ACTA METALLURGICA SLOVACA
2024, VOL. 30, NO. 3, 113-119

RESEARCH PAPER

STUDY OF FERROCHROME SMELTING TECHNOLOGY USING BRIQUETTES WITH VARIOUS CARBONACEOUS REDUCERS

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Received: 15.07.2024
Accepted: 03.09.2024

ABSTRACT

This study explores the ferrochrome smelting technology using briquettes with various carbonaceous reducers. The research addresses the significant challenge of dust and fine fractions of raw materials generated during the metallurgical industry's crushing, beneficiation, storage, and transportation processes. Briquettes were produced and tested by agglomerating chrome ore dust with carbonaceous reducers for their mechanical properties and effectiveness in smelting processes. The study concludes that carbonaceous reducers' ash content significantly affects the chrome ore-containing briquettes' thermal stability and electrical conductivity. Low ash content was associated with better performance in the smelting process. Using briquettes with various carbonaceous reducers offers a flexible approach to charge composition, depending on specific production needs and the availability of reducers. The results highlight the potential for improved environmental impact, reduced material losses, and enhanced efficiency in ferrochrome production.

Keywords: ferrochrome; agglomeration; coal; coke

INTRODUCTION

The formation of dust and fine fractions of valuable raw materials during crushing, beneficiation, storage, and transportation presents a significant challenge for the metallurgical industry [1-3]. This issue, while not new, remains relevant due to several factors such as material loss, decreased efficiency of subsequent processing, and increased costs. The use of fine fractions in industrial furnaces and units is problematic as it degrades production processes, smelting, and agglomeration due to their tendency to disperse and cause uneven heat distribution [4-7]. Additionally, dust and fine particles can cause air and water pollution, settle on surfaces, and form suspensions in the air, necessitating additional environmental protection measures and compliance with regulatory requirements.

Preventing such dust formation primarily involves using more advanced installations and equipment, optimizing crushing and beneficiation technology, and more careful storage and transportation of raw materials. However, this entails substantial capital investments for equipment modernization and does not solve the problem of disposing of already-formed dust, including that which is inevitably produced even under these improved conditions.

This issue also exists in the production of ferrochrome and chromium-containing alloys [8-10]. For instance, at the largest plant in Kazakhstan, the Aktobe Ferroalloy Plant (AktZF), fine fractions of chrome ore formed during crushing are stored. Due to their dispersive nature, the direct introduction of this material into the furnace leads to its easy removal by the furnace's gas flows.

Dispersive materials are primarily used in powder metallurgy, mainly in pure powders, with minimal use of dust-like waste [11-14]. Therefore, an effective solution is the agglomeration of chrome ore dust for further use in metallurgical processes [15-17].

The pyrometallurgical processing of fine-grained materials through agglomeration, pelletization, and briquetting is essential for enhancing the efficiency of ferrochrome production and other metallurgical processes. Research has highlighted the significance of improving yield through advanced agglomeration techniques [18] and using fine-grained coke breeze in ferrochrome production [19]. Various methods for agglomerating fine ferroalloy waste materials, including low- and high-temperature pelletization (up to 1500 °C), have been developed. These methods frequently incorporate binders such as sodium silicate, which contribute to producing mechanically robust pellets [20, 21]. Furthermore, recent studies [22, 23] emphasize these techniques' environmental benefits and material recovery improvements, reinforcing their importance in modern metallurgy.

The high Cr_2O_3 content, up to 50%, and the necessity of dust disposal make this material valuable. Since carbon is an effective and accessible reducing agent for chromium oxide ore, agglomeration should be carried out by introducing carbonaceous reducing agents [24, 25].

Comprehensive research is required to select the optimal reducing agent, considering both the reduction and agglomeration processes [26-30].

MATERIAL AND METHODS

Carbonaceous reducers with less than 10 mm particle sizes were selected to produce briquettes. The technical and chemical compositions of the reducers are provided in **Table 2**; calculations were made for the compositions of 6 variants of briquettes: 5 with a 10% excess of carbon required for the complete reduction of the ore (variants № 1 – 5), and one without excess carbon (variant № 6). The results of these calculations are presented in **Table 1**.

Table 1 Compositions of experimental briquettes from chrome ore and carbonaceous reducers

Variant, №	Components	Content, %
1	Chrome ore	78.53
	CPR coke	21.47
2	Chrome ore	80.84
	Special coke	19.16
3	Chrome ore	77.24
	CPR coke	9.03
	Special coke	5.15
	Borly coal	8.58
4	Chrome ore	71.94
	Shubarkol coal	28.06
5	Chrome ore	72.63
	Borly coal	27.37
6	Chrome ore	79.22
	CPR coke	20.78

The ore portion of the briquette consists of chrome fines (less than 10 mm), with the following chemical composition, %: 31.7 Cr, 12.2 Fe, 2.5 Si, 10.9 Al, 34.5 O, 0.002 S, and 0.020 P. The phase composition of the ore consists of chrome spinel (Mg, Fe)(Cr, Al)$_2$O$_4$ and serpentine $3MgO \cdot SiO_2 \cdot H_2O$. The compositions of other raw materials are provided in **Table 2**.

The briquettes were produced at the pilot-industrial site of the Zh. Abishev Chemical-Metallurgical Institute. The materials were manually dosed into cones on floor scales in the specified proportions. Dry mixing of the materials (fraction <10 mm) was carried out in a batch mixer with twin rotors and Z-shaped blades. Liquid glass was used as a binder in the amount of 6-7 % of the dry mass of the mixture. The mixing duration before pressing was 20 minutes, with 5 minutes dedicated to dry mixing. Briquetting was then performed using a ZZXM-4 briquetting press, with a production capacity of up to 2 tons per hour. The total pressure of the briquetting press, according to its technical specifications, is 15 tons. The linear average dimensions of the briquettes were 50×10 mm with a size variation of ± 10%. Experimental batches of briquettes exceeding 1000 kg were produced.

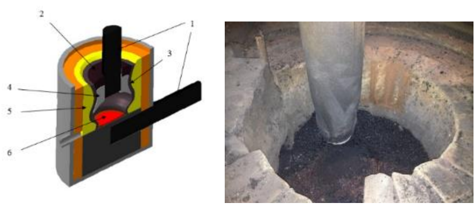
The briquettes were dried in a drying oven at 300°C for 16 hours and under natural conditions at an average temperature of 25°C for three days. Three samples from each variant of briquettes were taken to assess the mixing quality and the uniform distribution of the carbonaceous reducer within the briquettes.

Technological studies of the smelting process of chromium ferroalloy by the carbothermic method were carried out in a large-scale laboratory arc single-phase furnace with a graphite conductive hearth and a power of 200 kVA. The temperature in the arc discharge reaches 3000°C and is maintained by a graphite electrode with a diameter of 150 mm. The furnace is lined with chromomagnesite bricks. The graphical structure of the furnace bath is shown in **Fig. 1**. The furnace was preheated for 12 hours on a coke bed, which acts as an electrical conductor. After the preheating period, the furnace was completely cleaned of the remnants of the coke bed. During the preheating period, the electrical regime was conducted at a secondary voltage of 24.6 V and a high-side current of 150-200 A. During the experiments, the operating voltage was set at 36.6 V.

Table 2 Chemical composition of carbonaceous reducers used for the briquettes

Material	Technical composition, %						Chemical composition of ash, %					Reactivity [31], ml/(g·s)
	C_{solid}	A	V	S	P	W	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	
Coke CPR	61.8	22.5	8.0	0.27	0.013	7.32	43.0	14.7	19.77	9.4	4.25	1.70
Special coke*	71.3	9.5	10.4	0.25	0.012	8.53	47.7	17.8	19.22	4.66	3.15	8.02
Borly coal	41.6	30.2	18.1	0.40	0.010	9.66	59.1	32.9	8.26	0.55	0.39	-
Shubarkol coal	37.1	5.8	41.5	0.46	0.009	15.1	61.2	28.1	3.15	0.23	0.45	-

*Special coke was produced from Shubarkol coal. It is used in the production of various ferroalloys.



1 – electrodes; 2 – initial charge; 3 – zone of softened charge; 4 – transition zone; 5 – wall crust; 6 – melt and metal-carbide overlay

Fig. 1 Structure of the Bath of the Ore-Thermal Furnace with a 200 kVA Transformer

Smelting was carried out continuously, with the charge loaded in small portions as the furnace throat subsided and periodic metal tapping every 2 hours into cast iron molds. The tap hole was opened using an iron rod. Each tap's metal and slag were weighed, and samples were taken for chemical analysis.

RESULTS AND DISCUSSION

Briquette drying

Tables 3 and **4** present the chemical compositions of the briquettes dried in the oven and under natural conditions, respectively. It should be noted that the carbonaceous materials within the briquettes ignited during oven drying. This process continued as the briquettes cooled in the air. There was no intense combustion with flame emission; rather, there was a slow smoldering of the carbonaceous reducers, accompanied by smoke release.

This process was particularly pronounced in briquettes containing Borly coal (variants 3 and 5). Due to the continuous combustion of the carbonaceous materials, the briquettes remained hot for a long time (up to 3 days). When unloading the basket with variant 5 briquettes, a noticeable reddening of the briquettes in the bottom part of the basket was observed. In some briquettes, the reductant was observed to burn off. Surface and internal structure analysis confirmed that the combustion primarily occurred in larger particles of the reductant located on the surface of the briquette. Inside the briquette, only partial combustion took place (**Fig. 2**).

DOI: 10.36547/ams.30.3.2056

Therefore, caution should be exercised in the future when drying carbonaceous briquettes, especially those containing easily flammable coal.

Table 3 Chemical composition of briquettes dried in the oven

№ briquette variant		Chemical composition, %									
		Cr_2O_3	FeO	SiO_2	MgO	Al_2O_3	CaO	S	P	C_{solid}	W
1	1.1	42.39	11.41	11.90	15.61	6.88	0.13	0.071	0.0081	11.05	0,34
	1.2	41.32	12.42	11.80	15.96	7.41	0.13	0.076	0.0081	10.82	0,29
	1.3	42.24	12.66	11.03	15.81	7.14	0.13	0.075	0.0080	10.03	0,42
average composition		41.98	12.16	11.58	15.79	7.14	0.13	0.074	0.0081	10.63	0.35
2	2.1	42.92	9.31	11.60	17.38	6.40	0.81	0.074	0.0081	9.49	0,49
	2.2	43.31	11.11	10.80	15.71	6.36	0.13	0.076	0.0080	9.77	0,50
	2.3	40.87	9.27	10.50	16.79	6.49	0.54	0.063	0.0081	12.83	0,54
average composition		42.37	9.90	10.97	16.63	6.42	0.49	0.071	0.0081	10.70	0.51
3	3.1	42.31	9.20	10.45	17.23	7.62	0.67	0.097	0.0081	10.51	0,54
	3.2	46.66	8.96	11.30	17.82	8.48	1.01	0.095	0.0080	3.82	0,33
	3.3	41.93	9.44	9.40	15.61	6.76	0.14	0.071	0.0081	11.90	0,45
average composition		43.63	9.20	10.38	16.89	7.62	0.61	0.088	0.0081	8.74	0.44
5	5.1	42.70	13.50	11.07	16.69	7.22	0.81	0.064	0.0081	7.07	0,55
	5.2	46.89	12.60	11.90	16.89	8.29	0.13	0.116	0.0080	2.97	0,43
	5.3	42.54	12.40	10.25	16.20	8.20	0.13	0.038	0.0080	8.68	0,81
average composition		44.04	12.83	11.07	16.59	7.90	0.36	0.073	0.0080	6.24	0.60
6	6.1	43.61	12.00	9.87	16.40	7.21	0.27	0.063	0.0080	9.46	0,45
	6.2	44.07	12.24	10.07	16.64	7.60	0.20	0.077	0.0081	8.12	0,47
	6.3	40.26	12.10	9.10	16.50	7.60	0.25	0.084	0.0079	12.62	0,68
average composition		42.65	12.11	9.68	16.51	7.47	0.24	0.075	0.0080	10.07	0.53

As a result of the combustion of carbonaceous materials, the solid carbon content in the briquettes decreased from the expected 15% to 10-11%, and in some cases to 2-3% (variants 3 and 5). This can be explained, among other things, by the high content of volatile substances and the optimal chemical composition of the ash, which does not create significant barriers to coal combustion, and the relatively high carbon content [32-34]. Therefore, the briquettes dried in the oven can be considered unsuitable for use in smelting.

Fig. 2 shows traces of burnt coke on the briquettes dried in the oven. The briquettes dried under natural conditions are characterized by a uniform appearance, with visible preserved coke particles.

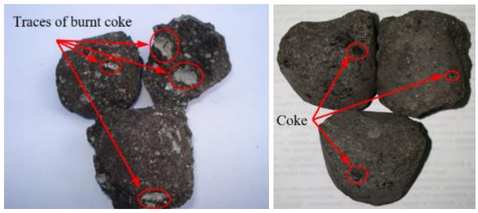


Fig. 2 Briquettes Dried in the Oven (a) and Under Natural Conditions (b)

Table 4 Chemical composition of briquettes dried under natural conditions

№ briquette variant		Chemical composition, %									
		Cr_2O_3	FeO	SiO_2	MgO	Al_2O_3	CaO	S	P	C_{solid}	W
1	1.1	39.34	10.02	10.38	17.40	6.70	0.40	0.052	0.0081	13.38	5,08
	1.2	38.50	9.12	10.06	16.50	6.61	0.50	0.053	0.0080	13.70	3,10
	1.3	38.88	10.07	10.25	16.40	6.61	0.60	0.063	0.0081	13.14	4,87
average composition		38,91	9.74	10.23	16.77	6.64	0.50	0.056	0.0081	13.41	4.35
2	2.1	38.58	10.57	10.35	16.30	6.70	0.50	0.052	0.0080	13.70	6,42
	2.2	38.58	9.93	10.77	16.60	6.35	0.54	0.059	0.0080	14.80	6,02
	2.3	39.15	10.60	11.22	16.50	6.10	0.51	0.059	0.0085	12.88	6,13
average composition		38,77	10.37	10.78	16.47	6.38	0.52	0.057	0.0082	13.79	6.19
3	3.1	37.97	9.82	10.57	15.90	6.78	0.61	0.074	0.0081	14.27	6,12
	3.2	38.58	9.28	10.65	16.19	7.21	0.43	0.069	0.0080	13.70	5,87
	3.3	37.74	10.20	11.05	17.20	7.28	0.45	0.075	0.0080	14.33	5,39
average composition		38,10	9.77	10.76	16.43	7.09	0.50	0.073	0.0080	14.10	5.79
4	4.1	43.61	13.20	9.67	16.84	5.23	0.74	0.051	0.0081	9.69	2,84
	4.2	45.36	12.50	8.07	17.28	6.75	0.67	0.032	0.0081	7.85	4,03
	4.3	44.45	12.31	8.40	16.59	6.84	0.54	0.027	0.0081	8.61	3,98
average composition		44,47	12.67	8.71	16.90	6.27	0.65	0.037	0.0081	8.72	3.62
5	5.1	37.82	10.25	12.40	16.49	7.23	0.40	0.115	0.0084	14.60	6,83
	5.2	35.68	9.78	12.05	15.45	7.38	0.34	0.077	0.0084	15.00	6,08
	5.3	38.65	10.17	12.40	14.86	7.64	0.48	0.090	0.0084	14.40	6,50
average composition		37,38	10.07	12.28	15.60	7.42	0.41	0.094	0.0084	14.67	6.47
6	6.1	39.19	10.80	10.40	17.59	6.86	0.55	0.059	0.0081	13.45	3,50
	6.2	39.80	10.11	10.10	16.93	5.88	0.60	0.072	0.0080	13.90	3,30
	6.3	40.18	9.44	10.10	15.87	6.27	0.62	0.048	0.0080	13.10	3,50
average composition		39,72	10.12	10.20	16.80	6.34	0.59	0.060	0.0080	13.48	3.43

As seen in **Table 4**, the briquettes dried under natural conditions are characterized by a consistent content of solid carbon and overall chemical composition, indicating uniform distribution of the reducer within the briquettes. These briquettes were tested for mechanical strength using standard GOST 21289-2018 methods (compressive strength, drop resistance, impact resistance (GOST 15137-77), and abrasion resistance). The test results are presented in **Table 5**.

Table 5 Briquette strength

№ briquette variant	Strength			
	Compressive strength, kg/cm²	Drop resistance, %	Impact resistance, %	Abrasion resistance, %
1	188.7	95.0	52.7	18.4
2	152.4	92.0	62.0	14.0
3	165.5	97.0	59.3	15.6
4	157.8	92.0	37.7	22.0
5	170.5	99.0	71.7	7.9
6	167.7	96.0	52.0	18.4

The table shows that the briquettes containing carbonaceous materials in all six variants exhibit sufficiently high strength.

Ferrochrome Smelting

A series of tests were conducted for the smelting of ferrochrome using briquettes dried under natural conditions. The resulting briquettes did not disintegrate in the furnace throat. The furnace throat operated without blowholes, with uniform gas release across its entire surface. The charge settled evenly, and the metal tapping proceeded smoothly (**Fig. 3**).

Fig. 3 View of the furnace throat and metal tapping

After preheating the furnace over two smelting cycles with a traditional charge, the process transitioned to using briquette-based charges. The tests were divided into seven periods in the following sequence:
1. Briquettes with a complex reducer (CPR coke + special coke + Borly coal)
2. Briquettes with CPR coke
3. Briquettes with CPR coke without excess reducer
4. Briquettes with special coke
5. Briquettes with Shubarkol coal
6. Briquettes with Borly coal
7. Traditional charge

The chemical composition of metal and slag is shown in **Table 6.**

Table 6 Chemical composition of metal and slag, furnace productivity, and chromium recovery rate.

Stage	Metal composition					Slag composition								Furnace productivity, kg Cr/day	Cr recovery, %
	Cr	Si	C	S	P	Cr_2O_3	SiO_2	CaO	MgO	Al_2O_3	FeO	S	P		
1	68.97	1.03	9.59	0.024	0.0096	8.18	30.15	1.09	41.48	17.35	1.41	0.18	0.011	200.3	82.52
2	66.66	1.23	8.90	0.027	0.0081	10.5	31.38	1.06	40.05	15.30	1.28	0.20	0.011	181.1	79.06
3	68.12	0.79	8.92	0.023	0.0098	13.43	31.28	1.01	37.5	14.63	1.27	0.13	0.011	180.8	74.79
4	66.48	1.12	8.29	0.033	0.0094	12.04	31.25	1.10	38.33	13.82	1.14	0.10	0.011	127.7	-
5	65.65	1.13	8.88	0.029	0.0085	25.09	25.79	1.04	30.73	10.41	4.63	0.08	0.011	49.3	37.7
6	67.31	1.60	9.32	0.025	0.00112	7.97	31.68	0.91	38.47	19.56	1.95	0.23	0.011	159.9	78.72
7	68.61	1.14	8.63	0.033	0.0011	3.72	33.11	0.81	44.16	18.54	0.70	0.24	0.011	175.9	81.95

Stage 1: Testing began with briquettes containing a complex reducer. The briquette composition was identical to the current charge used in the smelting of carbon ferrochrome. The charge during this period consisted solely of briquettes (38.85 kg), composed of: 30.00 kg chrome ore, 3.51 kg CPR coke, 2.01 kg special coke, and 3.33 kg Borly coal. This variant was operated for 0.75 days, with 9 smelting cycles. During this period, the charge descended evenly without collapses, and no disintegration of the briquettes was observed in the furnace throat. The process ran smoothly, and metal and slag tapping were stable.
Stage 2: After completely using the first variant briquettes, we switched to briquettes with CPR coke. The charge during this period also consisted solely of briquettes (38.2 kg), composed of: 30.0 kg chrome ore and 8.2 kg CPR coke. This variant was operated for about a day, with eight smelting cycles. The furnace's operation and the furnace throat's condition during this period did not differ from the previous period. The charge descended evenly without collapses, and no disintegration of the briquettes was observed.
Stage 3: The main goal of producing briquettes without excess carbon (in the other variants, the briquette composition was calculated with a carbon excess coefficient of 1.05) was to achieve lower carbon content in the alloy. The charge consisted of 37.9 kg of briquettes composed of: 30.0 kg chrome ore and 7.9 kg CPR coke. This variant was operated for 0.58 days, with seven smelting cycles. The expected reduction in carbon content in the metal did not occur. The lack of carbon led to an increase in chromium oxide content in the slag to 13.43%, which in turn increased the slag ratio to 1.19 and reduced chromium recovery to 74.79%. Furnace productivity remained at the previous level.
Stage 4: In the following test period, briquettes with special coke were used in the charge, consisting of 37.1 kg, composed of: 30.0 kg chrome ore and 7.1 kg special coke. This variant was operated for 0.66 days, with eight smelting cycles. The use of briquettes with special coke significantly worsened the furnace operation mode. Frequent slagging of the furnace throat, the appearance of blowholes, and unstable current load were observed. As a result, productivity decreased to 127.7 kg Cr/day.
Stage 5: During this stage of large-scale laboratory tests, smelting was conducted using a charge with Shubarkol coal briquettes, consisting of 41.7 kg, composed of: 30.0 kg chrome ore and 11.7 kg Shubarkol coal. This variant was operated for 0.33 days, with 4 smelting cycles. The short test period was due to the extremely unsatisfactory furnace operation mode: frequent slagging of the furnace throat, appearance of blowholes, unstable current load, low metal yield, and high slag output (25.09%). The slag ratio reached 4.4, compared to ≈1 during normal furnace operation. Consequently, productivity decreased to 49.3 kg Cr/day, and chromium recovery dropped to 37.7%. This led to prematurely end the tests with Shubarkol coal briquettes and move to the next test period.
Stage 6: During this stage of large-scale laboratory tests, smelting was conducted using a charge of 41.3 kg of Borly coal briquettes, composed of 30.0 kg of chrome ore and 11.3 kg of Borly coal. This variant was operated for 0.58 days, with 7 smelting cycles. The transition to Borly coal briquettes generally

normalized furnace operation, stabilizing the current load. The furnace throat operated without blowholes, with uniform gas release across its surface.

Stage 7: As a comparative variant, the current charge used at the Aktobe Ferroalloy Plant for smelting carbon ferrochrome was selected, composed of: 20.0 kg lump chrome ore, 10.0 kg fine chrome ore, 2.6 kg CPR coke, 2.0 kg special coke, and 3.3 kg Borly coal. This variant was operated for 0.85 days, with 9 smelting cycles. The furnace throat operated without blowholes, with uniform gas release across its surface. The charge settled by itself. Furnace productivity was 175.9 kg Cr/day, with a chromium recovery rate of 81.95%.

Since special coke made from Shubarkol coal and Shubarkol coal itself in the composition of the briquettes demonstrated poor results during smelting, it can be assumed that this is due to the properties of the original coal. Yet the current lack of comparative data on these properties relative to other reducing agents means that definitive conclusions cannot be drawn.

However, as noted above, special coke is successfully used in the electric arc smelting of other types of ferroalloys.

A techno-economic analysis was conducted based on the results of the large-scale laboratory tests for smelting carbon ferrochrome from briquettes (**Table 7**).

Table 7 Results of the techno-economic analysis.

Indicator	Unit	Stages						
		1	2	3	4	5	6	7
1. Operating time	days	0.75	0.66	0.58	0.66	0.33	0.58	0.85
2. Number of smelting cycles	unit	9	8	7	8	4	7	9
3. Charge input								
Briquettes (dry)	kg	655.6	535.5	492.2	370.9	167.0	453.9	
Including Cr ore	kg	506.4	420.6	389.9	299.8	120.1	329.7	
Cr_2O_3 content	%	52.5	52.5	52.5	52.5	52.5	52.5	
Cr content	kg	182.0	151.2	140.2	107.8	43.2	118.5	
CPR coke	kg	59.2	115.0	102.3	0.0			
Special coke	kg	33.8			71.1			
Shubarkol coal	kg	0.0				46.9		
Borly coal	kg	56.3					124.2	
Cr ore 0-10 mm	kg							162.9
Cr_2O_3 content	%							52.5
Cr content	kg							58.6
Cr ore 10-80 mm	kg							346.9
Cr_2O_3 content	%							52.2
Cr content	kg							123.8
Total Cr ore 50 % Cr_2O_3		532.1	441.9	409.8	315.0	126.2	346.4	533.0
Cr content		182.0	151.2	140.2	107.8	43.2	118.5	182.4
Quartzite	kg		14.0	13.0	10.0	4.8		17.0
Carbonaceous reducers								
CPR coke	kg				2.0	1.2	3.3	61.1
Special coke	kg							34.0
Borly coal	kg							56.1
Total reducers								
CPR coke	kg	59.2	115.0	102.3	2.0	1.2	3.3	61.1
Special coke	kg	33.8			71.1			34.0
Shubarkol coal	kg					46.9		0.0
Borly coal	kg	56.3					124.2	56.1
Total reducers	kg	121.6	115.0	102.3	71.4	28.4	68.3	123.7
4. Electricity	kW·h	1368.0	1080.0	1248.0	1184.0	480.0	800.0	1384.0
5. Metal produced								
Total	kg	217.8	179.3	153.9	126.8	24.8	138.6	217.8
	kg Cr	150.2	119.5	104.8	84.3	16.3	93.3	149.4
Chemical composition of metal	%							
Cr		68.97	66.66	68.12	66.48	65.65	67.31	68.61
Si		1.03	1.23	0.79	1.12	1.13	1.60	1.14
C		9.59	8.90	8.92	8.29	8.88	9.32	8.63
S		0.024	0.027	0.023	0.033	0.029	0.025	0.033
P		0.0096	0.0081	0.0098	0.0094	0.0085	0.0112	0.0110
6. Slag produced	Kg	208.2	185.5	182.7	161.5	109.2	149.3	215
Cr in slag	kg Cr	11.65	13.33	16.79	13.30	18.75	8.14	5.47
Slag ratio		0.96	1.03	1.19	1.27	4.40	1.08	0.99
Chemical composition of slag	%							
Cr_2O_3		8.18	10.50	13.43	12.04	25.09	7.97	3.72
SiO_2		30.15	31.38	31.28	31.25	25.79	31.68	33.11
CaO		1.09	1.06	1.01	1.10	1.04	0.91	0.81
MgO		41.48	40.05	37.50	38.33	30.73	38.47	44.16
Al_2O_3		17.35	15.30	14.63	13.82	10.41	19.56	18.54
FeO		1.41	1.28	1.27	1.14	4.63	1.95	0.70
S		0.18	0.20	0.13	0.10	0.08	0.23	0.24
P		0.011	0.011	0.011	0.011	0.011	0.011	0.011

DOI: 10.36547/ams.30.3.2056

7. Technical-economic indicators								
Productivity	kg Cr/day	200.3	181.1	180.8	127.7	49.3	159.9	175.9
Average weight per smelting cycle	kg Cr	16.69	14.94	14.98	10.54	4.07	13.33	16.60
Cr recovery	%	82.52	79.06	74.79	78.21	37.70	78.72	81.95
Specific material consumption								
Cr ore 50%Cr_2O_3	kg/t Cr	3542.3	3697.4	3908.5	3737.3	7753.5	3713.1	3567.0
Reducer	kg/t Cr	809.6	962.0	975.7	847.1	1747.0	732.1	827.6
CPR coke	kg/t Cr	394.1	962.0	975.7	23.7	73.7	35.4	408.9
Special coke	kg/t Cr	224.8			843.0			227.5
Shubarkol coal	kg/t Cr					2878.01		
Borly coal	kg/t Cr	374.5					1331.6	375.4
Quartzite	kg/t Cr		117.1	124.0	118.6	294.8		113.8
Specific energy consumption	kWh/t Cr kWh/t FeCr	9106.8 6208.9	9036.0 6023.4	11904.2 8109.1	14045.6 9337.5	29481.9 19354.8	8575.3 5772.0	9261.7 6354.4

The benefits of using briquettes compared to traditional charge materials can be seen by comparing variants 1 and 2, which used identical charge materials differing only in their preparation method (briquettes versus traditional charge). The use of briquettes resulted in:
- A 14.1% increase in productivity;
- An 11.5% increase in chromium recovery into the metal;
- A 3.6% saving in reducer consumption;
- A 6.9% saving in electricity consumption.

CONCLUSION

1. The production of briquettes from chrome ore fines and coal allows for the utilization of generated dust and fine fractions, improving the environmental situation at the production site and reducing the loss of valuable components. Drying briquettes at elevated temperatures leads to the combustion of carbonaceous components. Briquettes dried under natural conditions demonstrated high compressive, impact, and abrasion strength, making them suitable for use in production processes.
2. The use of these briquettes ensures stable operation of the electric arc furnace in ferrochrome smelting. The furnace throat operated without blowholes, with uniform gas release across its surface. The best techno-economic indicators were achieved with briquettes containing a complex reducer (CPR coke + special coke + Borly coal), CPR coke, and Shubarkol coal.
3. Using briquettes with various carbonaceous reducers allows for a flexible approach to charge composition depending on specific production tasks and the availability of reducers. Samples of ferrochrome with comparable contents of the main elements were obtained, and in some cases, harmful impurities such as phosphorus (0.011-0.012%) and sulfur were reduced.

Acknowledgement: This research is funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant No. AP19676290)

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DOI: 10.36547/ams.30.3.2056