

Recovery of Zn from Auger Press Briquettes Made from Steelmaking Sludge

Illia Tkalenko^{1,*}, Oleksii Kovtun², Nikita Koriuchev¹, Leonid Platonov¹,
and Daniel Shehovsov¹

ABSTRACT

The presence of zinc in metallurgical byproducts poses a constraint on their reutilisation within the realm of ferrous metallurgy. This study delves into the viable prospect of zinc extraction from briquettes manufactured through the auger pressing technique by pyrometallurgical methods. These briquettes are crafted from converter sludge, anthracite, and a multifaceted binding agent. The study encompasses laboratory and industrial trials, spanning the auger pressing technological line, and a tunnel kiln. The consequential outcome of this process yields metallized iron-infused briquettes, effectively purged of zinc content. These briquettes emerge as a propitious raw material option for steelmaking endeavours.

Submitted: September 10, 2023

Published: November 06, 2023

 10.24018/ejeng.2023.8.6.3106

¹AMCOM GROUP LLC, USA

²AMCOM Ukraina LLC, Ukraine.

*Corresponding Author:
e-mail: ilt@amcom-intl.com

Keywords: Auger Press, Briquetting, Metallisation, Zinc Recovery.

1. INTRODUCTION

Currently, there is a pressing concern regarding the recycling of byproducts derived from metallurgical processes into secondary production cycles. Across the global landscape, substantial volumes of sludge and particulate matter stemming from both blast furnace and steelmaking operations (EAF and BOF, respectively) are generated. These byproducts exhibit diverse compositions, encompassing elements including, but not limited to, iron, zinc, lead, sodium, cadmium, and nickel [1]–[3]. The presence of zinc in iron-containing waste complicates the implementation of the reverse iron recovery process from dusts and sludges during reintroduction into blast furnaces and steelmaking operations. This necessitates the need for many enterprises to accumulate these byproducts in specialised storage facilities (sludge ponds and slag dumps). Recycling zinc-containing waste is of significant importance, considering the efforts of the global metallurgical industry to implement measures aimed at reducing the adverse impact of zinc-containing waste on the environment and human health. This study is the first in a series of studies conducted by our group to find effective solutions for the removal of zinc from briquetted byproducts of metallurgy using auger pressing, with the goal of reintroducing them into production to achieve circular economic objectives and carbon neutrality.

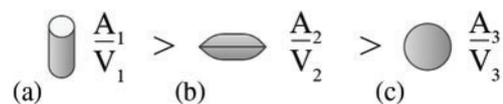


Fig. 1. Surface-area-to-volume ratio: (a) auger pressing briquette (b) roller press briquettes (c) pellet.

The utilisation of briquettes prior to zinc removal is well known [4]; however, the selection of the optimal composition of the charge and the search for more effective solutions remain relevant.

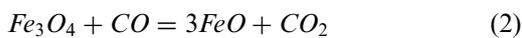
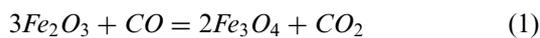
Auger pressing was selected for briquetting because a cylindrical shape [5]–[7] is preferable for zinc removal. This is because the surface-area-to-volume ratio is higher for the cylindrical briquettes than for the briquettes produced by roller pressing [8] or spherical pellets, as shown in Fig. 1. The cylindrical shape facilitates a more efficient drying, calcination, and melting process, as the briquettes dry and heat more rapidly. Auger pressing enables charge homogenisation and ensures sufficient briquette strength. Briquettes produced using the vibration pressing method were not taken into account because they have a significantly larger volume than those mentioned above [5].

This study explores the pyrometallurgical removal of ZnO from briquettes obtained by auger pressing. The briquettes were manufactured from converter sludge, a carbonaceous reducing agent, and an air-hardening binder. Simultaneously with zinc volatilisation, partial metallisation and reduction of iron oxides occurred according to the



Fig. 2. Production of briquettes from a laboratory auger press.

following reactions (1)–(5):



or



The experimental study was conducted under laboratory conditions and is discussed in the following sections. In addition, the laboratory results were validated in the industrial plant of a commercial customer.

2. EXPERIMENTAL STUDY

2.1. General

An experimental study was conducted under laboratory conditions to recover Zn from briquettes made from converter sludge using a reducing agent. Briquettes were produced by auger pressing using a laboratory auger press [5], [7].

2.2. Equipment

The equipment used in the research includes:

2.2.1. Laboratory Auger Press

Auger diameter: 65 mm.

Engine power: 4.6 kW.

A laboratory auger press was used to compress the materials using a rotating auger while passing through the die openings as shown in Fig. 2. To control the compaction process, the press is equipped with a frequency converter, which allows the adjustment of the auger rotation speed and monitoring of the operation progress. No vacuum was used during the pressing process.

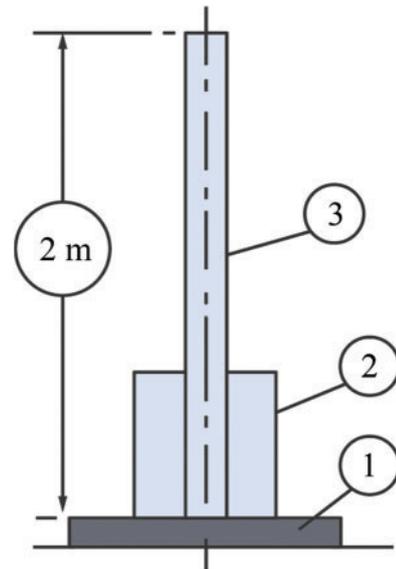


Fig. 3. Drop strength test equipment with (1) heavy plate, (2) tube or collar, (3) vertical pipe.

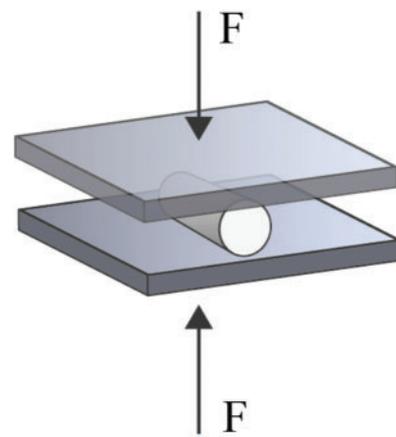


Fig. 4. Scheme of loading in crushing strength tests.

2.2.2. Drop Strength Test Equipment

Drop height: 2 m.

Impact onto a steel plate with a thickness of 30 mm.

The essence of this method lies in the mechanical impact of the briquettes within the dropping device. After three drops were completed, the sample was sieved through screens and the strength indicator was calculated based on the percentage distribution of the material on the screens. This calculation involved determining the percentage ratio of the undersized product to the initial sample quantity. Fig. 3 illustrates a schematic of the dropping process.

2.2.3. Hydraulic Press

Measurement range: from 0.2 to 100 kN.

Load rate: from 0.2 to 2 kN/s.

A hydraulic press served as a means of exerting a substantial force on materials, enabling the execution of diverse tests and the formation of materials under pressure. The cylinder velocity could be adjusted according to the specific requirements of a given task. Cylindrical briquettes were placed on the formation surface of the plate as shown in Fig. 4. The resulting tensile force during the fracture corresponded to the minimum load.

TABLE I: SIEVE ANALYSIS OF DRIED BOF SLUDGE

Fraction, mm	Content, %
0–0.075	4
0.075–0.1	8.1
0.1–0.5	33.6
0.5–1	23.8
1–3	16.2
3–5	8.6
5–8	5.2
>8	0.5

2.2.4. Drying Oven

Temperature: 105 °C.

A drying oven was used to dry materials at specific temperatures.

2.2.5. Muffle Furnace with Gas Cleaning System

Internal chamber volume: Not less than 80 L

Operating temperature range: From 50 to 1250 °C.

Temperature fluctuations: ± 1 °C.

Heating time to maximum temperature: No more than 60 min.

Continuous operating time: Not less than 16 h.

Chamber dimensions: 560 mm \times 360 mm \times 400 mm.

The muffle furnace provided controlled high-temperature conditions for the processing, heating, and thermal testing of the materials. The gas-capture system ensured the safety and effective management of the processes inside the furnace.

2.3. Composition of Charge for Auger Pressing Briquettes

Converter sludge obtained from a closed-loop metallurgical enterprise in Eastern Europe was selected as test material. The particle size distribution of the initially dried converter slag is presented in Table I. Its chemical composition is provided in Tables II and III.

The presence of fractions larger than 1 mm in the sludge was attributed to conglutination. During the preliminary pressing, the conglomerates were abraded and disrupted. Sludge's Zn content exceeding 3% renders it unsuitable for blast furnace operations and significantly restricts its application in steelmaking, even after agglomeration.

Anthracite with a particle size between 0–3 mm was used as the reductant. To ensure plasticity and hot and cold strengths, a multicomponent binder of the VA 4500 series was utilised. The binder is a dry powder consisting of a blend of organic and mineral components designed to confer both cold and hot strengths to the briquettes. Water is required to activate the binder, which is set up upon exposure to air.

To assess the applicability of the method, briquette compositions were proposed: BR1 with a reductant content of 25% (Table I) and BR2 with 10% (Table II) of the total dry mixture mass along with the binder.

The initial moisture content of the sludge was 1.9%.

The moisture content of the briquette immediately after exiting the press for recipe 1 (Table I) was 11.4%, while for recipe 2 (Table II), it was 12.11%.

TABLE II: MAIN CONSTITUENTS, THEIR CONTENTS, AND ELEMENTAL ANALYSIS IN AUGER PRESSING BRIQUETTE RECIPE 1 (BR1)

Elements	Content, %			
	BOF sludge (0–3 mm)	Anthracite	Binder AMCOM VA4500	Calculated total content
Fe _{total}	53.80			39.27
FeO	58.30			42.56
Fe ₂ O ₃	11.90			8.69
SiO ₂	1.67		1	1.24
CaO	11.35		1	8.31
MgO	2.27			1.66
Al ₂ O ₃	0.32		0.6	0.25
TiO ₂	0.10			0.07
P	0.04			0.03
Zn	3.60			2.63
Cr	0.04			0.03
MnO	0.69			0.50
S	0.13			0.09
C	2.18	95.00	35.00	26.04
Mass fraction in charge	73	25	2	

TABLE III: MAIN CONSTITUENTS, THEIR CONTENTS, AND ELEMENTAL ANALYSIS IN AUGER PRESSING BRIQUETTE RECIPE 2 (BR2)

Elements	Content, %			
	BOF sludge (0–3 mm)	Anthracite	Binder AMCOM VA4500	Calculated total content
Fe _{total}	53.80			47.34
FeO	58.30			51.30
Fe ₂ O ₃	11.90			10.47
SiO ₂	1.67		1	1.49
CaO	11.35		1	10.01
MgO	2.27			2.00
Al ₂ O ₃	0.32		0.6	0.29
TiO ₂	0.10			0.09
P	0.04			0.04
Zn	3.60			3.17
jn	0.04			0.03
MnO	0.69			0.61
S	0.13			0.11
C	2.18	95.00	35.00	12.12
Mass fraction in charge	88	10	2	

During testing, the briquettes were produced using the auger pressing method, with a total quantity of 25 kg for each mixture (Tables I and II). The diameter of the briquettes was 25 mm. The briquettes were cut into lengths that did not exceed 40 mm. For mechanical testing, 20 kg was selected from each batch of briquettes and 5 kg was chosen for reductibility testing. It is important to emphasise that the briquette production process does not involve the use of a vacuum.

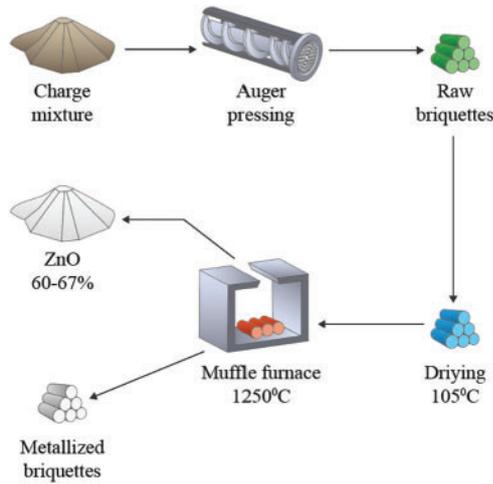


Fig. 5. The procedure for conducting laboratory tests for dezincification of briquettes produced by auger pressing.

TABLE IV: RESULTS OF STRENGTH TESTS

Samples	Drop strength test, %	Crushing strength tests, kN per pcs	Crushing strength tests after 1250 °C (30 min), kN per pcs
BR1	97	2.1	2
BR2	99	2.2	4.7

2.4. Test Procedure

The laboratory tests proceeded in the following sequence: preparation of the mixture, production of briquettes using a laboratory auger press, drying the briquettes in a drying oven to achieve constant weight, heating the briquettes in a muffle furnace in an atmospheric air environment up to 1250 °C (over the course of an hour) and holding them for two hours with capturing zinc. The presence of carbon in the briquette ensured a reduced atmosphere. The procedure steps are schematically depicted in Fig. 5.

In the next section, the results of mechanical and metallurgical tests are presented.

3. RESULTS

3.1. General

The briquettes obtained during the laboratory tests underwent mechanical testing and were subsequently directed to drying ovens and muffle furnaces for the reduction of metal oxides.

3.2. Strength Tests

The mechanical strength tests were conducted as described in Section 2.2. The tests were performed according to a methodology similar to that described previously [5]. Drop-strength tests were conducted at room temperature, and compression tests were conducted both before and after heating in the furnace. The average test results for the samples are summarised in Table IV.

As shown in Table IV, the BR1 samples exhibit a slightly lower strength, which can be attributed to their significantly higher anthracite content. An explanation for the



Fig. 6. Photos of the auger pressing briquettes (recipe 1) during laboratory test after 30 min.

substantial difference in the crushing strength tests after heating is presented in Section 3.4.

3.3. Zn Reduction Experiments

After drying to achieve a constant weight, the briquettes were loaded into a cold muffle furnace. Ten briquettes were loaded individually for each sample mixture. Heating to a temperature of 1250 °C was carried out in a normal atmospheric air environment, taking 58 min for the BR1 sample and 61 min for the BR2 sample. Upon reaching 1250 °C, two briquettes were extracted from the furnace. The next two briquettes were extracted at 30 min, 1 h, and 1.5 h, respectively. Photographs depicting the progress of the tests are provided in Figs. 6 and 8.

After the tests, all the remaining raw dried BR2 briquettes underwent zinc removal and were subjected to a holding period of 60 min at a temperature of 1250 °C, as shown on a Fig. 8c.

The furnace heating profile is depicted in Fig. 7.

After extraction from the furnace, the diameter of the BR2 briquette was approximately 22 mm and its length was approximately 38 mm. Thus, the volume loss was approximately 26.43%, as shown in Fig. 9. Its weight loss was 20.8%.

Chemical compositions of both the initial and cooled samples were analysed using an Elevatech Prospector 2 instrument. The results of the determination of Fe and Zn contents are presented in Figs. 10 and 11.

After heating in a muffle furnace, the BR2 sample briquettes retained their shape, and as indicated by the mechanical testing results in Table IV, they demonstrated an increase in strength after firing.

The graphs indicate that the zinc reduction process initiates even before reaching the temperature of 1250 °C. For both the BR1 and BR2 samples, within an hour of attaining the 1250 °C mark, the zinc content decreases to 0.15% and 0.2% respectively, subsequently dropping to levels of 0.04%–0.08%. Remarkably, just 60 min after reaching 1250 °C (or 120 min from the beginning of the experiment), the extent of Zn removal reached 94%, which

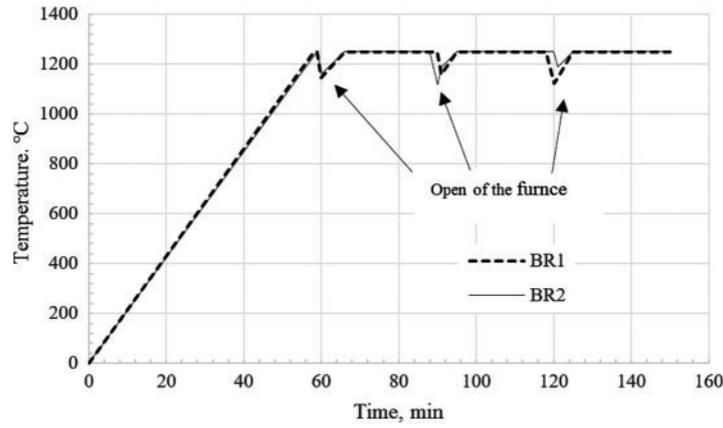


Fig. 7. Heating of the muffle furnace.

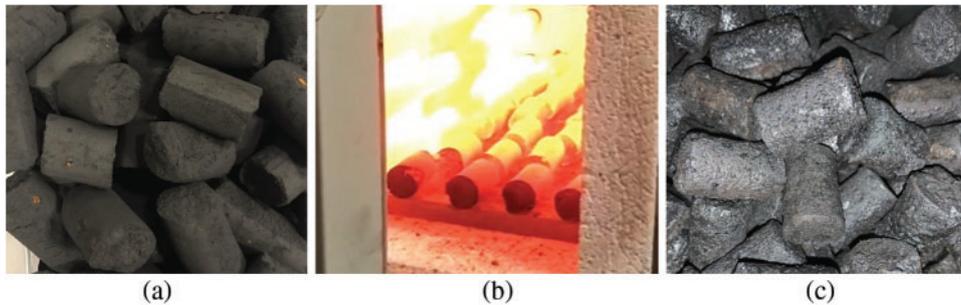


Fig. 8. Photos of the auger pressing briquettes (recipe 2) during laboratory test: (a) briquettes after the pressing (b) heating in the furnace at 1250 °C (c) all metallized briquettes after cooling.



Fig. 9. The change in briquette volume after calcination in a muffle furnace.

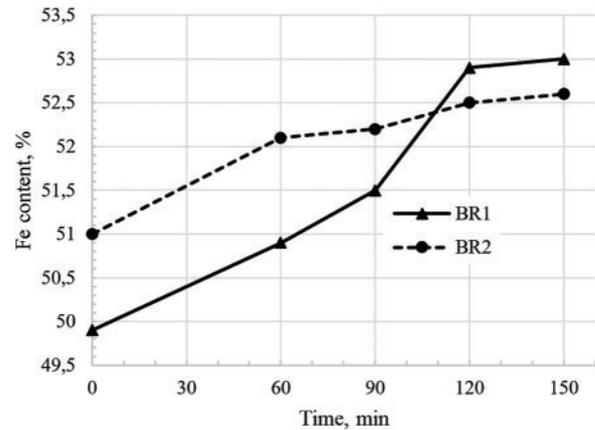


Fig. 10. Content of the Fe in the samples during the heating.

further increased to 98% within 30 min, as shown in Fig. 12.

In the briquettes, Fe metallisation occurred from the oxides, as shown in Fig. 8c.

The recovery of iron in briquettes occurs to a degree of more than 90%. Fig. 13 shows a photograph of the surface of a polished section of a BR2 briquette after exposure to the furnace at a magnification of 800.

In the laboratory, dust composed primarily of zinc oxide was captured. The appearance of the captured zinc oxide is depicted in Fig. 14; it comprises agglomerated dusty particles that disintegrate upon contact.

The ZnO content of the obtained dust was 67.3%. The chemical compositions obtained using an Elevatech Prospector 2 instrument and converted to oxides are presented in Table V.

This concentrate could serve as a raw material for the zinc industry.

3.4. Discussion

As shown in Fig. 6, BR1 briquettes were covered with cracks and exhibited high porosity. They are brittle, with many adhering to the mould, leading to unsatisfactory

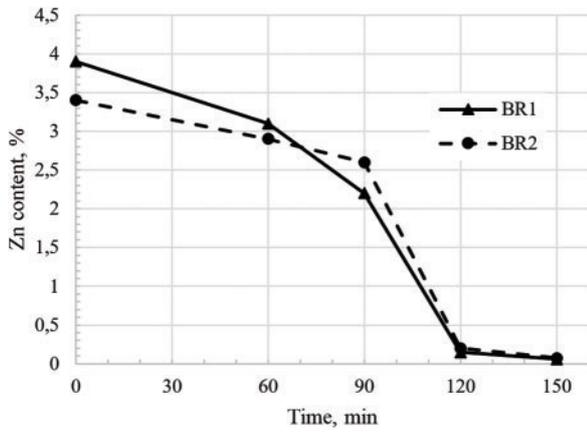


Fig. 11. Content of the Zn in the samples during the heating.

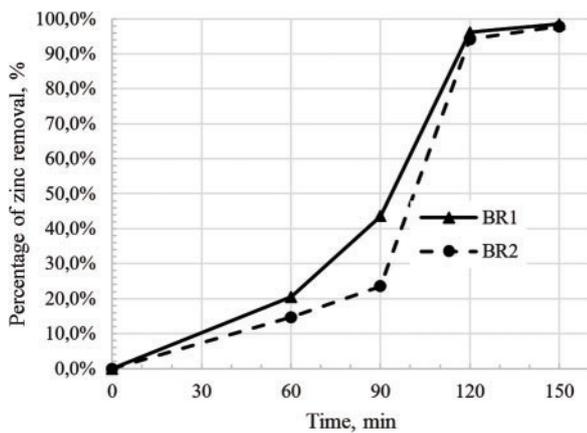


Fig. 12. Percentage of zinc removal during testing.

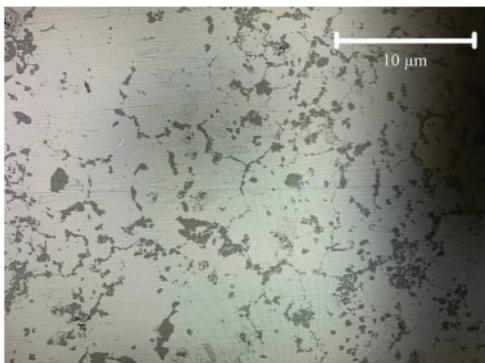


Fig. 13. Briquette BR2 after heat treatment (800 magnification).

results despite the slightly better Zn removal rates compared with the BR2 samples, as shown in Fig. 12. Further processing and sending of the BR1 material for metallurgical processing after repelletisation is necessary for its subsequent use. In contrast, the BR2 briquettes retained their shape and possessed a compressive strength of over 4.7 kN per briquette, while still exhibiting visible pores. With their metallisation, they resemble directly reduced iron (DRI), making them suitable for direct use in steelmaking. For both samples, over 94% of the Zn was removed within 60 min, which is sufficient considering the energy consumption for heating. However, if further removal of Zn is required, the reaction can be extended.



Fig. 14. Zinc oxide concentrate captured by the gas cleaning system.

TABLE V: ELEMENTAL ANALYSIS OF THE ZN-CONTENT DUST

Element	Content, %
ZnO	67.3
FeO	16.7
CaO	2.1
SiO ₂	3.8

Future research directions should encompass varying briquette diameters, reductant types and contents, temperature profiles, and furnace atmospheres to enhance the fundamental understanding of the process.

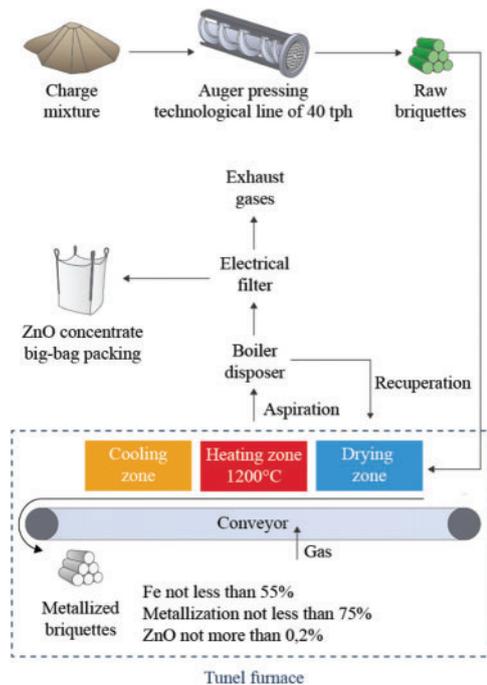


Fig. 15. Scheme of industrial test.

4. INDUSTRIAL TESTS

An industrial experiment was conducted at the end of 2019 to validate the laboratory test results. Industrial trials of the technology were carried out using a production

line equipped with an auger pressing unit with a capacity of 40 tons/h, coupled with a tunnel kiln equipped with natural gas burners. The heating zone temperature was set at 1200 °C, and the briquettes were exposed to this temperature for 1 h. The composition of the briquette mixture corresponds to that of the BR2 sample, as indicated in Table III. The moisture content of the mixture was reduced to 11.5% using an industrial press. The preliminary drying of the briquettes was facilitated by heat released from the reduction zone. The experimental procedure is illustrated in Fig. 15.

Throughout the testing process, the following achievements were realized:

- Zinc content in the captured concentrate: 60%–65%
- Briquettes metallization is more than 90%
- Fe_{total} content in the briquettes: no less than 55%
- Residual zinc in briquettes: no more than 0.2%

The elimination of the need for briquette curing, minimizing handling operations, and direct conveyance of briquettes to the drying phase enabled a reduction in the requisites for cold mechanical strength, and brought down the binder content to 1.2%.

5. CONCLUSION

Conclusions drawn from the conducted research:

1. Briquettes produced by auger pressing exhibit an extended surface area, facilitating the removal of Zn through pyrometallurgical methods.
2. Briquettes formed from converter slag and anthracite, followed by firing, achieved a metallisation of more than 90% with a zinc content below 0.2% and an efficiency of Zn removal ranging from 94%–98%. Therefore, they are promising raw materials for the steelmaking industry. The obtained zinc concentrate is also a valuable raw material.
3. Laboratory testing findings were validated through industrial equipment trials.
4. There is potential in investigating the Sensitivity of observed processes to factors such as temperature, briquette size, and furnace atmosphere.
5. Prospects lie in testing this approach using different raw materials such as EAF dust from gas cleaning.

REFERENCES

- [1] Guézennec AG, Huber JC, Patisson F, Sessieq P, Birat JP, Ablitzer D. Dust formation in electric arc furnace: birth of the particles. *Powder Technol.* 2005;1–3(157):2–11. <https://doi.org/10.1016/j.powtec.2005.05.006>
- [2] Xylia M, Duerinck J, Meinke-Hubeny F. Eceee industrial summer study proceedings, European Council for an energy efficient economy. *Worldwide Resource Efficient Steel Production*, Paris, 2016.
- [3] Zhao G, Li R, Xing X, Ju J, Li X, Zu J. Removal behavior of Zn and alkalis from blastfurnace dust in pre-reduction sinter process. *Green Process Synth.* 2023;1(12):1–11. <https://doi.org/10.1515/gps-2023-0045>.
- [4] Xia L, Mao R, Xu X, Wei M, Yang F. Reduction process and zinc removal from composite briquettes composed of dust and sludge from a steel enterprise. *Int J Miner Metall Mater.* 2015;(22):122–31. <https://doi.org/10.1007/s12613-015-1052-8>
- [5] Vitikka O, Iljana M, Heikkilä A, Tkalenko I, Koriuchev N, Shehovsov D, et al. Suitability of auger pressing briquettes for blast furnace use based on laboratory tests. *Minerals.* 2022;12(7):868. <https://doi.org/10.3390/min12070868>
- [6] Lurie LA. *Briquetting in Metallurgy (in Russian)*. Moscow: Metallurgizdat; 1963.
- [7] Koriuchev N, Kovtun O, Shehovsov D, Tkalenko I. Repair of worn-out parts of auger presses by surfacing method. *Eur J Eng Technol Res.* 2023;4(8):12–6. <http://dx.doi.org/10.24018/ejeng.2023.8.4.3072>
- [8] Uhrynski A, Bembenek M. The thermographic analysis of the agglomeration process in the roller press of pillow-shaped briquettes. *Mater.* 2022;8(15):1–16. <https://doi.org/10.3390/ma15082870>