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BRIQUETTING OF FERROSILICOCHROME DUST AS A REDUCING AGENT FOR CHROMIUM–MANGANESE LIGATURE PRODUCTION

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Abstract. Ferrosilicochrome (FeSiCr) dust generated during the crushing of commercial ferroalloys represents a fine-dispersed secondary material with a significant reducing potential; however, its direct application in metallurgical processes is limited due to high dust losses and poor technological behavior. In this study, a briquetting technology for FeSiCr dust was developed and investigated with the aim of its use as a reducing agent for the production of chromium–manganese ligatures.

Experimental briquettes were prepared using sodium silicate (liquid glass) as a binder at contents of 5% and 10%, followed by natural and oven drying. The influence of binder content and drying conditions on the physical and mechanical properties of the briquettes was evaluated through drop tests and sieve analysis in accordance with relevant standards. The results showed that increasing the binder content from 5% to 10% slightly improved mass retention during drying; however, its effect on mechanical strength was limited. The difference in strength between briquettes with 5% and 10% binder did not exceed 1.5–4%, depending on the drying regime.

Based on the comparative analysis, a binder content of 5% sodium silicate was identified as sufficient to ensure the minimum mechanical strength required for handling, transportation, and furnace charging, while maintaining economic efficiency. The proposed briquetting approach enables the rational utilization of FeSiCr dust as a secondary reducing agent and contributes to improving resource efficiency and sustainability in ferroalloy production.

Key words: FeSiCr dust, briquetting, sodium silicate binder, chromium–manganese ligature, mechanical strength, secondary reducing agent, ferroalloy production.

Introduction.

Briquetting is one of the widely used technological methods in metallurgy for preparing fine and dust-like materials for high-temperature processing. This approach makes it possible to increase the bulk density of charge components, reduce dust losses, ensure uniform material distribution within the furnace working volume, and stabilize the course of reduction processes. Briquetting is especially relevant for the recycling of secondary materials and metallurgical by-products that contain valuable elements but exhibit limited technological applicability in their initial dispersed state [1-4].

During the production of FeSiCr, a significant amount of fine dust is generated at the stages of crushing and classification of the finished alloy. This FeSiCr dust is characterized by a highly dispersed structure and contains silicon, iron, residual chromium, and aluminum impurities, which determine its potential reducing ability. Despite this, FeSiCr dust formed during crushing is usually not returned to the main technological cycle and accumulates as a difficult-to-utilize by-product [5].

At the same time, the chemical composition and physicochemical properties of FeSiCr dust allow it to be considered a promising secondary reducing agent for the production of chromium–manganese ligatures (Cr–Mn alloys). Silicon and aluminum present in an active form are capable of effectively participating in the reduction of chromium and manganese oxides under high-temperature conditions. However, the direct use of dust-like FeSiCr material in smelting units is limited due to its high entrainment, low bulk density, tendency to segregate in the charge, and instability of reduction reactions.

One of the most rational ways to involve FeSiCr dust generated during crushing into the metallurgical process is its preliminary briquetting. The formation of briquettes increases the mechanical strength and density of the reducing material, reduces losses of silicon and chromium caused by dust carryover, and creates conditions for a more uniform and controllable course of reduction reactions during chromium–manganese ligature smelting. In addition, briquetting enables targeted control of the reducing mixture composition through the selection of binders and optimization of briquette formulations.

In this regard, the development of a briquetting technology for FeSiCr dust used as a reducing agent in the production of chromium–manganese ligatures represent an important scientific and technical task aimed at improving the resource efficiency and technological stability of metallurgical processes, as well as expanding the possibilities for the rational utilization of secondary products of ferroalloy production.

Materials and methods of research.

FeSiCr dust used in this study was obtained during the crushing and screening of commercial FeSiCr alloy. The dust was characterized by a fine particle size distribution and contained silicon, iron, residual chromium, and minor amounts of aluminum, which determine its potential reducing ability. Prior to briquetting, the dust was dried to remove excess moisture and homogenized to ensure uniform composition. As a binder, a mineral-based binding material was used to provide sufficient mechanical strength of the briquettes while maintaining thermal stability under high-temperature smelting conditions. The binder content was selected experimentally to achieve a balance between briquette strength and minimal influence on the chemical composition of the smelting charge. Water was added as a temporary plasticizing agent to facilitate briquette formation.

Briquettes were produced by mixing FeSiCr dust with a predetermined amount of binder and water until a homogeneous mixture was obtained. The prepared mixture was then compacted using a mechanical press under controlled pressure to form briquettes of a specified geometry and size. After forming, the briquettes were air-dried at ambient conditions to achieve sufficient green strength and to remove free moisture. The briquetting parameters, including pressing pressure, binder content, and moisture level, were selected to ensure adequate mechanical integrity of the briquettes during handling, transportation, and charging into the furnace.

The obtained briquettes were evaluated in terms of their technological properties. Mechanical strength was assessed by compression testing to determine the resistance of briquettes to mechanical breakage during handling. Visual inspection was carried out to identify cracks and structural defects. Thermal behavior of the briquettes was evaluated qualitatively during heating, with particular attention to their structural stability, disintegration tendency, and gas evolution behavior prior to melting.

Results and their discussion.

To determine the effect of the type and amount of binder on the quality of the produced briquettes, an experimental design was developed. Initially, a control group consisting of ten briquettes prepared from pure FeSiCr dust without any binder was produced. Subsequently, liquid glass ($Na_2SiO_3 \cdot nH_2O$) was used as a binder, and two additional groups were prepared in which the binder content corresponded to 5 wt.% and 10 wt.% of the total added water mass, respectively. In each case, ten briquettes were produced, resulting in a total of thirty briquette samples.

All experimental samples were compacted under a pressure of 10 t, ensuring identical compaction conditions for all briquettes. This approach enabled a reliable comparison of briquette strength and allowed a comprehensive evaluation of the influence of binder content on their mechanical properties.

To assess the effect of drying conditions on the final strength of the briquettes, the samples from each group were divided into two subsets. Of the total thirty briquettes produced, fifteen were dried under natural conditions at room temperature (20–25 °C) for 24 h, while the remaining fifteen were thermally treated in a drying oven at 200 °C for 120 min. This methodology made it possible to comparatively analyze the influence of drying regimes on the structural and mechanical properties of the briquettes and to identify optimal technological parameters.

The mechanical strength of the produced briquettes was determined using a conventional method in accordance with GOST 21289–75. According to this procedure, each briquette was dropped from a height of 2 m onto a flat metal plate, and its resistance to impact loading was evaluated. This test simulates mechanical stresses encountered under industrial conditions, such as transportation and furnace charging. After testing, sieve analysis was performed to determine the particle size distribution of the resulting fragments, and the mass fractions of the +10 mm (intact or large fragments) and −10 mm (fine fraction) size classes were quantified. A schematic representation of the technological sequence for preparing a single briquette under laboratory conditions is shown in Figure 1.

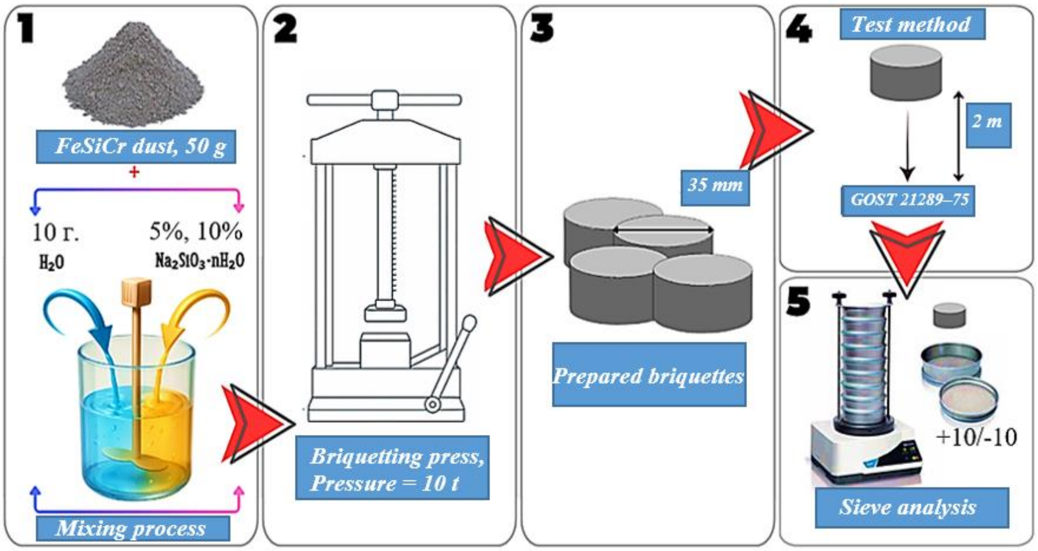

Figure 1. Schematic of the process for preparing one FeSiCr dust briquette

To quantitatively evaluate the quality of the produced briquettes and to determine the optimal composition and technological parameters, a comparative analysis of the test results obtained for all experimental groups was performed. The main objective of the analysis was to assess the influence of the binder content (liquid glass) at levels of 0%, 5%, and 10%, as well as the drying method (natural and artificial), on the mechanical strength of the briquettes. During each test, the mechanical stability of the briquettes was evaluated by dropping them from a height of 2 m onto a rigid surface, and the number of intact and damaged samples after impact was visually recorded.

For a more accurate quantitative assessment of briquette strength, the particle size distribution of the material after each drop test was determined by sieve analysis. As a result, the mass fractions of two main size classes were calculated: the +10 mm fraction (intact briquettes or large fragments that withstood the mechanical load and were considered suitable) and the −10 mm fraction (crushed material and fines, considered technologically unsuitable). The proportion of the +10 mm fraction was adopted as the primary criterion for briquette quality. The overall appearance of the produced briquettes is shown in Figure 2, while the complete quantitative results of the conducted experiments are summarized in Table 1.

Table 1. Characteristics of Briquettes Containing 5% and 10% Liquid Glass

№	Liquid glass – 5%			Liquid glass – 10%		
	Dimensions, (Ø / h)	Weight, g	Weight after drying, g	Dimensions, (Ø / h)	Weight, g	Weight after drying, g
1	35/15	43,10	41,15	35/14	48,65	44,05
2	35/15	44,65	40,10	35/14	43,45	41,00

3	35/15	44,00	41,20	35/14	46,00	42,15
4	35/15	48,00	43,30	35/15	43,00	42,10
5	35/15	48,70	44,25	35/15	46,50	43,50
6	35/15	46,95	43,10	35/15	47,10	43,75
7	35/15	43,45	40,30	35/15	48,10	46,30
8	35/15	46,70	42,15	35/16	47,75	44,20
9	35/16	49,30	43,95	35/16	47,35	43,95
10	35/16	49,15	44,50	35/16	49,50	46,41

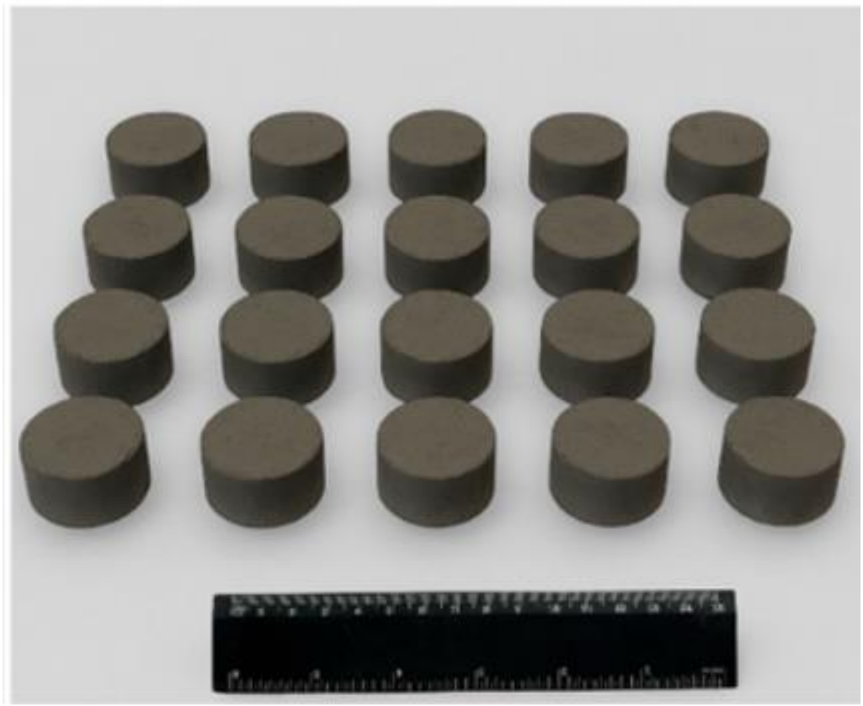

Figure 1. The initial briquette samples prepared from FeSiCr dust for testing

The main physical characteristics of the prepared briquettes, including their dimensions, initial mass, and mass after drying, are summarized in Table 2. These data allow a quantitative assessment of the influence of binder content (5% and 10% liquid glass) and drying conditions on briquette mass and density. To ensure experimental reliability, ten samples were prepared for each group. As shown in the table, all briquettes exhibited stable geometric dimensions (approximately 35 mm in diameter and 14–16 mm in height), indicating uniform pressing conditions.

For briquettes containing 5% liquid glass, the average initial mass after pressing was 46.4 g, which decreased to 42.4 g after drying, corresponding to a mass loss of about 8.6%, mainly due to evaporation of free moisture. In contrast, briquettes with 10% liquid glass showed a lower mass loss during drying, decreasing from an average of 46.7 g to 43.7 g (approximately 6.4%). This indicates that increasing the binder content reduces moisture loss during drying and contributes to higher final density.

Overall, the results demonstrate that a higher liquid glass content improves mass retention and leads to the formation of denser and more stable briquettes. Binder-free briquettes were not included in the analysis due to their insufficient mechanical strength, which made them unsuitable for comparative evaluation.

Based on the results obtained from the three-drop strength tests performed from a height of 2 m in accordance with the relevant state standard, no significant difference was observed between the briquettes containing 5% and 10% liquid glass. According to the sieve analysis, the yield of the +10/−10 mm fraction ranged from 66–91% for briquettes with 5% liquid glass and from 70–93% for those containing 10% liquid glass.

On average, for briquettes dried in a drying oven, samples with 10% liquid glass exhibited mechanical strength values approximately 1.5–2% higher than those with 5% binder. For briquettes dried at room temperature, the difference was slightly higher, amounting to about 3–4%.

Overall, increasing the liquid glass content from 5% to 10% does not have a significant effect on briquette strength. Based on these results, a binder content of 5% can be considered sufficient and economically optimal for the briquetting of FeSiCr dust under laboratory-scale and industrial conditions. This concentration provides the minimum mechanical strength required for handling, transportation, and furnace charging, while maintaining the economic efficiency of the process.

Table 2. Strength indicators of briquettes with different liquid glass contents

Лақтыру №	Briquettes bonded with 5% liquid glass		Briquettes bonded with 10% liquid glass	
	Dried in a drying oven	Dried at room temperature	Dried in a drying oven	Dried at room temperature
	Sieve analysis, +10/–10, %	Sieve analysis, +10/–10, %	Sieve analysis, +10/–10, %	Sieve analysis, +10/–10, %
1	91,11/8,79	87,36/12,64	93,14/6,86	90,00/10,00
2	83,64/16,36	79,14/20,96	85,32/14,68	81,28/18,72
3	81,27/18,73	66,71/33,29	82,13/17,87	70,12/29,88

Conclusion

In this study, a briquetting technology for FeSiCr dust generated during crushing operations was developed and systematically evaluated with the aim of its use as a reducing agent in the production of chromium–manganese ligatures. The results demonstrated that preliminary briquetting is an effective approach for transforming fine FeSiCr dust into a technologically suitable form for high-temperature metallurgical processing.

Experimental investigations showed that the binder content and drying conditions influence the physical and mechanical properties of the produced briquettes. Increasing the sodium silicate (liquid glass) content from 5% to 10% led to improved mass retention during drying and slightly higher final density. However, the effect of binder content on mechanical strength was found to be relatively limited. The difference in strength between briquettes containing 5% and 10% binder did not exceed 1.5–4%, depending on the drying regime, indicating that a further increase in binder content does not provide a significant technological advantage.

Based on the comparative analysis of drop tests and sieve analysis results, a binder content of 5% sodium silicate was identified as sufficient to ensure the minimum mechanical strength required for handling, transportation, and furnace charging of briquettes. This binder level provides an optimal balance between mechanical stability and economic efficiency, making it more suitable for large-scale laboratory studies and potential industrial application.

Overall, the developed briquetting technology enables the rational utilization of FeSiCr dust as a secondary reducing agent and contributes to improving resource efficiency and sustainability in ferroalloy production. The obtained results provide a solid experimental basis for further studies focused on the metallurgical performance of the briquettes during chromium–manganese ligature smelting.

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ХРОМ-МАРГАНЕЦ ЛИГАТУРАСЫН ӨНДІРУ ҮШІН ТОТЫҚСЫЗДАНДЫРҒЫШ РЕТІНДЕ ФЕРРОСИЛИКОХРОМДЫ ШАҢДЫ БРИКЕТТЕУ

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Аңдатпа. Ферроқорытпа өндірісінде қорытпаларды ұсату кезінде түзілетін ферросиликохром (FeSiCr) шаңы жоғары тотықсыздандырғыш әлеуетке ие ұсақдисперсті екінші реттік материал болып табылады. Алайда оның металлургиялық процестерде тікелей қолданылуы шаңдану шығындарының жоғары болуына және технологиялық қасиеттерінің жеткіліксіздігіне байланысты шектеулі. Осы жұмыста хром-марганецті лигатура алу үшін тотықсыздандырғыш ретінде ферросиликохром шаңын қолдануға арналған брикеттеу технологиясы әзірленіп, кешенді түрде зерттелді.

Эксперименттік брикеттер байланыстырғыш ретінде сұйық шыны қолдану арқылы 5% және 10% мөлшерде дайындалып, кейін табиғи және пештік кептіруден өткізілді. Байланыстырғыш мөлшері мен кептіру жағдайларының брикеттердің физикалық және механикалық қасиеттеріне әсері тастау сынақтары мен електік талдау арқылы тиісті стандарттарға сәйкес бағаланды. Зерттеу нәтижелері байланыстырғыш мөлшерін 5%-дан 10%-ға дейін арттыру кептіру кезінде массаның сақталуын аздап жақсартатынын, алайда оның брикеттердің механикалық беріктігіне тигізетін әсері шектеулі екенін көрсетті. 5% және 10% сұйық шыны қосылған брикеттер арасындағы беріктік айырмашылығы кептіру режиміне байланысты 1,5–4% шегінде болды.

Салыстырмалы талдау нәтижесінде сұйық шынының 5% мөлшері брикеттерді тасымалдау, тиеу және пешке беру үшін қажетті минималды механикалық беріктікті қамтамасыз етуге жеткілікті әрі экономикалық тұрғыдан оңтайлы екені анықталды. Ұсынылған брикеттеу тәсілі ферросиликохром шаңын екінші реттік тотықсыздандырғыш ретінде тиімді пайдалануға мүмкіндік беріп, ферроқорытпа өндірісінің ресурстық тиімділігі мен тұрақтылығын арттыруға ықпал етеді.

Түйін сөздер: ФСХ шаңы, брикеттеу, сұйық шыны, хром-марганецті лигатура, механикалық беріктік, екінші реттік тотықсыздандырғыш, ферроқорытпа өндірісі.

БРИКЕТИРОВАНИЕ ФЕРРОСИЛИКОХРОМОВОЙ ПЫЛИ В КАЧЕСТВЕ ВОССТАНОВИТЕЛЯ ДЛЯ ПРОИЗВОДСТВА ХРОМОМАРГАНЦЕВОЙ ЛИГАТУРЫ

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Аннотация. Ферросиликохромовая пыль (FeSiCr), образующаяся при дроблении товарных ферросплавов, представляет собой мелкодисперсный вторичный материал с высоким восстановительным потенциалом. Однако её прямое применение в металлургических процессах ограничено из-за значительных пылевых потерь и неудовлетворительных технологических характеристик. В данной работе разработана и исследована технология брикетирования ферросиликохромовой пыли с целью её использования в качестве восстановителя при получении хром-марганцевых лигатур.

Экспериментальные брикеты изготавливались с применением жидкого стекла (силиката натрия) в качестве связующего в количествах 5% и 10% с последующей естественной и печной сушкой. Влияние содержания связующего и условий сушки на физические и механические свойства брикетов оценивалось с использованием испытаний на падение и ситового анализа в соответствии с действующими стандартами. Установлено, что увеличение содержания связующего с 5% до 10% незначительно улучшает сохранность массы при сушке, однако его влияние на механическую прочность является ограниченным. Разница в прочности между брикетами с 5% и 10% связующего не превышала 1,5–4% в зависимости от режима сушки.

На основании сравнительного анализа установлено, что содержание жидкого стекла на уровне 5% является достаточным для обеспечения минимальной механической прочности, необходимой для транспортирования, загрузки и подачи брикетов в плавильный агрегат, при сохранении экономической эффективности процесса. Предложенный подход к брикетированию обеспечивает рациональное использование ферросиликохромовой пыли в качестве вторичного восстановителя и способствует повышению ресурсной эффективности и устойчивости ферросплавного производства.

Ключевые слова: ФСХ пыль, брикетирование, силикат натрия, хром-марганцевая лигатура, механическая прочность, вторичный восстановитель, ферросплавное производство.