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RESEARCH PAPER

Influence of iron ore concentrate on the properties of briquettes produced from ferroalloy production waste

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ABSTRACT

The article presents the results of research on the briquetting of finely dispersed dust (FDD) from ferroalloy production using iron ore concentrate. The obtained results indicate that increasing the iron ore concentrate content in the briquetting charge up to 15% contributes to an improvement in the strength and density of the briquettes. The composition of the resulting briquettes corresponds to that of FeSi50-grade ferrosilicon, allowing them to be used as a substitute for standard FeSi50. The proposed method for processing fine dust waste, considering the large reserves of FDD and the simplicity of the initial charge composition, demonstrates promising potential for waste utilisation and the subsequent application of the obtained product in the metallurgical industry.

Keywords: briquettes, ferrosilicon, finely dispersed dust, strength, density, iron ore concentrate.

INTRODUCTION

Ferroalloy production, which plays a crucial role in ferrous metallurgy, particularly in the deoxidation and alloying of steel, generates substantial amounts of dust-like by-products. Without preliminary agglomeration, these fine materials cannot be reintegrated into standard metallurgical processes. One of the primary types of waste generated during ferroalloy production is fine-dispersed dust (FDD). The formation of FDD is an inherent by-product of the technological process and contributes to reduced overall process efficiency. In addition to its negative impact on productivity, FDD poses significant environmental risks. It occupies large storage areas, contributes to airborne particulate emissions, and, in certain cases, exhibits pyrophoric behaviour [1, 2].

Due to the factors above, all research dedicated to briquetting methods using various charge compositions and briquetting techniques is highly relevant and holds significant practical importance.

Previous studies [3,4] investigated multiple aspects of the briquetting process, including the selection of suitable binders and technological additives aimed at improving briquette quality. However, most of this research has been primarily concerned with enhancing the mechanical strength of the briquettes, as their transportation poses the greatest practical difficulties.

A promising direction is also the alkaline processing of industrial waste, as demonstrated in [5], where the kinetics of leaching carbon-containing waste to form humic acid compounds were studied.

Similar approaches were considered in [6], which confirmed the applicability of kinetic models in the alkaline leaching of fine waste materials.

However, an equally critical issue in the briquetting of fine-dispersed dust (FDD) is the inherently low density of the resulting briquettes. Reduced density adversely affects their behaviour in metallurgical melts. Specifically, low-density briquettes tend to float on the molten surface, leading to incomplete assimilation during smelting. This phenomenon contributes to chemical segregation, diminished electrical conductivity of the melt, and ultimately, a decline in the quality of the final steel product. Preliminary experiments reported in [7] explored the addition of iron ore concentrate to the briquetting mixture in amounts ranging from 3% to 10% by weight. The results indicated that the inclusion of iron ore concentrate significantly improves both the strength and density of the briquettes. These enhanced properties are comparable to those of specification-grade FS70 ferrosilicon alloys.

It is important to note that most ferroalloy production facilities do not limit their output to a single grade of ferrosilicon. Instead, they typically manufacture a range of grades, from FS20 to FS90. It is well established that the density of ferrosilicon increases as the silicon content decreases. Consequently, the results obtained for FS70-grade briquettes cannot be directly extrapolated to FS20 or FS45 grades, as densities of these alloys differ significantly from that of FS70.

This study builds upon the research presented in [8]. The objective of this investigation is to determine an optimal briquetting mixture composition for fine-dispersed dust (FDD), incorporating iron ore concentrate, to produce briquettes suitable for alternative ferrosilicon grades.

MATERIAL AND METHODS

The briquetting mixture consisted of the following components: fine-dispersed dust (FDD) generated during ferrosilicon production, off-grade fine ferrosilicon (FF) with particle sizes below 3 mm, iron ore concentrate (IOC) and bentonite clay used as a binder. **Table 1** and **Table 2** present the chemical and fractional compositions of the main charge components.

The components were mixed in the specified proportions using a laboratory mixer. After preparing the briquetting mixture, briquette samples with dimensions of 40 mm in diameter and 10 mm in height were formed using an RP-50 press. The compaction process was carried out under a constant pressure of 40 kN [9]. Subsequently, the briquettes were dried in a Snol-67/350 drying oven at 40°C for 2 h.

Samples IOC 5 and IOC 30, containing 5% and 30% iron ore concentrate, respectively, exhibited low mechanical strength and were prone to disintegration during transportation. Consequently, these compositions were excluded from further investigation because they failed to meet the mechanical strength requirements for briquettes.

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Table 1 Chemical Composition of the Main Charge Components

Component	FDD	IOC	FF	Bentonite Clay
Si	71,5	12,25	47,0-52,0	65,2
Fe	26,7	49,4	40-42,22	23,73
O	0,06	32,44	0,2	0,5
S	0,002	0,038	0,1	0,476
P	0,042	0,064	0,02	0,51
Al	1,104	3,3	2,0	9,364
Mn	0,251	2,285	0,6	0,166
Cr	0,05	0,021	0,5	-
Zn	-	0,222	-	0,054

Table 2 Fractional Composition of the Components

Particle Size	**≤ 0.05 mm**	**0.05-0.2 mm**	**0.2-1.0 mm**	**1.0-3.0 mm**	**≥3.0 mm**
FDD	14%	16%	55%	13%	2%
IOC	-	82,3%	6%	6%	5,7%
FF	14,5%	20,25%	10%	46,86%	7,89%
Bentonite Clay	25%	51,5%	16%	5%	2%

For the subsequent experimental investigation, briquette samples were prepared with varying iron ore concentrate (IOC) contents ranging from 5 wt.% to 30 wt.%. The composition of the samples is presented in **Table 3**.

Table 3 Composition of Experimental Briquettes

Sample Label	**FDD Content, %**	**IOC Content, %**	**FF Content, %**	**Bentonite Clay, %**	**Water, %**
IOC 5	50	5	40	3	2
IOC 10	50	10	35	3	2
IOC 15	50	15	30	3	2
IOC 25	50	25	20	3	2
IOC 30	50	30	15	3	2

The remaining experimental samples were subjected to detailed analyses, including structural characterisation, chemical and elemental composition assessments, as well as measurements of compressive strength and density.

The elemental composition of the samples was investigated using micro-spectral analysis (MSA) performed on a Carl Zeiss AURIGA scanning electron microscope equipped with a microanalysis system and an EBSD detector (Carl Zeiss NTS GmbH). The analysis area ranged from 50 to 75 µm, allowing for a detailed examination of phase distribution and elemental variations. For mapping, texture analysis and phase identification, the HKL system was employed.

X-ray phase analysis was performed using a Bruker D8 Advance diffractometer over a diffraction angle (2θ) range of 15° to 95°, employing Co Kα radiation with a step size of 0.025°. Data acquisition utilised a position-sensitive LynxEye detector. Phase identification and diffraction pattern interpretation were carried out using the ICDD PDF-2 database (version 2023).

Compressive strength was measured on an INSTRON testing machine.

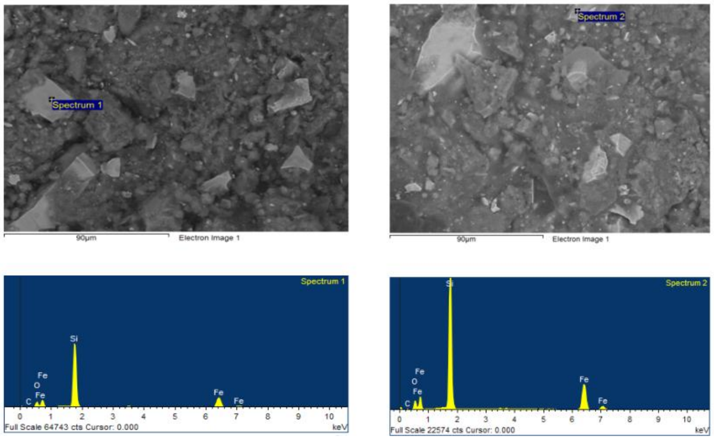
Sample density was determined using the pycnometric method, as specified in GOST 32183.

These findings align with previous research on iron ore tailings and mineral waste briquetting [10], emphasising the importance of composition control and structure optimisation.

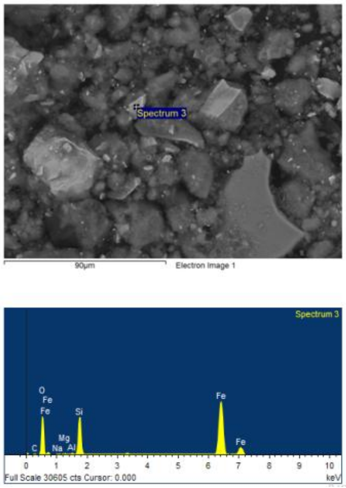
RESULTS AND DISCUSSION

At the initial stage of the study, micro-X-ray spectral analysis (µ-XSA) was conducted in various phase regions of the experimental samples.

Fig. 1 presents the structures along with the corresponding spectra of the samples.



(a) Sample IOC 10 (b) Sample IOC 15



(c) Sample IOC 25

Fig. 1 Structures and spectra of the samples obtained using a scanning electron microscope (SEM) AURIGA equipped with a micro-X-ray spectral analysis (MXSA) system: (a) sample with 10% iron ore concentrate (IOC 10); (b) sample with 15% concentrate (IOC 15); (c) sample with 25% concentrate (IOC 25). The SEM images show the surface morphology of the briquettes, while the EDS spectra, as part of the MXSA, reveal the elemental composition, including key elements such as iron (Fe) and silicon (Si).

Table 4 presents the elemental chemical composition of the experimental briquettes (based on MSA data) alongside that of FS50-grade ferrosilicon (GOST 1415-93), which was used as a reference material.

As expected, all samples contained silicon, iron, oxygen, and carbon. Trace amounts of calcium, aluminum, manganese, and sodium were also detected. The presence of these elements can be attributed to the composition of the bentonite clay used as a binder. The relatively high oxygen content in the experimental samples suggests that iron is likely present in oxidised form, primarily as iron oxide.

Table 4 Elemental composition of experimental samples and FS 50

Grade	Si	Fe	C	O	S	P	Al	Mn	Cr	Other elements
FS 50	48,0- 53,0	Not standardized	≤0,1	Not standardized	≤0,02	≤0,03	≤3,5	≤0,6	≤0,5	Regulated upon request
IOC 10	53,52	32,90	0,1	10,03	0,02	0,03	1,42	0,6	0,3	Rest
IOC 15	51,8	33,30	0,1	10,23	0,02	0,03	1,66	0,44	0,5	Rest
IOC 25	48,21	35,1	0,1	10,5	0,02	0,03	1,08	0,27	0,5	Rest

To identify the specific phases in which these elements are present, X-ray diffraction (XRD) analysis was conducted. The results are presented in **Fig. 2.**

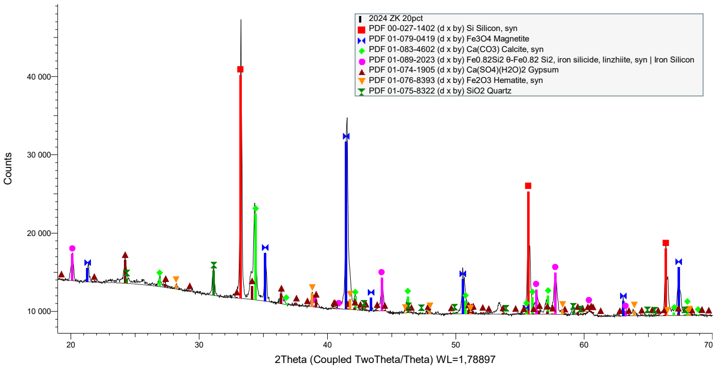


Fig. 2 Qualitative phase analysis of the IOC 15 sample (DiffracSuite EVA v6.0; ICDD PDF-2 2023, fragment of the diffractogram; logarithmic scale on the y-axis to display low-intensity lines).

This spectrum corresponds to sample IOC 15; however, a similar phase composition was observed in the other samples as well. X-ray diffraction analysis revealed that the dominant phases include magnetite, quartz, hematite, iron silicides and calcium-bearing compounds. In commercial-grade ferrosilicon alloys, the phase composition differs slightly depending on the specific grade. It typically includes iron silicides, elemental silicon, silicon dioxide, and impurity-enriched phases.

Returning to the data presented in **Table 4**, it should be noted that the experimental samples are consistent with FS50-grade ferrosilicon in terms of silicon content. However, their total iron content is lower than that of standard-grade ferrosilicon alloys. This is due to the fact that, in the experimental samples, iron is primarily present in the form of magnetite and hematite.

Nevertheless, regulatory documents such as GOST 1415-93 specify only the allowable contents of Si, C, S, P, Al, Mn, and Cr. These standards do not define the required form or precise concentration of iron for any particular ferrosilicon grade. Based on this observation, it can be reasonably concluded that the experimental samples conform to the FS50 grade in terms of their elemental composition.

Table 5 presents the results of compressive strength and density measurements.

Table 5 The results of compressive strength and density measurements

Sample Number	Density, kg/m³	Compressive Strength, MPa
FS50	4600 [12]	34 [13]
IOC 10	4900	34,6
IOC 15	5200	35,2
IOC 25	5300	35,7

The data in **Table 5** indicate that the briquette density increases with higher iron ore concentrate (IOC) content, exceeding the reference FS50 alloy density by 14%. While the compressive strength shows only a modest increase (approximately 5%), the achieved values meet the minimum strength requirements necessary for transportation of the product, as defined in [11-13].

CONCLUSION

The conducted research has demonstrated that the addition of iron ore concentrates in the range of 10–25 wt.% to the briquetting mixture for fine-dispersed dust from ferroalloy production results in briquettes with a chemical composition that corresponds to that of FS50-grade ferrosilicon. The resulting briquettes exhibit sufficiently high compressive strength and density, meeting the requirements for safe transportation and efficient smelting performance. The presence of oxygen in the experimental briquettes remains an open question. While the content of oxygen and iron is not regulated in standard FS50 ferrosilicon, it is evident that the occurrence of oxygen in the form of iron oxides may influence subsequent metallurgical processes. Therefore, the distinction between the chemical state of iron in the briquetted material and conventional ferrosilicon must be taken into account, particularly in deoxidation and alloying applications.

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