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Study on the Possibility of Smelting Manganese Ligature from Ferromanganese Ore Beneficiation Tailings

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Abstract. *Amid the growing scarcity of quality mineral resources for the metallurgy, the processing of low-grade ores and residual materials from beneficiation has become increasingly important. This study examines the feasibility of producing manganese ligature from high-silica ferromanganese ore beneficiation tailings from the Ushkatyn III deposit. The aim of the research was to assess the technological applicability of this material for the non-standard manganese ligatures production. Pilot-scale smelting experiments were carried out in a 200 kVA ore-thermal electric furnace. The results showed that smelting of the Ushkatyn III tailings yielded a high-carbon ferromanganese ligature containing 40-55% Mn and 4-6% C. The findings confirm the potential of using ferromanganese ore tailings as an alternative raw material for the high-quality manganese ligatures production.*

Keywords: *manganese ligature, ferromanganese ore, beneficiation tailings, ore-smelting process, low-grade raw materials, phase analysis.*

Introduction

Modern metallurgy is faced with the problem of decreasing availability of high-quality raw materials for ferroalloys production and steel. Undoubtedly, the negative dynamics are influenced by the gradual depletion of deposits and the slow replenishment of the mineral resource base [1]. As of 2023, 20 million tons of manganese ores were mined in the world. The lion's share of global production comes from South Africa (7.2 million tons), Gabon (4.6 million tons) and the United States (3 million tons). At the same time, our Republic accounts for 0.13 million tons [2, 3]. About 60% of the total production comes from high-grade ores with a manganese content of 40-52%, 40% comes from ores with a manganese content of 25-35% [4].

Recent studies emphasize the increasing interest in utilizing low-grade manganese raw materials and man-made wastes. One study highlighted the inefficiency of traditional beneficiation methods for complex ores and the need for alternative approaches [5]. Another demonstrated the feasibility of producing ferromanganese alloys from manganese-containing wastes, confirming the practical potential of secondary resources [6].

With the growing demand for metallurgical products, the comprehensive utilization of mineral resources becomes increasingly important. Low-grade ores have complex mineralogical compositions and a high dispersion of valuable components, which reduces the efficiency of conventional beneficiation methods such as flotation, gravity, and magnetic separation [7, 8]. In the context of a deficit of high-quality raw materials, mining and processing wastes previously considered substandard are gaining interest. At the Ushkatyn III deposit, beneficiation generates large volumes of tailings containing 17-29% manganese, with about 49-50% of the ore mass represented by fine fractions (-10+2.5 mm and -2.5+0.0 mm). These technogenic materials offer potential for producing non-standard manganese ligatures without additional beneficiation, agglomeration or iron removal.

This study aims to experimentally assess the feasibility of producing manganese ligatures with 30-50 % Mn directly from low-grade ferromanganese ore tailings, providing a cost-effective alternative to conventional high-grade ferroalloys.

Materials and methods of research

The raw materials used for the manganese ligatures production included beneficiation tailings from the Ushkatyn III deposit. As reductants for smelting, low-ash coal from the Shubarkol deposit and special coke were employed. Lime was used as a fluxing additive. To study the raw materials and smelting products the following methods were applied: chemical analysis, X-ray fluorescence analysis, X-ray diffraction and ore-thermal electric smelting.

Analyses were conducted at the Zh. Abishev ChMI. The chemical composition of the samples was determined using a vacuum wavelength-dispersive X-ray fluorescence spectrometer, Spectroscan MAX-GVM. The spectrometer operates on the principle of irradiating the sample with X-rays, measuring the intensity of the secondary fluorescent radiation at specific wavelengths, and determining the elemental concentrations based on pre-established calibration curves.

X-ray diffraction analysis of the investigated materials was performed using an Empyrean diffractometer by Malvern Panalytical, located at Abylkas Saginov Karaganda Technical University. The diffractometer is equipped with an X-ray tube with a copper anode. The identification of the diffraction patterns was carried out using the Match! 4 software, which implements the Rietveld refinement method with the FullProf database.

Experimental studies were conducted in a 200 kVA ore-thermal furnace. A furnace transformer of this capacity enables conditions that closely resemble industrial settings, making it possible to determine the optimal process parameters. The design and operating principles of the furnace unit, located in the Zh. Abishev ChMI are described in detail by the authors in reference [9].

Scientific results and discussion

Study of raw material characteristics

Beneficiation tailings of ore from the Ushkatyn III deposit. Table 1 shows the average oxide composition of iron-manganese ore tailings from the Ushkatyn III deposit obtained in the study.

This raw material can be used directly, without additional stages of enrichment, agglomeration and iron removal. This significantly simplifies and reduces the cost of the technological scheme for the manganese ligature production.

The mineralogical composition of the samples is confirmed by the results of X-ray phase analysis, presented in Figure 1 and Table 2.

The results of X-ray phase analysis showed that the ore has a complex multicomponent composition with a predominance of manganese oxides and silicates, which determines the features of its processing and metallurgical stage. The mineral composition is represented mainly by oxide and silicate compounds of manganese with impurities of carbonate and iron-containing phases. The main mineral is hausmannite (Mn_3O_4). This phase is a typical manganese oxide of mixed valence and plays a key role in the formation of the ore substance. A significant content of braunite ($Mn_7O_{12}Si$) and rhodonite ($MnSiO_3$) indicates the active participation of silicate forms of manganese in the mineralogy of the ore. Carbonate minerals are represented by calcite ($CaCO_3$) and rhodochrosite ($MnCO_3$). Among the iron-containing phases, hematite (Fe_2O_3) and bixbyite ($(Mn,Fe)_2O_3$), which is a solid solution form of manganese and iron oxides, were found. The presence of quartz (SiO_2) was also detected.

Reductants. Low-ash coal from the Shubarkul deposit and special coke were chosen as reducing agents for smelting manganese ligatures due to their high carbon content (50.4% and 86.8%, respectively), as well as favorable technical and oxide characteristics, which are presented in Table 3.

Shubarkul coal is characterized by a high yield of volatiles (42%) and low ash content (2.9%), which contributes to the active reduction of manganese oxides and the reduction of slag formation. Ash contains a moderate amount of silica (57.09%) and alumina (22.19%), which allows adjusting the slag composition if necessary. Special coke is characterized by a high concentration of carbon, low content of volatile substances and moisture, which makes it an effective reducing. Its ash contains similar components (SiO_2, Al_2O_3), but in slightly lower concentrations, while it has an increased content of MgO and Fe_2O_3,

Table 1 – Oxide composition of beneficiation tailings

Oxide composition, %						
Mn_{total}	Fe_{total}	SiO_2	Al_2O_3	MgO	CaO	S/P
24.1	11.2	47.7	2.6	1.4	4.9	0.27/0.029

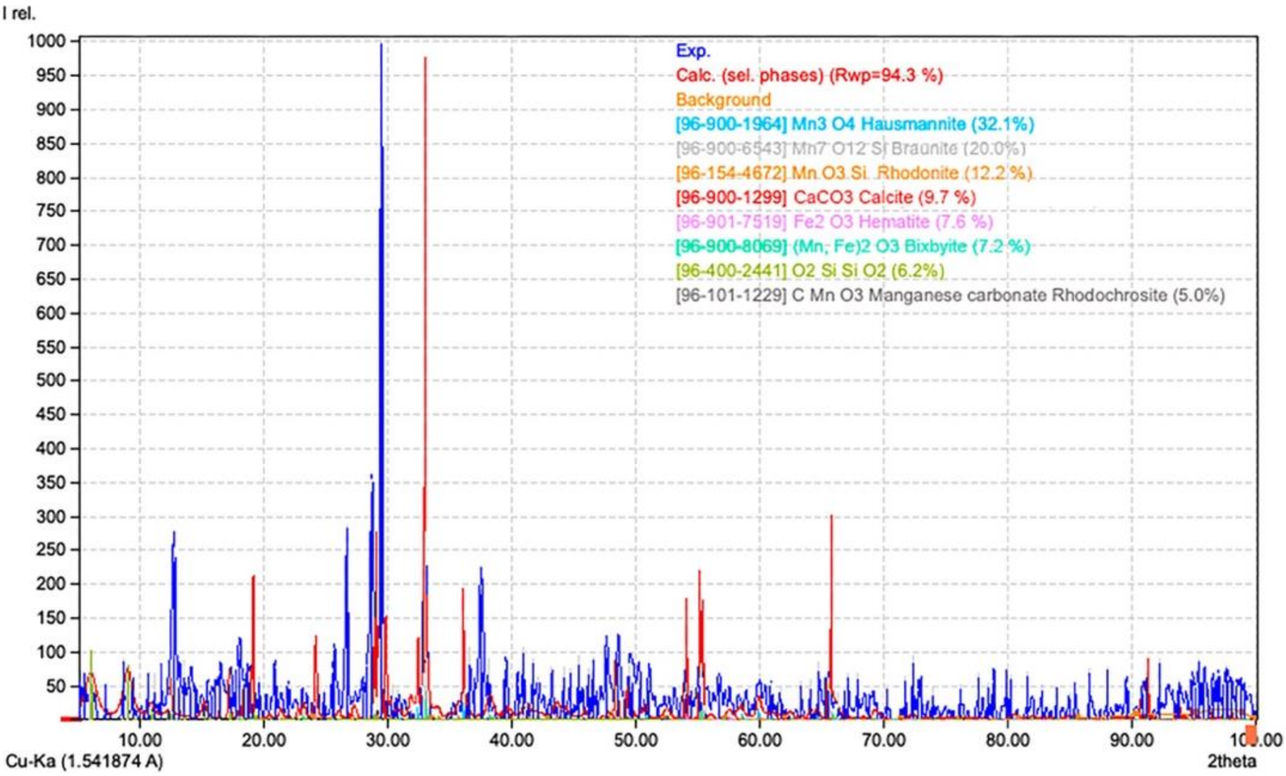

Figure 1 – X-ray diffraction pattern of ferromanganese ore beneficiation tailings

Table 2 – Results of X-ray phase analysis of ferromanganese ore tailings

Name of mineral	Formula	Content, %
Gausmannite	Mn_3O_4	32.1
Brownite	$Mn_7O_{12}Si$	20.0
Rhodonite	$MnSiO_3$	12.2
Calcite	$CaCO_3$	9.7
Hematite	Fe_2O_3	7.6
Bixbyit	$(Mn,Fe)_2O_3$	7.2
Quartz	SiO_2	6.2
Rhodochrosite	$MnCO_3$	5.0

which can affect the composition and properties of the slag.

The selection of these reducing agents ensures the necessary reducing capacity while simultaneously controlling the slag-forming components, which is important for the stability of the melt and the quality of the resulting ligatures.

Results of large-scale laboratory studies

Before the tests, the furnace equipment and charge materials were prepared. The preparation of the charge materials included their crushing and averaging to a certain size. After 12 hours of heating and coking the furnace bath, charge of the charge mixture was loaded. The charge mixture was loaded around the electrode, gradually raising the charge. The smelting was carried out continuously, with the charge being loaded in small portions as the furnace throat settled, with periodic tapping of the metal every 2 hours into cast iron moulds. The taphole was opened with an iron rod. As a result of the tests conducted using beneficiation tailings from two deposits, batches of ligatures were obtained with an average chemical composition reflected in Table 4.

The obtained samples were also examined by X-ray phase analysis to clarify their phase composition. The result obtained on the X-ray diffractometer is presented in Figure 2, Table 5.

X-ray phase analysis of the obtained ligature sample allowed to establish their mineralogical composition and phase distribution pattern depending on the initial raw material. Ferromanganese and carbide phases predominate in the composition of the ligature, which indicates the development of reduction processes involving carbon and the formation of a metal matrix with the inclusion of manganese and iron carbides. Such a composition is typi-

Table 3 – Technical characteristics and oxide composition of reducing agents

Material	Content, %									
	Technical composition				Oxide composition of ash					
	C_{solid}	A	V	W	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	P_2O_5
Shubarkul coal	50.4	2.9	42.0	9.0	57.09	22.19	2.68	2.56	7.11	0.54
Special coke	86.8	5.8	4.3	10.6	60.91	22.31	2.68	4.70	7.53	0.133

Table 4 – Chemical composition of high-carbon ferromanganese ligature

Ligature	Mass content, %					
	Mn	C	Si	P	S	Fe
High carbon ferromanganese ligature	40-55	4-6	6-10	0.1-0.15	up to 0.02	the rest

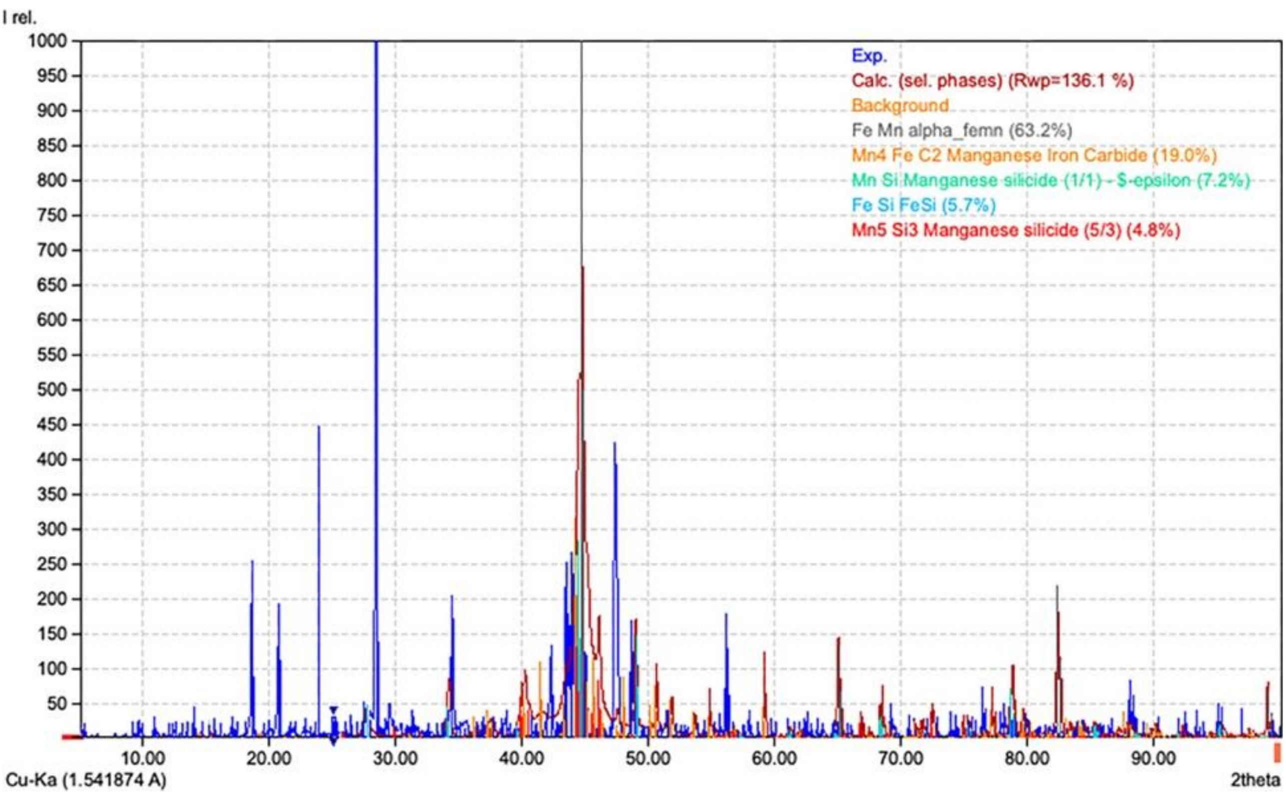

Figure 2 – X-ray diffraction pattern of high-carbon ferromanganese ligature

Table 5 – Phase composition of high-carbon ferromanganese ligature (Ushkatyn III)

Formula / phase	Mass content, %
FeMn (α-femn)	63.2
Mn_4FeC_2	19.0
MnSi	7.2
FeSi	5.7
Mn_5Si_3	4.8

cal for high-carbon ferromanganese alloys and indicates the effectiveness of oxide reduction with moderate participation of silica.

As a result of large-scale laboratory tests on the smelting of manganese ligatures based on ore tailings from the Ushkatyn III deposit, the technological feasibility of obtaining ferromanganese and ligatures without the stage of preliminary enrichment of the raw materials was confirmed. Despite the relatively low manganese content in the initial beneficiation tailings, it was possible to obtain alloy with a manganese content of 40-55 %, which meets the requirements for high-carbon ferromanganese and silicomanganese products. Thus, the obtained results demonstrate the prospects of using beneficiation tailings of poor manganese ores to obtain alloys of various types.

Conclusion

Thus, the obtained results indicate the prospects of using beneficiation tailings of poor manganese ores to obtain manganese ligatures. As a result of the experiments conducted using the ore of the Ushkatyn III deposit, a pilot batch of high-carbon ferromanganese ligature was obtained, containing 40-55% manganese, 4-6% carbon and 3-7% silicon. The obtained results indicate the efficiency of the recovery processes and confirm the potential for using beneficiation tailings as an alternative raw material for obtaining alloys. The absence of preliminary enrichment and agglomeration stages makes the proposed approach economically feasible and resource efficient.

Overall, the proposed manganese ligature can be considered as a viable and cost-effective alternative to traditional manganese ferroalloys, such as commercial ferromanganese. Its production from inexpensive man-made raw materials not only facilitates waste recycling and increases resource efficiency but also allows for the alloying needs of steels that do not require high manganese concentrations, making the resulting composition optimal in terms of quality and cost.

For the final assessment of the practical applicability of the obtained ligature in the steel industry, it is planned to conduct additional pilot industrial smelting and metallurgical tests in an induction furnace. The purpose of these tests will be to determine the influence of the ligature on the chemical composition, structure and operational characteristics of various steel grades.

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Темір-марганец кенін байытудан қалған қалдықтардан марганецті лигатураны балқыту мүмкіндігін зерттеу

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Аңдатпа. *Металлургия үшін сапалы минералдық шикізат тапшылығының артуы жағдайында кедей кендер мен байытудан қалған қалдықтарды қайта өңдеудің маңызы арта түсуде. Бұл зерттеуде Ушкатын III кен орнының жоғары кремнийлі темір-марганец кенінің байыту қалдықтарынан марганецті лигатура өндіру мүмкіндігі қарастырылады. Зерттеудің мақсаты – материалдың стандартты емес марганецті лигатураларды өндіруге жарамдылығын бағалау. 200 кВА қуаттылығындағы рудотермиялық пеште тәжірибелік балқытулар жүргізілді. Нәтижесінде Ушкатын III қалдықтарын балқыту арқылы 40-55% Mn және 4-6% C бар жоғары көміртекті ферромарганецті лигатура алынғаны анықталды. Алынған мәліметтер темір-марганец кенінің отсевтерін жоғары сапалы марганецті лигатураларды өндіруге арналған балама шикізат ретінде пайдаланудың әлеуетін растайды.*

Кілт сөздер: *марганецті лигатура, темірмарганец кендері, ұнтақ қалдықтар, рудотермиялық электрбалқыту, байытылуы қиын шикізат, фазалық құрамы.*

Исследование возможности выплавки марганцевой лигатуры из хвостов обогащения железомарганцевой руды

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Аннотация. *На фоне растущего дефицита качественного минерального сырья для металлургии всё большую актуальность приобретает переработка бедных руд и остаточных продуктов обогащения. В настоящем исследовании рассматривается возможность получения марганцевой лигатуры из отсевов высококремнистой железомарганцевой руды месторождения Ушкатын III. Целью работы являлась оценка технологической пригодности этого материала для производства нестандартных марганцевых лигатур, пригодных для* *легирования сталей. Были проведены укрупнённые плавки в руднотермической электропечи мощностью 200 кВА. Результаты показали, что при плавке отсевов Ушкатын III получается высокоуглеродистая ферромарганцевая лигатура с содержанием марганца 40-55% и углерода 4-6%. Полученные данные подтверждают потенциал использования отсевов железомарганцевых руд в качестве альтернативного сырья для производства высококачественных марганцевых лигатур.*

Ключевые слова: *марганцевая лигатура, железомарганцевые руды, хвосты обогащения, руднотермическая электроплавка, труднообогатимое сырье, фазовый состав.*

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