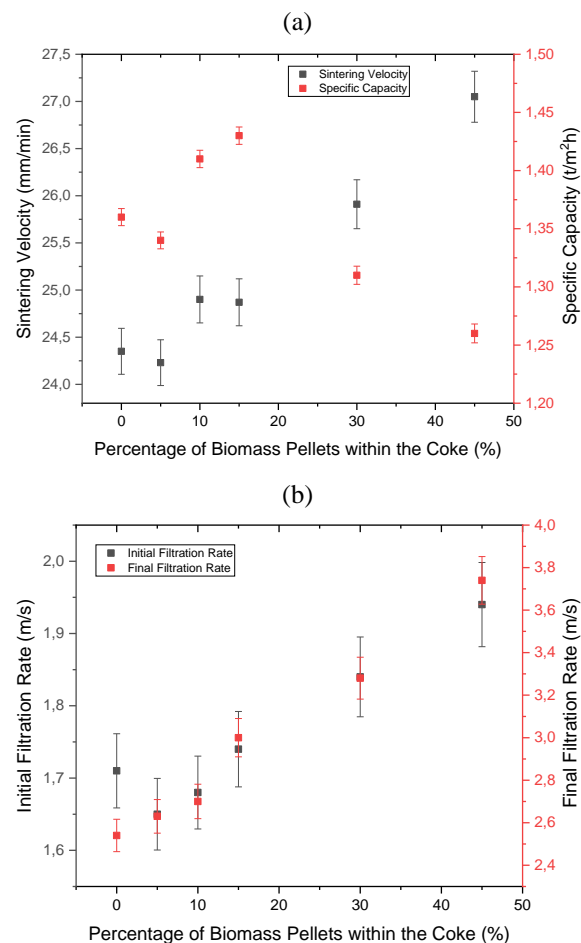
Table 7 shows the sintering process parameters and the resulting sinter obtained using biocoke with a high proportion of biomass pellets at a temperature of 950°C.

**Table 7. Parameters of the sintering process and the resulting sinter obtained using biocoke with a high proportion of biomass pellets, carbonized at a temperature of 950°C**

Sintering process and resulting sinter parameters	Biocoke			
	Proportion of biomass pellets within the biocoke, wt.%			
	10	15	30	45
Sinter yield (+10 mm), %	63.67	63.09	60.09	56.91
Sintering velocity, mm/min	24.90	24.87	25.91	27.05
Specific capacity, t/m <sup>2</sup> ·h	1.41	1.43	1.31	1.26
Initial filtration rate, m/s	1.68	1.74	1.84	1.94
Final filtration rate, m/s	2.70	3.00	3.28	3.74
Sinter abrasion strength, % (-0.5 mm)	2.94	2.99	3.03	3.07
Sinter impact strength, % (+5 mm)	80.57	80.01	72.03	56.70
Reducibility, %	70.00	70.30	72.10	77.40

The sintering velocity increases significantly when using biocokes with biomass pellets of 30 and 45 wt.%. This result is facilitated by an increase in the fuel combustion rate with an increase in the filtration of the blend layer, which follows from the change in the filtration rate indicators (Fig. 5b). At the same time, the HHV of these biocokes remains at a relatively high level compared to other types of fuel (Table 5). In addition, the filtration rate increases with an increase in the sinter porosity, which, however, affects the decrease in the strength and yield of the sinter (Table 7).

When studying the effect of biocoke on the specific capacity, mixed results have been obtained, according to which the highest specific capacity is observed when using biocokes with 10 and 15 wt.% wood pellet additives. These biocokes have physical-chemical and physical-mechanical properties that make it possible to ensure the optimal sintering velocity and obtain sinter strength at the level when using laboratory coke breeze or biocoke with 5 wt.% biomass additives as fuel. Figures 6a and 6b show the effect of biocoke with a high proportion of biomass pellets on the yield and quality of iron ore sinters. The observed decrease in the sinter yield +10 mm from 65.66 to 56.91% is associated with the formation of a brittle porous structure of the sinter. Along with that, the specific capacity of the process decreases from 1.40 t/m<sup>2</sup>·h for industrial coke breeze to 1.26 t/m<sup>2</sup>·h for biocoke with 45 wt.% biomass pellets. The authors in [30] report that the sintering velocity increases, the specific capacity, yield +10 mm, and sinter strength tend to decrease with partial coke breeze replacement.



**Figure 5. Effect of using biocoke on the sintering process: (a) impact on sintering velocity and specific capacity; (b) impact on initial and final filtration rates**

The sinter impact strength remains at the same level for laboratory coke breeze and biocoke with a content of 5-15 wt.% and decreases sharply when using biocoke with a content of 30 and 45 wt.%. Biocoke's presence can explain this deterioration with a high charcoal content, which has an increased reactivity and does not provide the required thermal level in the sintering zone for the required time. More porous and reactive biocoke burns out in less time than is necessary to form a sufficient amount of melt in the sintering zone, especially for large iron ore lumps. Increasing the proportion of biomass additives to obtain biocoke increases sinter abrasion strength but is not very significant for 30 and 45 wt.%. Intense combustion of biocoke particles contributes to the melting of nearby materials and forming a highly porous structure. In contrast, iron ores located between fuel particles do not fully participate in the process of liquid-phase sintering.

When using biocoke produced with 30 and 45 wt.% biomass pellets, the sinter reducibility value is higher than that of industrial or laboratory coke breeze, as shown in Figure 7.

Thus, in the case of using coke breeze, the reducibility ranges from 68.2-69.2%, and when using biocoke, these values are in the range of 68.1-77.4%. Therefore, obtaining a sinter with a highly porous structure positively affects its reducibility. It is well known that higher porosity sinter provides higher reducibility but a lower strength [2]. However, the low impact strength of 72% does not allow the use of the resulting sinter in a BF.

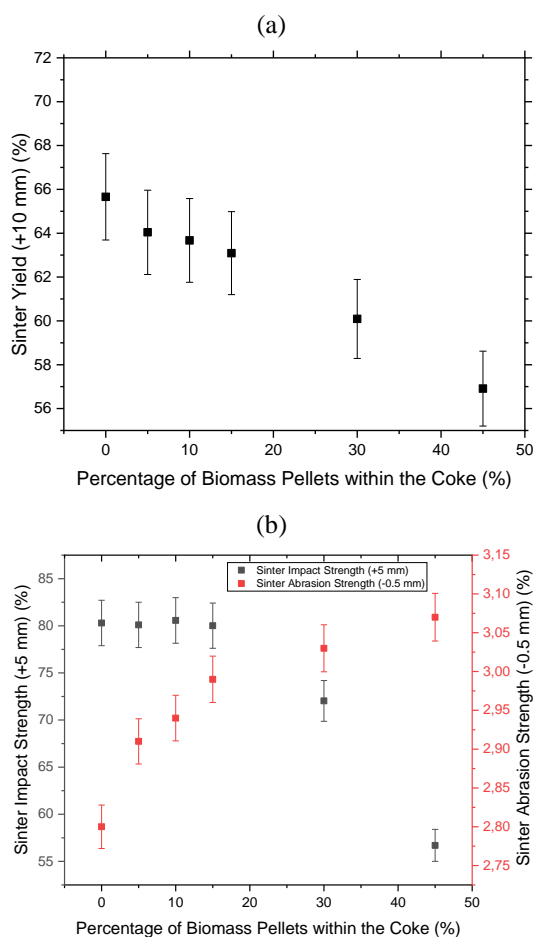


Figure 6. Effect of using biocoke: (a) on the yield +10 mm of iron ore sinter; (b) on the strength quality of iron ore sinter

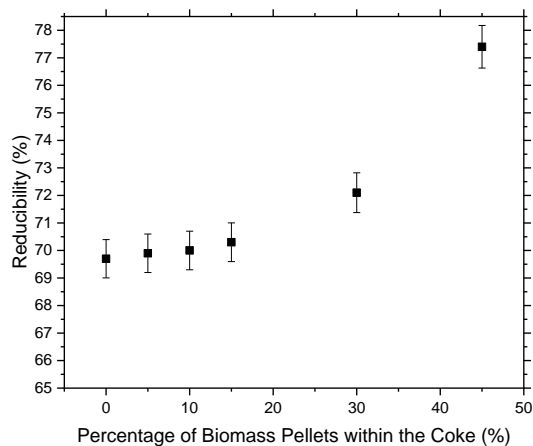


Figure 7. Effect of using biocoke on the iron ore sinter reducibility

The low reducibility of the sinter obtained using conventional coke breeze is evidenced by the fact that a significant melting of the sinter leads to the closure of the pores. In this case, the sinter becomes denser and passes reducing gases through itself worse. As a result, their reducibility decreases as the strength of the molten sinters increases.

#### 4. Conclusions

In this paper, the effect of biocoke with the constant addition of 5 wt.% biomass pellets and at different final carbonization temperatures of 950 or 1100°C on the iron ore sintering performance and strength properties of sinter has been experimentally studied. In addition, the effect of a high proportion of 10-45 wt.% biomass pellets at the same carboniza-

tion temperature of 950°C on the iron ores sintering and the resulting sinter quality has been substantiated. The conducted studies lead to the following conclusions:

1. The effect of biocoke obtained at a temperature of 1100°C with the addition of 5 wt.% biomass pellets on the sintering process performance and the sinter quality corresponds to that when using industrial coke breeze.

2. The use of biocoke with the addition of 5-15 wt.% biomass pellets and obtained at a temperature of 950°C does not significantly affect the yield +10 mm and impact strength of the sinter. The results obtained are within the standard deviation, which indicates the possibility of using biocoke with 15 wt.% biomass pellets instead of industrial coke breeze. The specific capacity of the sintering process is increased when using biocoke with 10 and 15 wt.% biomass pellet additives compared to conventional industrial coke breeze and laboratory coke breeze.

3. When using biocoke obtained at a temperature of 950°C and with 30 and 45 wt.% wood pellet additives, there is a noticeable decrease in the yield and strength of the sinter.

4. When using biocoke with a high proportion of biomass pellets, this increases the sintering velocity. On the one hand, this contributes to an increase in the reducibility of the iron ore sinter, and on the other hand, to the production of sinter with a highly porous structure, which leads to a decrease in the yield of +10 mm and the strength of the sinter.

5. Biocoke obtained at a temperature of 950°C instead of conventional coke breeze can reduce biofuel production's energy costs and contribute to a sustainable process of iron ore sintering.

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## Вплив біококсу на агломерацію залізних руд та властивості міцності агломерату

Л. Кеуш, А. Коверя, М. Бойко, М. Ягольник, А. Груб'як, Л. Молчанов, В. Мокляк

**Мета.** Метою дослідження є обґрунтування використання біококсу як палива при агломерації залізних руд, а також його вплив на характеристики процесу агломерації та властивості отриманого агломерату. Для повної заміни традиційного коксового дріб'язку, біококс виробляють із використанням 5 мас.% деревних пелет біомаси за різних температур карбонізації 950 або 1100°C. Далі досліджується вплив біококсу на процес агломерації та якість агломерату при високій частці пелет біомаси 10, 15, 30 і 45 мас.% і температурі карбонізації 950°C.



**Методика.** Для отримання лабораторного коксу або біококсу, карбонізацію проводять у шахтній електропечі. Після цього, з використанням агломераційної установки, проводять агломерацію залізних руд. Для оцінки процесу агломерації та якості отриманого агломерату, на лабораторній агломераційній установці за допомогою пластинчастого анемометра, призначеного для вимірювання середньої швидкості спрямованого потоку в промислових умовах, визначають швидкість фільтрації. Для оцінки впливу коксу та біококсу на фізико-хімічні властивості агломерату було досліджено відновлюваність отриманого агломерату в печі з вертикальним нагріванням.

**Результати.** Визначено, що біококс, карбонізований за температури 950°C, має хороші перспективи та потенціал для переходу до сталого процесу агломерації залізної руди.

**Наукова новизна.** Доведено, що біококс із співвідношенням гранул біомаси до 15 мас.%, отриманий за температури 950°C, не впливає на параметри, що характеризують процес спікання. Показники міцності агломерату відповідають використанню 100 мас.% звичайного коксового дріб'язку. Біококс, застосований з високою часткою пелет біомаси 30 і 45 мас.%, спричиняє погіршення якості агломерату.

**Практична значимість.** Результати використання біококсу з додаванням пелет біомаси від 5-15 мас.% та за температури 950°C знаходяться в межах стандартного відхилення, що робить можливим використання біококсу з пелетами біомаси до 15 мас.% замість промислового коксового дріб'язку.

**Ключові слова:** біококс, коксовий дріб'язок, агломерація залізної руди, процес агломерації, продуктивність агломерації, міцність, деревні пелети