Conditions for The Preparation of Stable Ferrosilicon Dust Briquettes

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Summary

The article presents the results of the selection of optimal conditions for the preparation of mixture and the briquetting conditions for obtaining stable ferrosilicon dust briquettes. The dust of 0–3 mm grain size fractionswhich are residues (by-products) of ferrosilicon melting processwas analyzed. Briquetting of dust allows obtainingvery solid agglomerates. The method of material preparation was to add a particular quantity of binder to dust and mixing them carefully. An adhesive of the water glass withor without addition an aqueous solution of starch were used. The addition of water glass to ferrosilicon in the amount of about 6% allows manufacturing tough briquettes, however, the application of adhesives in the form of a mixture of water glass (about 2.0%) and starch (about 3.0%) found to obtain higher strength parameters. Finding the binder allowed to develop of industrial production technology of high-quality ferrosilicon briquettes, which are suitable for use in domestic and foreign steel foundries. Briquettes are not to crumble and dissolve easy when adding for melting to recovery of silicon.

Keywords: ferrosilicon, briquettes, water glass, starch.

Introduction

Ferrosilicon (FeSi) is used in steel industry and casting as a deoxidizer and an alloying component in the production of steel and cast iron as a modifier, which is added in the process of meltEng. Steel made with addition of ferrosilicon is used in the production ofwire-cord meninges, ball bearings, metal cores of electrical transformers, etc.

Ferrosilicon is produced in a low shaft, three-phase arc-resistance furnaces, in aform of alloy,which is subsequently cast and crushed or granulation in water, drying and screenEng. Ferrosilicon is produced in several varieties of grain size of the particulate (0–0,03 mm) to coarse (10–80 mm) and a silicon content of from 41% to over 75% but not exceeding 96%. Manufacturers also produce dust ferrosilicon briquettes (Ø 60×35 mm) with 0–3 mm grain size fraction, based on the addition of water glass [1].

Production of ferrosilicon is an energy intensive process associated with high consumption of electricity and raw materials, such as ore, quartz/quartzite, fluxes and reducing agents as coke, coal and biomass. The production of ferrosilicon also generates residues, which are by-products, such as filter powders (silica fume),sludge from scrubber and slag from the melting process.

Convenient and economical way of using ferrosilicon dust is also the briquetting and pelleting [2, 3]. A large pressing force causes the briquettes are strong, they do not crumble andquickly dissolved in liquid bath, bringing a higher yield than standard silicon.

The aim of research was to determine the optimal conditions for the preparation of and conditions for briquetting to achieve sustainable ferrosilicon dust briquettes for use in the steel industry and iron foundries.

Materials for briquetting

There were used to briquetting tests dusts and ferrosilicon powders grain of size from 0 to 3 mm, manufactured at HutaŁaziska and ferrosilicon mixes with the addition of silicon metal. Their basic characteristics are given in Table 1.

Grain size of the analyzed material is appropriate touse in briquetting, when it meets the general principle that the grain size should not exceed 0.10 parts of the smallest dimension of the future briquettes. For briquetting materials with larger grain size of the material is required to meet the requirements of a stack of grain or contain an excess of dusty fraction.

In the process of preparing fine ferrosilicon to merge selected binders tested in earlier studies at the briquetting of carbonaceous substances, dust and ash, gypsum and iron-bearing waste [4, 5, 6]. These are:

- water glass,
- starch binder.

For tests of selected sodium water glass (aqueous solution of sodium silicate with the chemical

Tab. 1 Characteristics of ferrosilicon and silicon dust for briquetting with the addition of water glass and starch binders

Tab. 1 Charakterystyka fizykochemiczna pyłów żelazokrzemu i krzemuprzeznaczonych do brykietowania z dodatkiem szkła wodnego i spoiw skrobiowych

Wyszczególnienie Specification	Żelazokrzem Ferrosilicon			Mieszanina żelazokrzemuz krzemem A mixture of ferrosilicon and silicon		
	S	W	Z	FeSi/Z	FeSi/N	Si
Zawartość, %: Content in %:						
FeSi	75	70	68,5	79,4	90	96
Ca	0,25	–	–	–	0,28	0,28
Al	1,80	2,00	0,30	–	0,33	0,33
P	0,035	0,03	0,03	–	–	–
S	0,01	0,03	0,02	–	–	–
Zawartość wody, % Water content in %	<1	<1	<1	<1	20	<1
Uziarnienie, mm Granulation in mm	0–3	0–3	0–1	0–1	0–3	0–1
Rodzaj spoiwa uzupełniającego dla szkła wodnego Type of supplementary binder for waterglass	Borcet	skrobia ziemniaczana potato starch	Borcet	Borcet		

formula: $Na_2O•nSiO_2•nH_2O$) type 149 manufactured in the Chemical Plant "Rudniki" S.A. It has the form of opaque liquid without odor of 1,49–1,51 g/cm3 density and nutrient content of $Na_2O$and SiO_2in total 42.5%.

In studies using potato starch as a standard Superior Standard produced in the Potato Processing Plant "BEST" SJ, whichis a white, amorphous powder, tasteless and odorless and insoluble in cold water. The starch granules have a diameter from 2 to 120 microns, an ash content in the dry matter is not more than 0.35%, a pH of 5.5–7.5 and a relative humidity of not more than 20%. Moreover, thereused Borcetbinder, produced of the Chemical Factory BOCHEM Sp. z o.o. being a cationic polymer obtained by chemical treatment of corn starch.

Properties listed binder materials stems from their ability to reduce surface tension differences between the substrates, which under pressure briquetting process leads to the adhesive and cohesive merge and create the feed pellets [7]. At the same time, due to physical phenomena, in particular the temperature increases, the chemical reactions between the substrates, including:

- water glass ($Na_2SiO_3 = Na_2O.nSiO_2$) + iron compounds (X = Cl, S, O):

$$2FeX_3+3Na_2SiO_3 \rightarrow Fe_2(SiO_3)_3+6NaX$$

where:
$Fe_2(SiO_3)_3$ – iron metasilicate, insoluble in water, readily crystallizes to form a "reinforcement" of briquettes;

- water glass + saccharose (sugar $C_6H_{12}O_6$; starch = polysaccharide):

$$Na_2O.nSiO_2+H_2O \rightarrow 2NaOH+nSiO_2$$
$$NaOH+C_6H_{12}O_6 \rightarrow H_2O+C_6H_{11}O_6Na$$

The result of chemical reaction is a gel binding of individual grains in the following monolith [8, 9]:

$$2C_6H_{11}O_6Na + nSiO_2 + C6H_{11}O_6Na$$

The chemical reactions are endothermic first, and then pass in a strongly exothermic. The heat source is typically occurring phenomenon of friction in the mixing process, and briquettEng. In the process of formation of the briquettes is expedient, however, additional heating for the acceleration of curing by chemical reaction. For a permanent briquettes is also essential to provide pressure to the feed of briquetting of at least 150 kG/cm^2.

Research installation and methodology

Ferrosilicon briquetting carried out in three manufacturing plants installations designed and manufactured by the company Eco-Invest and Ecocoal Consulting Center. The production line includes:

- a planetary mixer,
- conveyor belt dispensing a mixture of ferrosilicon to the hopper of the briquetter,
- hopper tank,

- briquetting-roll driven by an electric motor gears,
- conveyor belt for drainage of briquetting products.

A photograph of an industrial producing plant of ferrosilicon briquettes is shown in Figure 1.

The material assumed to briquetting was plastic consistency of density up to 20% hydration, which provided a small friction force values in briquetting process. The method of preparation was to add the material to a given quantity of dust binder and mixing them thoroughly. Selection of the binder was performed experimentally in the laboratory and under production conditions was verified. Laboratory tests were carried out for one-component adhesives (water glass in different proportions), and two-component (water glass and a starch in an aqueous solution).

To optimize the ferrosilicon briquetting process were tests performed in several variants, the selection and the use of binders. The tests consisted of adding to a portion of ferrosilicon dust in a planetary mixer running, fixed dose binder. The mixture was stirred from 5 to 20 minutes, noting the increase in temperature and solidification of the feed build-up. In cases of high chemical reactivity of the ingredients, feed homogenization time was shortened accordingly. Prepared feed of ferrosilicon fed to the tray above the briquetting machine and then briquetted.

The effects of briquetting assessed the amount of generated solid and broken briquettes and the amount of not briquetted feed. In addition, the determined temperature and external shape of the surface of fresh briquettes.Pellets were subject to further measurements of temperature and mechanical strength as a function of time during transport and storage.

Briquettes were sent to test the mechanical strength of the damping method, commonly used for the valuation of briquettes obtained from metal-bearing materials. The study consisted of 10 pellets dropping from a height of 1.5 m on a steel backing and an taxation of their condition after discharge.Based on the results of experiments were determined that sufficient strength characterized by briquettes, which will not be destroyed after 3-fold expulsion cycle.

In addition to these tests and studies related to the manufacturing process the examination ofthe status and properties of briquettes as a function of time of aging and atmospheric effectswas carried out.

Results

Various tests allowed to determine the effect of water glass on the strength of ferrosilicon dust briquettes “S” (Table 1). In the same water glass binder an amount of 5.8, 9.0, 20 and 35% at room temperature and in an amount of 6.5% at 60^{o}C was tested. The test results are shown in Table 2

It is noted that the same water glass binder in the share to 10% ismixed quite difficultly in the analyzed material. Binder-component of water glass and starch to well moisturizing ferrosilicon grains and provides faster hardening of briquettes.

In this field of addition of water glass all resulting briquettes showed a damping resistance of briquetting on ramps spaced about 30 cm. All pellets, except forbriquettes with the 35% addition of water glass, after 72 hours seasoning resistance characterized by a full damping resistance. A series of these tests revealed that for the preparation of permanent ferrosilicon dust briquettes “S” it was 5.8% additionof water glass. A further increase of water glass in the feed, with no significant effect on the strength of the damping briquettes.

Tests were also performed with the “Z” typeferrosilicon briquetting (Table 1), under comparable con-

Fig. 1 Industrial line for ferrosilicon briquettes production

Rys. 1 Przemysłowa linia do produkcjibrykietowanego żelazokrzemu

Tab. 2 The effect of addition of water glass on the parameters of the mixture and the dumping strength of "S" type ferrosilicon briquettes

Tab. 2 Wpływ dodatku szkła wodnego na parametry mieszanki oraz wytrzymałość brykietów z pyłów żelazokrzemu typu „S"

Parametr Parameter	Zakres oceny od – do Range from – to	Udziałszkławodnego, % The share of water glass in %						
		0	5,8	6,5 (60 oC)	9,0	20	35	13,6 +5,7% Borcet
Konsystencja Consistency	sucha (1) – mokra (5) dry (1) – wet (5)	1	2	2	2	4	5	5
Urabialność Workability	trudna (1) – łatwa (5) difficult (1) – easy (5)	1	2	3	3	4	5	5
Zagęszczalność Compactability	mała (1) – duża (5) small (1) –large (5)	1	3	3	3	4	3	5
Odporność na zrzut: Dumping strength: - *in statu nascendi* z 30 cm - from 30 cm	zła (0) – dobra (+) bad (0) – good (+)	0	+	+	+	+	+	+
- po sezonowaniu 72 godz. - after 72 hours seasoning	mała (0) – duża (10) small (1) –large (5)	0	10	10	10	10	3	10

Tab. 3 Effect of binder for efficiency of "W" type ferrosiliconbriquetting

Tab. 3 Wpływ udziału spoiwa na wydajność procesu brykietowania żelazokrzemu typu „W"

Udział roztworu spoiwa w nadawie, % The share of the binder in the feed in %	Udział składników spoiwa w przeliczeniu na masę pyłu, % The proportion of the binder relative to the weight of dust in %			Wydajnośćprocesubrykietowania, % Efficiency of briquetting in %
	szkło wodne water glass	skrobia starch	woda water	
6,5	1,3	2,0	3,3	30
7,5	1,6	2,2	3,7	40
9,1	1,8	2,7	4,5	60–70
9,9	2,0	3,0	4,9	80–90
15,2	0,8	2,5	11,9	1–3

ditions, with the addition of water glass in an amount of from 5% to 10%. Material prepared in a planetary mixer to which the water glass was sprayed, and stirred until the formation of granules on the surface of the mixture. Exceeding the optimum mixing time can lead to feed solidification, which makes the process of briquetting difficult and threatens damage to the briquettEng. Mixing time of "Z" type ferrosilicon with the addition of 8% water glass ranged from 8 to 10 minutes. In the case of temperatures below 8°C the mixing time should be twice longer.

Briquetting ferrosiliconmixture "Z" type with water glass obtained briquettes undergoing rapid solidification while a sudden increase in the temperature to above 80 °C. The efficiency of the process of creating full and mechanically strong briquettes exceed 85%.

In the case of recycle scrap and subgrain to the mixer the solidified material must be separated.

Investigation of the effect of the bicomponent binder (water glass + starch binder) on the briquetting process and the properties of briquettes was conducted with three kinds ferrosilicon (“S”, “W” and “Z”) and a mixture of metallic ferrosilicon (Z + N + Si).

In trials conducted “S” type ferrosilicon briquetting with a mixture of binders (water glass 13.6% and Borcet 5.7%) was obtained briquettes with the highest dumpstrength. In this process, the feed preparation were easier by improving wetting, as compared to the feed of waterglass (Table 2).

Ferrosilicon briquetting of “W” type was composition tested and the amount of the multi-component binder, consisting of potato starch, water glass and water. Rated briquetting process yield as a proportion of unbroken pellets in relation to the feed (Table 3).

The results demonstrate that the best result is obtained ofbriquetting ferrosilicon dust with about ten percent of the binder consisting of water glass and starch (Fig. 2). The yield briquetting exceed 80%. It was found thatthe volume of added water in the binder mixtureis significant.

The resulting briquettes were dumpingtested after 20, 60 and 120 minutes after their preparation and after 3, 5 and 45 days of seasoning (Table 4). It turned out that the briquettes after an hour of their production have reached a full and the last dumpstrength.

It was found that green briquettes have an elevated temperature, which further increased to a temperature above 80°C in about 90 minutes, as a result of exothermic reactions. After two hours of seasoning sufficient strength of briquettes was obtained, and after two days, there was a significant reduction in the moisture content from about 10% to about 3%. In these briquettes, parallel longitudinal cracksafter three days appeared. Despite the occurrence of cracks, briquettes meet the test multiple trips shots performed in the period from 2 to 1080 hours of storage.

Under this test cycle was performed as research impact solution temperature binders briquetting process ferrosilicon. Adding to partially dry the gelled ferrosilicon resulted in shortening of the heated solution feed preparation time and increasing the quantity of briquettes undamaged. In determining the appropriate composition, temperature and mixing time solution adhesives, achieved the best performance briquetting process (above 95%) and ferrosilicon briquettes of very high resistance of the discharge (briquettes withstand multiple discharges from a height of 10 m).

In case of briquetting mixtures ferrosilicon with metallic silicon dust (Table 1) using a binder consisting of water glass and starch (Borcet), it was necessary to carry out further research to develop a process optimization procedure. Differences in briquetting procedures resulted from differences in surface properties and water content of the components of mixtures for briquettEng.

In all described ferrosilicon briquetting experiments, subgrain and solidified material was returned to the mixer to make up the feed. It has been found that the recycling of the highly positively briquetting performance affect and increase the strength of briquettes. Intensification of these processes is a result of the pressure forces to briquetting and the processing time increases, leading to an increase in the tempera-

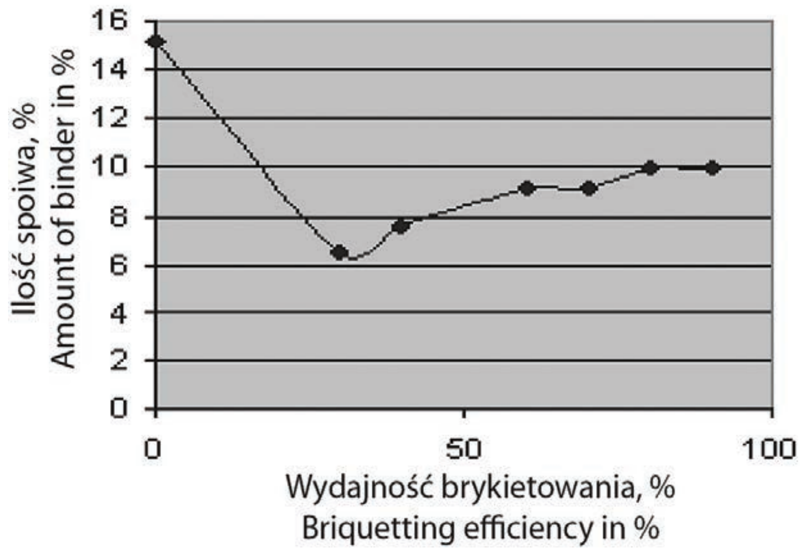

Fig. 2 Effect of binder for efficiency ofbriquetting

Rys. 2. Wpływ ilości spoiwa na wydajność procesu brykietowania

Tab. 4 Effect of seasoning time on the dumping strength of "W"type ferrosilicon briquettes

Tab. 4 Wpływ czasu sezonowania na wytrzymałość zrzutową brykietów żelazokrzemu typu „W"

Nr próby Sample No	Czas sezonowania, h Seasoning time in hours	Odporność na zrzut, % / ilość zrzutów Dumping strengthin % / number of shots	Zawartość wody, % Water content in %	Uwagi Comments
1	0,3	80	9,9	brykiety prawidłowo ukształtowane, parujące properly shaped briquettes, evaporating
2	1,0	100 / 1	–	brykiety parujące, dalszy wzrost temperatury briquettes evaporating, a further increase in temperature
3	2,0	100 / 5	–	brykiety ciepłe warm briquettes
4	24	–	2,8	–
5	48	–	2,5	–
6	72	100 / 14	2,2	pęknięciairysy cracks and scratches
7	96	–	1,9	–
8	120	100 / 10	1,6	ubytki na powierzchni surface defects
9	1080	100 / 12	–	bez zmian no change

ture and the development of exothermic reactions.

In terms of industrial production, sometimes it was appropriate to revise the composition of compound binder and adapt them to the actual characteristics of the raw materials and the implementation of the briquetting process (prolongation of time of receipt of briquettes, increasing the temperature of the briquettes, etc.).

On the basis of the examinations and tests to verify the results of research, launched three industrial briquetting installations of production ferrosilicon for domestic and foreign foundries and steel.

Discussion

Analyzing the results of laboratory tests and production it was found that possible reduction of the amount of binder administered to approximately 6% provided an improved system of adhesive dispensing and humidification ferrosilicon dust. The resulting mass briquetting should have the consistency of thick-plastic. In briquetting, other types of materials, such as ferro-waste, coal ashes and mules from the combustion of fuels, etc., were also found as optimum binder content at ranges from 6% to 8% by weight of the compound [4, 5, 6, 10, 11].

Briquettes obtained from the roll press in the form of fresh had relatively low resistance to gravity dump. The process of bonding the material to achieve full strength went from a few minutes to a few days of seasonEng. Similar results were obtained in other studies [12, 13], where it was stated that it is not always too long seasoning that is beneficial and can be the cause of the briquettes destruction [4].

To eliminate destruction of green briquettes the process of receiving the briquetteswasmodified, so that after leaving the fresh briquettes briquetting forming pits falling chutes flexible or elastic sieve and then with a fixed conveyor belt speed and appropriately-selected length, guaranteeing termination briquettes curing reaction. It is also necessary to eliminate multilayered fresh briquettes to eliminate their mutual sintering and to ensure good heat transfer (cooling or thermal insulation).

Briquettes solidification process is highly exothermic and the temperature rise was observed during 90 minutes to a value above 80°C, and then this temperature is maintained for 30–40 minutes. This was accompanied by eye-visible surface cracking briquettes, formed cracks and longitudinal stratification. A similar phenomenon occurred in clinical briquetting process of fine-grained iron-bearing waste with the addition of a binder with acetic acid [4], which led to the almost total destruction of the briquettes. In these trials while the exothermic reaction in briquettes gradually weakened, and the resulting damage to the structure is not visibly affected by a reduction in the strength of the briquettes.

The strength of briquettes was determined using gravity discharge test (multiple attempts to dump from a height of 1.5 m), which takes into account the conditions of loading, transport and unloading without losing briquettes coherence [6]. Other criteria for evaluating the strength of the briquettes on the basis of two tests are also used[10, 12]:

1. resistance to the gravity dump from a height of 2.0 m on steel or concrete base,
2. measurement of punch force causing the destruction of briquettes in the endurance testing machine.

The results of both tests were considered together and used to evaluate the mechanical strength of the briquettes produced in a roll press. The results obtained in these tests are difficult to compare with the reported in the literature, since no researchof strength in testing machine were performed, likeof mineral aggregates and artificial and auxiliary casting materials. Without going into the differences in quality assessment methods, it should be noted that the dump method have been accepted to control in the production process and the quality of ferrosilicon briquettes intended for domestic and foreign customers.

Studies confirmed the significant impact the value of feed compaction and the force of the pressures in briquetting process on the mechanical strength of briquettes [14, 15, 16]. Briquette strength increases with value of compaction [4].

Conclusions

Based on the tests and analysis of the results the following conclusions were drawn:

1. To obtain ferrosilicon briquettes using a dust and/or sand fraction is preferred to use a water glass as a binder or a mixture of water glass with the starch. Binders are to be added by spraying on the surface of ferrosilicon.
2. To ensure good merging of grains in the briquettes, fine-grained fractions of ferrosilicon should not be larger than 0.1 parts the smallest dimension of briquette.
3. The addition of water glass to ferrosilicon in an amount of about 6% guaranteed to create tough briquettes. Feed preparation process requires an particularly comprehensive mixing of the ingredients. The mixing time is usually from 5 to 20 minutes. At the end of the mixing a noticeable rise-in temperature and the bumps formation on the surface of the mixture has been found.
4. As a result of temperature expanding and water intense evaporation as well, briquettes are cracking, creating gaps and surface delamination which, however, did not affect for dumping resistance.
5. The use of mixtures of binders as a water glass and starch to provide ferrosilicon dust briquetting receiving the pieces with highest strength parameters. The maximum efficiency of briquetting obtained with 1.8 to 2.0% added water glass and 2.7 to 3.0% of starch.
6. Developed technologies of ferrosilicon dust briquettes with the required mechanical strength applied to industry and were the basis to start the three industrial plants that produce briquettes of high quality for the foundries and steel mills.
7. It is advisable to conduct further research on ferrosilicon dust briquetting using reduced quantities of binders and to determine the effect of surfactants on the process of preparing the feed.

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Streszczenie

W artykule przedstawiono wyniki badań nad doborem optymalnych warunkówprzygotowania mieszanki i brykietowania dla uzyskania trwałych brykietów z pyłów żelazokrzemu. Analizowano pyły o frakcji ziarnowej 0–3 mm, które stanowią pozostałości (produkty uboczne) procesu wytapiania żelazokrzemu.Brykietowaniepyłów umożliwiło uzyskanie bardzo zwartych aglomeratów. Sposób przygotowania materiału polegał na dodaniu do pyłów określonej ilości spoiwa oraz dokładnym ich wymieszaniu. Stosowano spoiwa z samego szkła wodnego oraz z dodatkiem skrobi w roztworze wodnym. Stwierdzono, że dodatek szkła wodnego do żelazokrzemu w ilości ok. 6% gwarantuje tworzenie trwałych brykietów, jednakże zastosowanie mieszaniny spoiw w postaci szkła wodnego (ok. 2,0%) i skrobi (ok. 3,0%) zapewnia otrzymanie brykietów o wyższych parametrach wytrzymałościowych. Dobór spoiwa umożliwił opracowanie technologii przemysłowej produkcji wysokiej jakości brykietów z pyłów żelazokrzemu,które nadają się do wykorzystania w krajowych i zagranicznych odlewniach stali. Brykiety te nie kruszą się i łatwo rozpuszczają w przypadku dodania do wytopu w celu odzysku krzemu.

Słowa kluczowe: żelazokrzem, brykiety, szkło wodne, skrobia