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Smelting options for carbon ferrochrome based on ore raw materials, middlings and their technological evaluation

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ABSTRACT
The article presents the results of large-scale laboratory tests carried out in the conditions of the Chemical and Metallurgical Institute named after V.I. Zh. Abishev on the use of briquetted mono-charge in the smelting of carbon ferrochrome on a 250 kVA furnace. The purpose of these studies was to determine the technological parameters of the use of briquetted mono-charge containing in its composition chrome ore, wastes from the production of high-carbon ferrochrome, middlings and various carbonaceous reducing agents. The main idea of using these briquettes was to multiply the contact surface of the reductant and ore, which should speed up the technological process. The principal possibility of smelting a standard alloy using briquetted mono-charge is shown. The alloy for individual charge options meets the requirements of the standards. In comparison with the technology without the use of briquettes, the mono-charge technology has shown advantages in all main parameters. The technology with the use of briquettes from the dust of the AktZF gas cleaning system is distinguished by a low yield of non-standard metal and slag, the bulk of the material goes into the gas collection system. Technologies from briquettes from fines pellet production area of Donskoy ore mining and processing plant and flash have very low specific technical and economic indicators and cannot be recommended for industrial use. Improvement of briquetting modes and technology of their smelting is required. The technical and economic indicators were higher than the current one, showed briquettes from ore and coke of the People's Republic of China, briquettes of ore from borlin and shubarkol coals of Kazakhstan.
Keywords: ferroalloy, carbon ferrochrome, mono-charge, reducing agent, slag, briquette.

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Introduction

In the conditions of the Chemical and Metallurgical Institute named after Zh. Abishev, large-scale laboratory tests were conducted on the use of briquetted mono-charge for the smelting of carbonaceous ferrochrome in a 250 kVA furnace. The duration of the experimental company was 9 days. Six variants of briquettes containing various reducing agents were tested. As a comparative variant, the charge materials used at the AktPF were used. A total of 98 swimming heats were held.

The furnace is lined with magnesite brick. The furnace hearth is made of a packed hearth mass that has been coked for 11 hours under current with periodic shutdown of the furnace [[1], [2], [3],

[4]]. The furnace transformer has four voltage stages: 18.2 V; 24.4 V; 36.6 V and 48.8 V. During the experiments, they worked at a voltage of 36.6 V and 48.8 V. The furnace has a graphite electrode with a diameter of 150 mm. The heating of the furnace began on a traditional charge.

After heating the furnace for 0.92 days on a traditional charge, they switched to a charge using briquettes.

The following is a consistent description of the technologies:

1 – traditional charge (China coke+special coke+Borly coal);

2 – briquettes with Shubarkol coal;

3 – briquettes with Borly coal;

4 – briquettes with coke ChNR;

5 – briquettes made of gas cleaning dust;

6 – briquettes from a small product from Pallet Production Site;

7 – briquettes from obloy;

Technical and economic indicators of the smelting of carbonaceous ferrochrome using briquetted mono-charge in enlarged laboratory conditions are shown in table 8.

Calculated part

Stage No. 1 (traditional charge). The tests began with a comparative version, as which the technology was chosen as close as possible to the technology at the Aktobe ferroalloy plant. According to this option, they worked for 0.92 days, carried out 11 melt. The average chemical analysis of melting products during this period was: metal – 67.05% Cr; 1.23% Si; 9.30%C; 0.024%S; 0.012%P; slag – 5.48% Cr_2O_3; 31.05% SiO_2; 0.74% CaO; 44.20% MgO; 17.01% Al_2O_3; 1.12% FeO; 0.215% S; 0.010% P.

The grate worked without fistulas, with uniform gas release over the entire surface of the grate. The charge sits down by self-propelled. The furnace capacity was 155.0 kg Cr/day, chromium extraction was 79.3%.

Stage No. 2 (briquettes with Shubarkol coal). At this stage, smelting was carried out using briquettes with Shubarkol coal in the charge in the amount of 42.4 kg per ear. According to this option, we worked for 0.75 days, conducted 9 melt. The average chemical analysis of melting products during this period was: metal – 69.12% Cr; 0.85% Si; 9.71% C; 0.020% S; 0.011% P; slag – 5.33% Cr_2O_3; 32.16% SiO_2; 1.09% CaO; 42.36% MgO; 17.29% Al_2O_3; 1.28% FeO; 0.206% S; 0.011% P.

The transition to briquettes with Shubarkol coal in general led to an intensification of the process with a more stable current load. The grate worked without fistulas, with uniform gas release over the entire surface of the grate. The furnace capacity was 165.9 kg Cr/day, chromium extraction was 88.17%.

Stage No. 3 (briquettes with Borly coal). At this stage of large-scale laboratory tests, smelting was carried out using briquettes with Borly coal in the charge in the amount of 42.0 kg per ear. According to this option, we worked for 0.5 days, conducted 6 melt. The average chemical analysis of melting products during this period was: metal – 70.28% Cr; 1.21% Si; 9.22% C; 0.027% S; 0.015% P; slag – 4.63% Cr_2O_3; 34.03% SiO_2; 1.10% CaO; 36.08% MgO; 20.57% Al_2O3; 0.35% FeO; 0.210% S; 0.011% P.

The grate worked without fistulas, with uniform gas release over the entire surface of the grate. The charge sits down by self-propelled. The furnace capacity was 152.6 kg Cr/day, chromium extraction was 84.91 %.

Stage No. 4 (briquettes with coke ChNR). In this test period, briquettes from ore fractions of 0-10 mm and coke of the ChNR in the amount of 30 kg per ear were used in the charge. According to this option, they worked for 1.25 days, spent 15 melt. The average chemical analysis of melting products during this period was: metal – 69.4 %Cr; 0.85%Si; 5.83%C; 0.018%S; 0.042%P; slag – 8.29%Cr_2O_3; 27.77% SiO_2; 3.03% CaO; 36.25% MgO; 8.41% Al_2O_3; 1.64% FeO; 0.011% P.

The compressive strength of the briquettes ranged from 154-238 kg per briquette. Such high strength ensured their safety during transportation from Aktobe to Karaganda.

Table 1 – Chemical composition of dust from the gas capture system during the testing of briquettes from the dust of the gas purification of the AktPF

Material	Chemical composition, %								
	MgO	CaO	Al_2O_3	SiO_2	Fe_2O_3	P_2O_5	Cr_2O_3	C	S
Dust from the furnace No. 1	69.74	0.68	3.07	11.98	-	0.033	-	3.21	1.3
Dust from the furnace No. 2	46.74	1.36	5.31	14.1	-	0.044	-	6.05	1.2

Stage No.5 (briquettes made of gas cleaning dust). The use of gas cleaning dust briquettes had very serious distinctive features. The braces themselves were made without the addition of additional binders. The gas cleaning dust itself, when water is added, sets like cement and acquires sufficient strength during subsequent pressing and drying.

During the melting, there was an intense release of dust, unlike other options. Dust was taken from the gas capture system, the chemical composition of this dust is shown in table 1.

As can be seen from these data, the dust is characterized by a relatively high MgO content and high dispersion. It is quite possible to use it as an additive to a mixture for the manufacture of periclase bricks or for a mixture in shotcrete masses for the shotcrete lining of converters. The output of slag and metal was insignificant. As can be seen from this table, the metal is characterized by large fluctuations in chromium and other impurities. It does not correspond to standard compositions and it is almost difficult to implement such a ferrochrome [[5], [6], [7]].

The chemical composition of the slag is also unstable. The output of metal and slag from melting to melting is also unstable, often either slag or metal came out in small quantities. This mode of operation is unacceptable and cannot be recommended for industrial development. At the same time, this technology is of particular interest for further research and possible improvement with the use of electric arc units for remelting steel scrap. Such briquettes can be put into the chipboard furnace together with scrap for direct alloying of steel or cast iron with chromium. The technology is characterized by a high energy consumption per 1 ton of chromium and low other indicators (table 2).

Stage No. 6 (briquettes from a small product from Pallet Production Site). The small product of Pallet Production Site DGOK is a dropout from the site for the production of pellets with a size of less than 5 mm. Currently, this material does not find proper use, although it contains an average of 50 % Cr_2O_3 in its composition. Using this material, we have obtained briquettes. The chemical composition of the briquettes is given in table 3.

Table 2 – Technological parameters of the smelting of high-carbon ferrochrome using briquettes from the dust of the gas purification of AktPF

Name of the articles	Unit of measurement	Parameters
Briquettes consumed	kg	1260
Metal received	kg	277.05
Slag is obtained	kg	226.2
Multiplicity of slag		0.816459123
Melt were carried out	pieces	25
Specific power consumption	kWh/t Cr	22166.3
Specific consumption of briquettes	kg/t Cr	7651.2
Working hours	day	2.17
Efficiency	Cr kg/day	75.95
Average Cr content in the metal	%	59.4

Table 3 – Chemical composition of briquettes from a small product of Pallet Production Site DGOK

Name of materials	Chemical composition, %								
	Cr_2O_3	SiO_2	MgO	CaO	FeO	Al_2O_3	P	S	C
Briquette from the Pallet Production Site	31.8	13.0	14.9	3.5	13.9	6.2	0.01	0.16	11.4

At this stage of large-scale laboratory tests, smelting was carried out using briquettes from the fines of the Pallet Production Site DGOC product in the amount of 30.0 kg per ear in the charge.

According to this option, they worked for 1.83 days, carried out 22 melt. The average chemical analysis of melting products during this period was: metal – 67.5% Cr; 2.09% Si; 5.35% C; 0.003% S; 0.024% P; slag – 9.38% Cr_2O_3; 28.0% SiO_2; 4.94% CaO; 39.24% MgO; 12.67% Al_2O_3; 2.65% FeO; 0.040% P.

The grate worked without fistulas, with uniform gas release over the entire surface of the grate. The charge sits down by self-propelled. The furnace capacity was 114.45 kg Cr/day, chromium extraction was 84.1 %. The main technological parameters are presented in table 4.

The strength of briquettes made of small items of the Pallet Production Site DOK ranged from 43-81 kg per briquette, which is significantly lower than the strength of briquettes made of gas cleaning dust of the AktPF. In addition, this material is heavily subjected to briquetting by the vacuum-extrusion method, the yield of briquettes is not more than 30 % of the total mass of materials passed through the press. In addition, the technology is distinguished by a very high specific energy consumption per 1 ton of chromium (10266.6 kWh/t Cr). The resulting metal complies with the standard. This technology with the use of briquettes from small things of Pallet Production Site DGOK can not yet be recommended for industrial use due to the above negative aspects. It is required to work out the briquetting modes and the technology of conducting the melting process.

Stage No. 7 (briquettes from obloy). Obloy is a fine-dispersed waste from the production of briquettes in the conditions of DGOK. This material does not find proper use, although it also contains an average of 49.96 % Cr_2O_3 in its composition. Using this material, we have obtained briquettes by the vacuum-extrusion method. The chemical composition of the briquettes is given in table 5.

The ratio of reducing agent, ore and binders is presented earlier in table 6.

Table 4 – Technological parameters of the smelting of high-carbon ferrochrome using briquettes from small of Pallet Production Site DGOK

Name of the articles	Unit of measurement	Parameters
Briquettes consumed	kg	1380
Metal received	kg	308
Slag is obtained	kg	458.5
Multiplicity of slag		1.49
Melt were carried out	pieces	22
Specific power consumption	kWh/t Cr	10266.6
Specific consumption of briquettes	kg/t Cr	6637.78
Working hours	day	1.83
Efficiency	Cr kg/day	113.6
Average Cr content in the metal	%	67.5

Table 5 – Chemical composition of briquettes from a small product of Pallet Production Site DGOK

Name of the articles	Chemical composition, %								
	Cr_2O_3	SiO_2	MgO	CaO	FeO	Al_2O_3	P	S	C
Briquettes from obloy	24.8	11.2	19.4	1.1	13.3	5.6	0.04	0.39	9.7

At this stage of large-scale laboratory tests, smelting was carried out using briquettes from the chip in the charge in the amount of 30.0 kg per ear. According to this option, we worked for 0.83 days, conducted 10 melt. The average chemical analysis of melting products during this period was: metal – 61.54% Cr; 1.59% Si; 5.17% C; 0.026% S; 0.033% P; slag – 13.63% Cr_2O_3; 24.27% SiO_2; 3.01% CaO; 41.24% MgO; 10.83% Al_2O_3; 2.78% FeO; 0.057% P_2O_5.

The grate worked unsatisfactorily with frequent emissions. The charge sits down with difficulty. The furnace capacity was 95.57 kg Cr/day; chromium extraction was 72.3 %. The main technological parameters are presented in table 7.

Table 6 – Compositions of experimental versions of briquettes made of chromium ore and carbon reducing agents

Option no.	Type of technology	Materials	Ratio,%
1	Traditional without briquetting	Chrome ore	77.24
		Coke ChNR	9.03
		Shubarkol coal	5.15
		Borly coal	8.58
2	Briquettes with Shubarkol coal	Chrome ore	71.94
		Shubarkol coal	28.06
3	Briquettes with Borly coal	Chrome ore	72.63
		Borly coal	27.37
4	Briquettes with coke ChNR	Chrome ore	74.0
		Coke ChNR	18.5
		Binder	7.5
5	Briquettes made of gas cleaning dust	Gas cleaning dust without additives	-
6	Briquettes from a small product from Pallet Production Site	A small product of Pallet Production Site	71.43
		Coke ChNR	21.43
		Binder	7.14
7	Briquettes from obloy	Obloy	71.43
		Coke ChNR	21.43
		Binder	7.14

Table 7 – Technological parameters of the smelting of high-carbon ferrochrome using briquettes from the chip

Name of the articles	Unit of measurement	Parameters
Briquettes consumed	kg	750
Metal received	kg	129.5
Slag is obtained	kg	502.9
Multiplicity of slag		3.9
Melt were carried out	pieces	10
Specific power consumption	kWh/t Cr	21777.5
Specific consumption of briquettes	kg/t Cr	9417.1
Working hours	day	0.83
Efficiency	Cr kg/day	95.57
Average Cr content in the metal	%	61.5

The discussion of the results

The strength of briquettes made of scrap ranged from 41-67 kg per briquette, which is lower than the strength of briquettes made of gas purification dust of the AktPF. In addition, this material is heavily subjected to briquetting by the vacuum-extrusion method, the yield of briquettes is not more than 20 % of the total mass passed through the press of materials. In addition, the technology is distinguished by a very high specific energy consumption per 1 ton of chromium (21777.5 kWh / t Cr). The resulting metal differs from the standard one. This technology using briquettes made of scrap can also not be recommended for industrial use due to the above negative aspects. It is necessary to work out the briquetting modes and the technology of conducting the melting process [[8], [9], [10]].

Below are the main technical and economic indicators of single-charge technologies, which, in our opinion, can be recommended for industrial testing, since they have significant advantages compared to traditional technologies (table 8).

Table 8 – Technical and economic indicators of carbon ferrochrome smelting with the use of briquetted mono-charge

Indicators	Unit of measurement	Periods			
		Traditional without briquetting	Briquettes with coke ChNR	Briquettes with Shubarkol coal	Briquettes with Borly coal
1. Working hours	day	0.92	1.25	0.75	0.50
2. The number of melt	pieces	11	15	9	6
3. The charge is set					
Dry briquettes	kg		930	555.1	350.1
including chrome ore	kg		688.2	392.5	250.1
content Cr_2O_3	%		50.0	52.5	52.5
it has chromium in it	kg		234.0	141.1	89.9
Coke ChNR	kg		172.05		
Shubarkol coal	kg			162.6	
Borly coal	kg				100.1
Chrome. ores of fr. 0-10 mm	kg	162.9	688.2		
content Cr_2O_3	%	52.5	50.0		
it has chromium in it	kg	58.6	234.0		
Chrome. ores of fr. 10-80 mm	kg	337.9			
content Cr_2O_3	%	52.2			
it has chromium in it	kg	120.6			
Total ore 50% Cr_2O_3		523.7	688.2	412.5	262.8
it has chromium in it		179.2	234.0	141.1	89.9
Quartzite	kg			14.0	
Carbon reducing agents:					
Coke ChNR	kg	56.4	172.05		
special coke	kg	34.0			
Shubarkol coal	kg			162.6	
Borly coal	kg	56.1			100.1
The restorer of everything	kg	146.5	172.05	162.6	100.1
4. Electric power	kWh	1680.0	2448	1408.0	888.0
5. Metal received					
Total	kg	211.9	307.29	180	108.6
	kg Cr	142.1	212.95	124.4	76.3
Chemical composition of the metal					
Cr	%	67.05	69.4	69.12	70.28
Si	%	1.23	0.85	0.85	1.21
C	%	9.30	5.83	9.71	9.22
S	%	0.024	0.018	0.020	0.027
P	%	0.012	0.042	0.011	0.015
6. Slag is obtained	kg	243.5	372.36	176.7	118.0

It has chromium in it	kg Cr	9.13	20.99	6.44	3.74
Multiplicity of slag		1.15	1.21	0.98	1.09
Chemical composition of slag					
Cr_2O_3	%	5.48	8.29	5.33	4.63
SiO_2	%	31.05	27.77	32.16	34.03
CaO	%	0.74	3.03	1.09	1.10
MgO	%	44.20	36.25	42.36	36.08
Al_2O_3	%	17.01	8.41	17.29	20.57
FeO	%	1.12	1.64	1.28	0.35
S	%	0.215	0.204	0.206	0.210
P	%	0.010	0.011	0.011	0.011
7. Technical and economic indicators					
Efficiency	kg Cr/day	155.0	170.36	165.9	152.6
Average melting weight	kg Cr	12.92	14.19	13.82	12.72
Extracting chromium	%	79.30	90.0	88.17	84.91
Specific consumption of materials					
chrome. ore 50% Cr_2O_3	kg/ t Cr	3685.9	3224.73	3315.2	3442.7
reducing agent	kg/ t Cr	1031.2	806.18	1306.9	1311.1
Coke ChNR	kg/ t Cr	397.0	806.18		
special coke	kg/ t Cr	239.3			
Shubarkol coal	kg/ t Cr			1306.9	
Borly coal	kg/ t Cr	394.9			1311.1
Quartzite	kg/ t Cr			112.5	
Specific consumption of electric energy	kWh/ t Cr	11824	11470.69	11317	11635

Conclusions

The technology using briquettes from the dust of the gas purification of the AktPF is characterized by a low yield of metal and slag, the bulk of the material goes into the gas capture system. During these melts, the resulting ferrochrome does not correspond to the standard composition. The dust caught in the gas cleaning system contains a high concentration of MgO, which is a prerequisite for its use in the refractory industry. The technology has low specific technical and economic indicators, especially high power consumption. It is not recommended to use briquettes from the gas purification dust of the AktZF with a complete replacement of the traditional charge, they can be used as an additive to the usual charge in a certain proportion. Technologies made of briquettes from small pieces of of Pallet Production Site DGOK and debris have very low specific technical and economic indicators and cannot be recommended for industrial use. It is necessary to finalize the briquetting modes and the smelting technology.

Technical and economic indicators are higher, compared to the current one, showed briquettes from ore and coke of the People's Republic of China, briquettes from Borlin and Shubarkol coals of Kazakhstan.

Conflict of interests. On behalf of all authors, the correspondence author declares that there is no conflict of interest.

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Кен шикізаты мен өнеркәсіп өнімдері негізінде көміртекті феррохромды балқыту нұсқалары және оларды технологиялық бағалау

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ТҮЙІНДЕМЕ
Мақалада Ж.Әбішев атындағы химия-металлургия институты жағдайында қуаты 250 кВА пеште көміртекті феррохромды балқыту кезінде брикеттелген моношекқұрам қолдану бойынша жүргізілген кеңейтілген зертханалық зерттеулердің нәтижелері келтірілген. Бұл зерттеулердің мақсаты құрамында хром кені, жоғары көміртекті феррохром өндірісінің қалдықтары, аралық өнімдер және әртүрлі көміртекті тотықсыздандырғыштар бар брикеттелген моношекқұрамды пайдаланудың технологиялық көрсеткіштерін анықтау болды. Басты идея осы брикеттерді қолдану барасында тотықсыздандырғыш пен кеннің әрекет ету үрдісін ұлғайту болып табылады. Брикеттелген моношекқұрамды қолдана отырып, стандартты қорытпаны балқытудың негізгі мүмкіндігі көрсетілген. Шекқұрамның жекелеген нұсқалары бойынша қорытпа стандарттардың талаптарына сәйкес келеді. Брикеттерсіз технологиямен салыстырғанда моношекқұрам технологиясы барлық негізгі параметрлер бойынша артықшылықтарды көрсетті. АктЗФ газдан тазарту шаңынан брикеттерді пайдалану технологиясы стандартты емес металл мен шлактың төмен шығысымен сипатталады, материалдың негізгі бөлігі газды ұстау жүйесіне түседі. Дон тау-кен байыту комбинатының шекемтастар өндіру учаскесі мен облойдың ұсақ-түйек брикеттерінен жасалған технологиялар өте төмен техникалық-экономикалық көрсеткіштерге ие және оларды өнеркәсіптік пайдалану үшін ұсынуға болмайды. Брикеттеу режимдерін және оларды балқыту технологиясын жетілдіру қажет. Техникалық-экономикалық көрсеткіштер Қытай Халық Республикасы кені мен коксынан алынған брикеттер, Қазақстанның борлы және шұбаркөл көмірінен алынған кен брикеттері ағымдағы көрсеткіштермен салыстырғанда жоғары.
Түйін сөздер: ферроқорытпа, көміртекті феррохром, моношихта, тотықсыздандырғыш, қож, брикет.

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Варианты выплавки углеродистого феррохрома на основе рудного сырья, промпродуктов и их технологическая оценка

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АННОТАЦИЯ
В статье изложены результаты укрупненно-лабораторных испытаний, проведенные в условиях Химико-металлургического института им. Ж. Абишева по применению брикетированной моношихты при выплавке углеродистого феррохрома на печи мощностью 250 кВА. Целью этих исследований было определение технологических показателей применения брикетированной моношихты, содержащей в своем составе хромовую руду, отходы производсва высоко

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углеродистый феррохром, промпродукты и различные углеродистые восстановители. Главная идея применение этих брикетов заключалась в многократном увеличении поверхности контакта восстановителя и руды, что должно форсировать технологический процесс. Показана принципиальная возможность выплавки стандартного сплава с использованием брикетированной моношихты. Сплав по отдельным вариантам шихты соответствует требованиям стандартов. В сравнении с технологией без применения брикетов моношихтовая технология показала преимущества по всем основным параметрам. Технология с использованием брикетов из пыли газоочистки АктЗФ отличается низким выходом нестандартного металла и шлака, основная масса материала уходит в систему улавливания газов. Технологии из брикетов из мелочи участка производства окатышей Донского горно-обогатительного комбината и облоя имеют очень низкие удельные технико-экономические показатели и не могут быть рекомендованы для промышленного использования. Требуется доработка режимов брикетирования и технологии их выплавки. Более высокие технико-экономические показатели, по сравнению с текущей, показали брикеты из руды и кокса Китайской Народной Республики, брикеты из борлинских и шубаркольских углей Казахстана.

Ключевые слова: ферросплав, углеродистый феррохром, моношихта, восстановитель, шлак, брикет.

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