COMPARATIVE ANALYSIS OF THE USE OF IRON ORE CONCENTRATE WITH DIFFERENT BINDERS IN THE BRIQUETTING OF FERROALLOY PRODUCTION WASTE

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ABSTRACT

This study presents a comparative analysis of binder efficiency within the briquetting mixture used for processing fine-dispersed dust (FDD) generated during ferrosilicon production. Two types of binders were assessed: liquid glass and bentonite clay. The briquetting mixture consisted of fine-dispersed dust (FDD), undersized ferrosilicon (FS) particles, iron ore concentrate (IOC) sourced from the Sayak deposit (Kazakhstan), a binding agent and water. The use of this briquetting mixture enables the production of briquettes with a chemical composition corresponding to FS70 grade, as defined by GOST 1415-93. The findings demonstrated that bentonite is a more effective binder than liquid glass for this application. Its use led to the formation of briquettes with superior mechanical strength and higher bulk density.

KEYWORDS

Briquettes, bentonite, density, iron ore concentrate (IOC), liquid glass, strength, fine-dispersed dust (FDD), ferrosilicon.

1. INTRODUCTION

In Kazakhstan, over 1.86 million tons of ferroalloys are produced annually [1]. However, the ferroalloy production process generates significant volumes of waste, which require large areas for storage and pose a serious environmental threat due to atmospheric pollution. The primary waste product of ferroalloy manufacturing is fine-dispersed dust (FDD). FDD contains a silicon concentration comparable to that of standard-grade ferrosilicon. Nonetheless, it is classified as a non-conforming product due to its particle size distribution, which falls outside the acceptable range. The industrial reuse of FDD is feasible only after agglomeration, most effectively through briquetting. This process enables the transformation of FDD into a material with the same chemical composition as commercial-grade ferrosilicon. Moreover, it provides a sustainable method for the utilization of hazardous technogenic waste, thereby reducing the environmental footprint of ferroalloy production.

The most common binders in FDD briquetting are liquid glass, slaked lime, cement, kaolin clay and caustic soda. Liquid glass is often used as a binder in briquetting, as it is an accessible and cheap component. Many studies have been conducted using liquid glass as a binder [2-8].

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For example, in study [2], the authors examined the use of liquid glass (LG) and low-grade flour (LGF) as binders. It was proven that, during the briquetting of fine ferrosilicon dust, the most durable briquettes were obtained when 10–20% liquid glass was used as a binder in the mixture.

In the study [3], liquid glass was used as a binder in combination with electrofiltered dust from aluminum production, which contains resinous substances, including polycyclic aromatic hydrocarbons (PAHs). Experimental results demonstrated that the briquettes produced by this method exhibited a highly porous structure (45.5%), which facilitates the development of a well-defined active surface area and ensures an appropriate apparent density. However, the mechanical strength of these briquettes was found to be insufficient, limiting their practical application.

In the study [4], the authors investigated the potential use of blast furnace slag combined with liquid glass (sodium silicate) as an alternative binder in cemented paste backfill (CPB) systems. These systems are employed in the stabilization and disposal of sulfide-rich flotation tailings. The performance of this alkali-activated material was compared with that of ordinary Portland cement (OPC). The results indicated that alkali-activated slag with sodium silicate (AAS-SS) exhibited significantly higher resistance to acid and sulfate attack. Moreover, CPB specimens formulated with AAS-SS showed higher uniaxial compressive strength compared to those based on OPC.

In several studies [5–6], plasticizers were introduced as binders and mixed with liquid glass. However, a major drawback of this method is the oxidation of silicon in ferrosilicon during interaction with the binders. This results in a reduction of the active silicon content in the briquettes.

Study [7] also discusses various binders used in the pelletizing process of iron ore. Both traditional and alternative binders (including bentonite and liquid glass) are considered. Particular attention is given to their effects on pellet strength, metallurgical properties, and environmental aspects. Liquid glass can effectively enhance pellet strength; however, excessive use reduces reducibility and increases the silica content in the final product.

The literature review indicates that liquid glass is the most commonly used binder. However, briquettes produced with this material contain relatively high concentrations of alkali metals, which is undesirable for standard-grade ferroalloys [8].

In the present study, bentonite clay was selected as the binder.

The selection of bentonite clay as the binder is justified by its favorable physicochemical properties. It exhibits high dispersibility, plasticity, water swelling capacity, and excellent binding characteristics. These features make it widely used in metallurgical processes, particularly in the production of iron ore pellets. In contrast to liquid glass, bentonite clay possesses a more complex chemical composition. Bentonite is a complex mineral, and its composition is primarily determined by the content of montmorillonite in the clay. Montmorillonite has the formula $Si_8Al_4O_{20}(OH)_4 \times nH_2O$, where silicon may be partially substituted by various cations such as aluminum, iron, zinc, magnesium, calcium, sodium, potassium, and others [9].

The purpose of this study is to compare the efficiency of using a binder (bentonite clay or liquid glass), ensuring its highest strength and the subsequent sample in the briquetting of FDD for the production of ferrosilicon.

2. MATERIALS AND METHODS

The briquetting mixture consisted of fine-dispersed dust (FDD), undersized non-conforming ferrosilicon (FS), iron ore concentrate (IOC) sourced from the Sayak deposit (Kazakhstan) [10,11], and a binder component. Two types of binders were used in the study: liquid glass and bentonite clay. Both the binder and water were added in excess of 100% by mass, relative to the solid phase of the mixture. The chemical and particle size distributions of the individual components used in the briquetting mixture are presented in Tables 1 and 2.

Table 1 – Chemical composition of the main components of the briquetting mixture

Component	**Si**	**Fe**	**O**	**S**	**P**	**Al**	**Mn**	**Cr**	**Zn**
FDD	71.5	26.7	0.06	0.002	0.042	1.104	0.251	0.05	-
IOC	12.25	49.4	32.44	0.038	0.064	3.3	2.285	0.021	0.222
FS	47.0 – 52.0	40-42.22	0.2	0.1	0.02	2.0	0.6	0.5	-

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%
FS	14.5%	20.25%	10%	46.86%	7.89%

The composition of the briquetting mixtures used for preparing experimental briquette samples with different binders is presented in Table 3.

Table 3. Composition of experimental samples

Sample marking	**Binder**	**FDD, %**	**IOC, %**	**FS, %**	**Bentonite, %**	**Liquid glass, %**	**Water, %**
1	Bentonite	58	7	35	3	-	2
2	Bentonite	60	5	35	3	-	2
3	Liquid glass	58	7	35	-	3	2
4	Liquid glass	60	5	35	-	3	2

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 briquetting mixtures of the specified compositions were compacted under a constant pressure of 50 kN. The resulting briquettes were then dried at 40 °C for 2 hours in an air atmosphere.

This process is illustrated in Figure 1.

a b

Figure 1. Experimental briquettes:
(a) Sample 1 (with liquid glass): Briquette produced from 58–60% fine-dispersed dust (FDD), with equal portions of iron ore concentrate (IOC) and undersized non-conforming ferrosilicon (FS) as additives. (b) Sample 2 (with bentonite): Briquette produced from 58–60% fine-dispersed dust (FDD), with equal portions of iron ore concentrate (IOC) and undersized non-conforming ferrosilicon (FS) as additives.

The chemical composition of the samples was determined using a NITON XL2-100G and SPAS-05 spectrometer.

Compressive strength was measured on an INSTRON testing machine.
Sample density was assessed by the pycnometric method in accordance with GOST 32183. The mean values of the measurements were reported in the results section, and standard deviations were calculated to assess the variability and repeatability of the data.

The structure of the samples was investigated via scanning energy-dispersive spectrometer using a TESCAN VEGA microscope (2015). X-ray phase analysis (XRD) was performed on an Empyrean diffractometer (PANalytical).

3. Results and Discussion

Table 4 shows the chemical composition of the experimental samples.

Table 4. Chemical composition of the samples

Sample No.	**Si**	**Fe**	**C**	**S**	**P**	**Al**	**Mn**	**Cr**
0 (FS 70) SS 1415-93	68.0-74.0	26-28	0.1	0.02	0.04	2	0.4	0.4
1	70. 12	27.1	0.13	0.026	0.034	1.91	0.39	0.38
2	69.68	27.2	0.1	0.028	0.38	1.902	0.35	0.36
3	69.59	27.2	0.15	0.029	0.04	2.01	0.39	0.591
4	68.41	28.1	0.17	0.03	0.04	2.03	0.8	0.42

As shown in Table 4, all experimental samples meet the chemical composition requirements specified in GOST 1415-93 for FS70-grade ferrosilicon.

Figure 1 presents the structures of the experimental briquette samples.

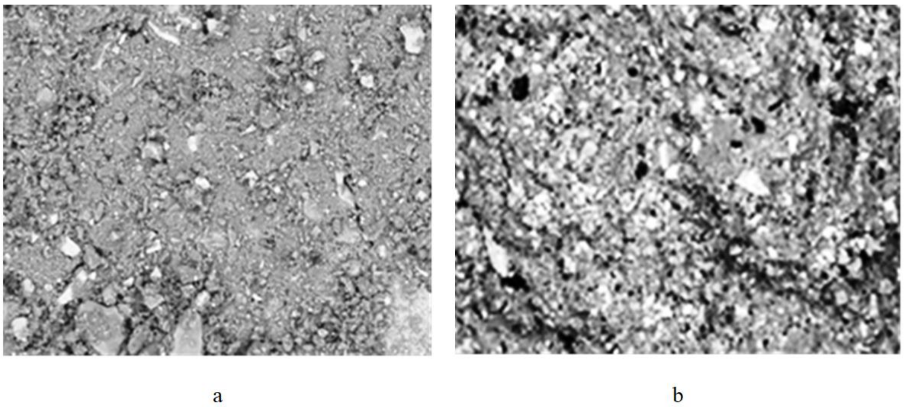

Figure 2. Structures of experimental samples:
a - with liquid glass (sample 3);
b - with bentonite (sample 1); (magnification X300)

It should be noted that the structures of the samples with the same binder appear similar regardless of the binder content. However, the structures with different types of binders show significant differences.

The structure of the samples with liquid glass appears more homogeneous and fine-grained (Fig. 2a). In contrast, the structure of the sample with bentonite (Fig. 2b) clearly shows the presence of relatively large, irregularly shaped inclusions. This structural difference suggests a corresponding variation in mechanical properties, particularly in terms of strength.
The density and compressive strength of the experimental briquettes were determined. The results of the analysis are presented in Table 5.

Table 5. Results of the experimental sample property analysis

Sample	**Compressive strength, MPa**	**Density, g/cm^3**
FS 70 GOST 1415-93	35 [12]	5.0 [13]
1	34.4	4.5
2	35.3	5.2
3	27.5	3.2
4	28.8	3.9

As shown in Table 5, briquettes produced with liquid glass exhibit lower compressive strength. The density values of samples with different binders vary slightly, but all remain within the acceptable limits defined by GOST.

Preliminary structural analysis suggested that samples 3 and 4, which were prepared using liquid glass, would exhibit higher compressive strength. This assumption was based on their more homogeneous and fine-grained structure. However, mechanical testing revealed the opposite trend. Samples containing bentonite, which displayed a coarser and more heterogeneous structure, demonstrated superior strength characteristics. This result may be attributed to the different bonding mechanisms of the binders. Bentonite likely provides stronger particle cohesion within the briquetting mixture due to the nature of its interparticle interactions.

Figure 3 presents the results of the Microprobe analysis (EPMA) performed at the binder points.

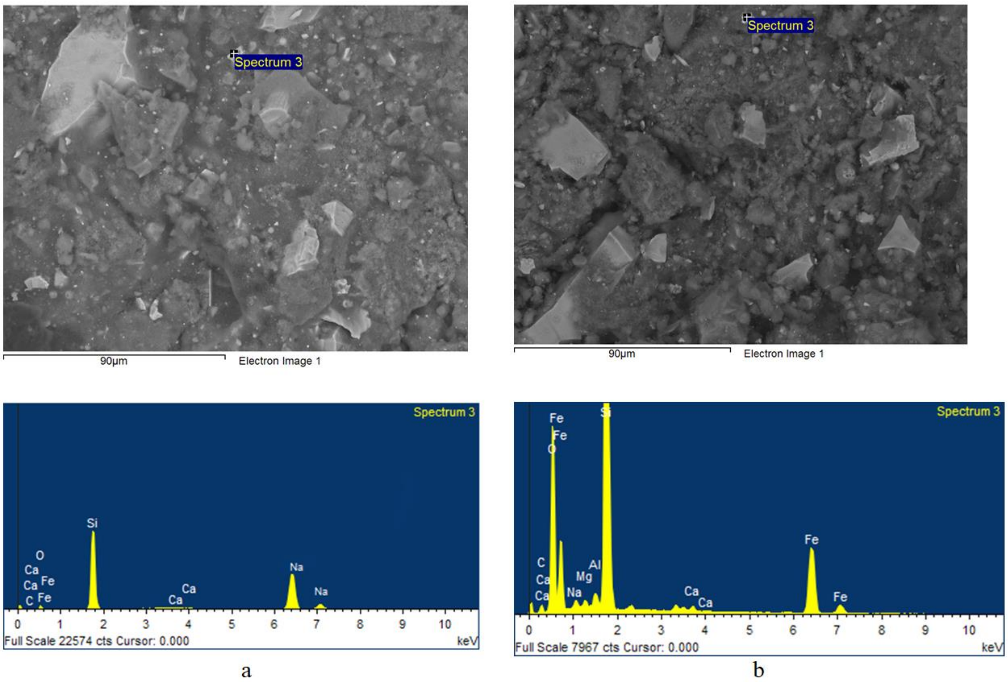

Figure 3. Microprobe analysis (EPMA) results for the experimental samples:
a – with liquid glass; b – with bentonite

Microprobe analysis (EPMA) results indicate that the binder phase (darker regions) in Sample 1 exhibits a more complex chemical composition, including elements such as Mn, Al, Si, Fe, and others. In contrast, the binder phase in Samples 3-4 is primarily composed of Na, Si, Mg, and a minor amount of Fe. It is evident that the more diverse elemental composition of the binder in Sample 1 implies a more complex mineralogical structure. This likely contributes to stronger interparticle bonding within the briquette, which may account for the higher compressive strength values observed.

Based on the obtained results, a diagram was constructed (Figure 4), clearly demonstrating the differences in the properties of the experimental samples. For ease of comparison, all data from Table 4 in the diagram are presented on the same scale.

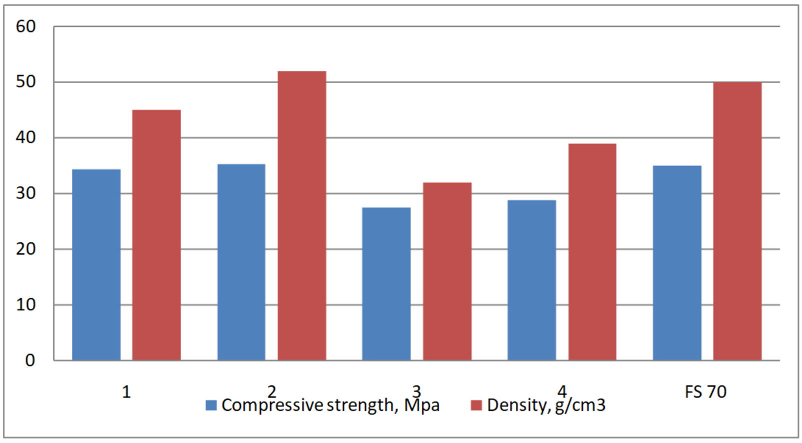

Figure 4. Comparative diagram of the properties of the experimental samples

As shown in Figure 4, the use of bentonite as a binder in the briquetting mixtures within the specified ranges is preferable to the use of liquid glass for briquetting ferroalloy production waste. These samples exhibit higher compressive strength and density values. Density, along with strength, is a critical physical property of briquettes. This is because briquettes tend to float during the melting process, which can lead to incomplete deoxidation and chemical liquation.

3.1. Statistical Analysis of Compressive Strength

To evaluate the repeatability and variation in compressive strength values, three briquettes were tested for each sample composition. The mean compressive strength and standard deviation (SD) for each sample are presented in Table 6.

Table 6. Statistical analysis of compressive strength

Sample	**Binder**	**Mean Strength (MPa)**	**Standard Deviation (MPa)**
1	Bentonite	34.4	±0.5
2	Bentonite	35.3	±0.4
3	Liquid Glass	27.5	±0.6
4	Liquid Glass	28.8	±0.7

The results show that samples with bentonite binder consistently outperformed those with liquid glass in compressive strength, with relatively low standard deviation, indicating good repeatability of the measurements. This further reinforces the conclusion that bentonite is a more effective binder for fine-dispersed dust (FDD) briquetting.

4. CONCLUSIONS

The conducted study demonstrated that briquettes formed using bentonite clay exhibited superior properties, namely, higher strength and density, compared to those produced with liquid glass as a binder. The improvement of such briquette characteristics ensures better preservation of the product during transportation. Furthermore, bentonite clay is a natural material that requires no preliminary processing, unlike liquid glass, which is an industrially manufactured product. Consequently, bentonite clay is a more cost-effective option, which positively impacts the overall production cost of the briquettes.

Moreover, the resulting briquettes comply with the requirements of GOST 1415-93 in terms of chemical composition, which confirms their potential for industrial application as a partial replacement for standard FS70-grade ferroalloy.

From a practical standpoint, it appears advisable to expand the scope of the proposed technology by exploring the use of bentonite and iron ore concentrate in processing waste from the production of other ferroalloys, such as ferromanganese and ferrochrome. This would allow the method to be adapted to different types of raw materials and increase its versatility within the metallurgical industry.

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