Application of bentopolymer composition as a binder to improve metallurgical properties of iron ore pellets

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The results of the experimental studies of metallurgical properties of iron ore pellets obtained using bentopolymer binders are presented in this article. Agglomeration of iron ore concentrate is a necessary operation to ensure the required permeability of the charge column and the strength of the material during its processing in a shaft furnace. Among the requirements for the quality indicators of pellets in terms of chemical properties, the key ones are the maximal iron content and the minimal silicon dioxide content. Optimization of their composition and structure is one of the important aspects of improving the quality of pellets. Development of new binders and roasting technologies allows creating pellets with improved characteristics, which contributes to increasing the efficiency of the blast furnace process and reducing pollutant emissions. In this work, the bentopolymer composition BPC-1A was used as a binder, the main component of which is high-quality natural sodium bentonite from the Dash-Salakhli deposit (Republic of Azerbaijan), the polymer part is represented by polyacrylamide. The studies were performed on four samples of roasted pellets with a binder consumption of 6–8 kg/t. The optimal granulometric composition of the pellets (the yield of −12+10 mm class was 75.6 % against the basic 69.8 %) was obtained while using the BPC-1A binder in the amount 7 kg/t. The highest value of the hot strength index according to ISO 13930-2015 was 97.16 % also at a dosage of 7 kg/t. Based on the totality of the obtained results of laboratory studies, the bentopolymer composition BPC-1A at a dosage of 7 kg/t of pellets can be recommended for pilot testing at Stoilensky mining and concentrating plant.
Key words: iron ore concentrate, pelletizing, bentonite, bentopolymer compositions, strength of iron ore pellets.
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Introduction

Iron ore production is one of the main strategic goals of Russia, which occupies the first place worldwide for iron ore reserves, with only 9 % of them presented by rich ores. Since the middle of the previous century, the deposits of poor ores (mainly ferriferous quartzites) make the base of the Russian iron ore industry [1].

Depletion of the reserves of rich iron ores and transition to mastering the deposits with low Fe content need more deep processing of raw materials. Tonnage of grinding and specific furnace of the obtained iron ore concentrate increase during the process of multi-stage grinding, which is accompanied by gangue removal. Additional concentration of magnetite concentrates for obtaining superconcentrates is also connected with additional grinding of material, what leads to reduce of final product coarseness before agglomeration.

Agglomeration of iron ore concentrate is the necessary operation for providing the required permeability of the charge column and the material strength during its processing in a shaft furnace. Sinter and/or pellets are used in blast furnace practice, while direct reduction shaft furnaces need only pellets.

Among the requirements for the quality indicators of pellets in terms of chemical properties, the key ones are the maximal iron content and the minimal silicon dioxide content. So, increase of Fe content in charge by 1 % provides saving coke consumption by 1.5 %, what can be achieved owing to more deep ore concentration [2].

Size of raw material particles is a technological restriction for agglomeration process. Optimal size of the particles for agglomeration is within the range 0.1–10 mm. Thus, taking into account granulometric composition of additionally concentrated concentrates (up to 90 % of -0.074 mm class), production of pellets remains the only possible method for their agglomeration.

Pyrometallurgical processes are among the main sources of unfavourable effect on the atmosphere, creating serious dangers for ecology. Emissions from sintering plants constitute the essential part (up to 50 %) in the structure of these emissions [3]. Based on this, the tendency of planned gradual termination of agglomerate use should be noted. So, Severstal JSC in 2024 took out of operation three agglomeration machines at Cherepovets metallurgical works within the framework of the Federal project “Clean air”. Agglomerate production volume reduced by 2 times and will be compensated by high part of iron ore pellets in blast furnace melting. Seven sintering machines (from eight existing) are planned to be taken out of operation additionally at the site of

Cherepovets metallurgical works in 2026 before putting into practice the new complex for pellets production [4].

Actuality of the researches, which were directed in quality improvement of pellets, is stipulated by several parameters having influence on the development of economics in general and metallurgical industry in particular. Optimization of composition and structure of pellets is considered as one of the important aspects of their quality improvement. Development of new binding materials and roasting technologies is an actual goal, because it allows creating pellets with improved chemical and mechanical properties, thus ensuring efficiency rise of blast furnace process and decrease of emission of pollutants [5, 6].

Mechanical and metallurgical properties of pellets are determined by many parameters, such as mineral composition of raw material [5], amount and composition of fluxes [6], structure of pellets [7], heat treatment procedure [8], size of pellets [9], roasting homogeneity along the layer height [10] and porosity of pellets [11].

The binding substance is an integral part of charge during agglomeration. Choice of a binder, its quality and functional properties determine the following aspects:

1. Optimization of granulometric composition of green pellets; increase of output of products with the control coarseness class rises productivity of agglomeration process and reduces circulating load of agglomerating equipment [12].

2. Humidity stabilization; supporting the optimal charge humidity has the decisive importance for manufacture of high-strength pellets and ensuring stability of agglomeration process [13].

3. Forming of macro- and microstructure; it is possible to improve a porous structure and obtain the preset mineral composition of solid phase owing to special additives, and thus to increase strength of roasted pellets [14].

Composite binders, which combine mineral and polymeric components, meet the above-mentioned requirements. Bentonite is conventionally jused as a mineral component and polyacrylamide can be used of its efficiency rise and decrease of SiO_2 content in charge for agglomeration. Quantitative evaluation of influence of such binder on quality of pellets is absent at present time, what stipulated necessity of conduction of this research.

The aim of this work is to establish the effect of use of bentopolymer composition BPC-1A (on the base of high-quality bentonite clay from the Dash-Salakhli deposit and polyacrylamide, an effective stabilizer for filtration of clay drilling mud) as a binder on macrostructure of iron ore pellets and their metallurgical properties.

Material and technique of the research

The requirements to metallurgical properties of iron ore pellets include high reducibility, high starting softening temperature and small temperature range of softening. Physical properties of pellets should ensure rather high compression strength of pellets, low crushability and wearing ability in cold state, as well as minimal deterioration of these indicators during reduction, high porosity and stability of granulometric composition.

It should be noted that several indicators are in mutual contradiction (reducibility and “hot” strength), while the appearances of softening, swelling and destruction appear due to crack formation, which increases reaction surface sizes, and, respectively, reducibility. Depending on the features of metal fabrication, technologists take a compromised solution among reducibility and strength.

To provide the complete metallurgical evaluation of roasted pellets, it is insufficient to use only one or two indicators of their properties. They should meet the requirements of all presented complex of metallurgical properties.

Pores are the integral part of microstructure of roasted pellets. When discussing technological properties of pellets, each of them should be considered as integrity of three components: ore phase (including the main part of iron), ferrosilicate glass (a binder, carrying pellet strength) and pores (microstructural elements, which determine the number of contacts between mineral phases and reducing gas).

It is evident that quantitative characteristics of volumetric porous structure can’t be determined directly by flat image obtained via microscopy. This image contains primary and sometimes distorted information about volumetric structure [15].

Porous structure of pellets, which is forming as a result of thermal strengthening, determines their most important metallurgical properties, such as “cold” and “hot” strength, reducibility and metallization degree. Forming and analysis of porous structure of pellets are observed in essential number of researches [16–20].

Size of pores is a decisive indicator of oxidation intensity. Increase of porosity leads to lowering of compression strength, because the average cross section square of cake mineral components decreases in this case. At the same time, increase of porosity can be accompanied by rise of reducibility due to increase of a contact surface between gaseous and solid phases.

It is shown in the work [21] that intensity of mass exchange processes is mainly determined by the features of porous structure, and in particular by such indicators as total volumetric porosity, distribution of pores by their sizes and surface of pores , which is acceptable for reactions.

Influence of structure on strength is described by the empiric formula:

$P = a$*exp*(-B), where

P – strength; a – coefficient taking into account parameters of sintering procedure; B – structure parameter.

Either the value of total porosity, or the value of the average radius of pores are used as B parameter. Just these indicators are considered as parameters of finishing of the sintering process.

Mass exchange processes are identified as oxidation process during sintering, reduction during agglomeration and metallization. Finishing of this processes determine finally quality of the obtained product.

Materials for the research are presented as charge composition for manufacture of pellets, they are identical to those used in the work [22], excluding the applied binder. This research used bentopolymer composition BPC-1A as a binder (**Table 1**), the main component of which is high-quality natural sodium bentonite from the Dash-Salakhli deposit (Republic of Azerbaijan), the polymer part is represented by polyacrylamide. Organic binders usually present high-molecular polymer compounds, containing hydroxyl, carboxyl, amino- and carbonyl reaction groups. The examples of these compounds are starch, sodium carboxymethyl cellulose, polyacrylamide as well as guar and xanthan gum; all of them have oxygen-containing groups which are able for chelation, coordination and other adsorbing interactions with surface of iron ore concentrates, what improved substantially agglomeration process [22, 23]. The technique of carrying out laboratorial agglomeration and roasting, as well as of determination of physical parameters of green, dry and roasted pellets, corresponds to those used in the work [24].

The complex of metallurgical properties, including the temperature of softening start and the temperature range of softening as well as reducibility and "hot" strength, were evaluated according to the standards GOST 26517-85, GOST 17212-84 and ISO 13930-2015 respectively in the laboratory of "TOREX" scientific, production and innovative company.

Depending on intensity of the process, softening can be quick or can take place in the large area along the furnace height and within the wide temperature range. The wider is the temperature range of softening, the larger area of the furnace space along its height is occupied by mass, which is not penetrated by gases and which occupies cavities between coke pieces, thus retarding gas flow upward and their distribution along the furnace cross section. In this connection, the softening range should me as narrow as possible [25]. Decrease of the height of tough-ductile interval in the lower part of the furnace is one of the main goals of blast furnace smelting.

The research technique concludes in heating a sample of the tested material in the inert gas (nitrogen) atmosphere, with determination of the softening temperature by starting of rigid rod dipping in a sample under the effect of external pressure, as well as the temperature range of softening in accordance with the standard values.

Reducibility of pellets is the most important parameter of their quality, which should be taken into account during evaluation of consumer properties of the prepared iron ore raw material. Reducibility means capacity of iron ore material to give up oxygen (with larger or smaller speed) from iron oxides to reducing gas. Its role increases with improvement of blast furnace practice and decrease of specific coke consumption.

"Hot" strength is material ability to withstand the loads without destruction at the increased temperature in the reducing atmosphere. During blast furnace practice, the material is subjected to essential mechanical loads, which are connected with pressure of the charge materials column and gas dynamic effects. High "hot" strength is necessary for preventing destruction and wearing, which result in forming of fine fractions and dust. Such appearances decrease gas penetration of a layer, retards iron reduction processes and deteriorates in general technical and economical parameters of metal production.

Research results and discussion

The results of examination of four samples of roasted pellets along the whole complex of the required indicators are presented in the **Table 2**. One of these samples is initial (its binder and binder consumption 8 kg/t are identical to current production), other three samples are production ones, with BPC-1A binder and its consumption 8, 7 and 6 kg/t.

Decrease od bentonite consumption in comparison with the basic level is the important task, because bentonite clay consists of silicon and aluminium oxides with 70 % [26] and its addition can lead to lowering of pellets quality in Fetot content by 0.4–0.6 % [27]. Use of bentopolymer compositions as a binder allows not only to optimize bentonite clay consumption, but also to provide increase of iron content in roasted pellets.

Optimal (for output of the class 10-12 mm) granulometric composition of pellets (output of the class -12+10 mm was 75.6 % against the basic 69.8 %) was obtained with use of the binder BPC-1A in the amount 7 kg/t. When increasing

Table 1. Qualitative characteristics of binders

Material	Swelling index, ml/2g	Swelling, times	Effective viscosity, mPa·s
Bentonite clay from the Dash-Salakhli deposit	28.5	15.6	100
BPC-1A (Bentonite clay from the Dash-Salakhli deposit + 0.5 % polyacrylamide)	32.3	17.2	151

Table 2. Physical parameters of manufactured pellets

Binder consumption, kg/t	Output of class –12+10 mm, %	Dropping strength, times (h = 500 mm)	Compression strength of green pellets, kg/pel.	Compression strength of dry pellets, kg/pel.	Porosity, %	Compression strength of roasted pellets, kg/pel.	W, %
Bentonite 8 kg/t	69.8	3.1	0.89	3.52	20.46	291	8.33
BPC-1A 6 kg/t	68.1	2.5	0.69	2.26	21.31	282	8.62
BPC-1A 7 kg/t	75.6	2.4	0.71	1.82	22.07	279	8.72
BPC-1A 8 kg/t	36.2	2.2	0.67	2.01	22.72	212	8.47

this amount to 8 kg/t, critical decrease of output of pellets with the control coarseness class up to 36.2 % is noted, what is considered as violation of kinetics of a pellet growth in a pelletizer. It can be connected with excessive pelletizing ability of obtained charge and forming of extra large amount of nuclei without their consequent growth – the main mass of finished pellets is characterized by the "minus" coarseness class.

Strength of green pellets using BPC-1A binder with consumption 6 kg/t decreased significantly from 0.89 to 0.69 kg/pel. (by 22.5 % in comparison with the basic value), while humidity increases. When increasing this amount to 7 and 8 kg/t, strength of dry pellets was 0.71 and 0.67 kg/pel. respectively.

Achieving the ultimate strength for the preset structure type by acting stresses is the condition of destruction of each body. In this case, destruction work consists of two components: energy of elastic deformations and work of plastic deformation, which is localized in the area of cracks end. In the case of a green pellet, the size of plastic deformation area, which influences on the sample strength, is determined by viscosity of jelly-liked mixture (colloid) of bentonite and water. The larger is the effective viscosity indicator, the smaller distance is identified for motion of cracks end near the front of an elastic wave. Polymer part of BPC binder ensures increase of effective viscosity of a binder suspension [22]. Thus, the nature of dry pellet strength is determined by the properties of polymer bentonite suspension, in addition to technological parameters of pelletizing, capillary properties and humidity of charge.

Use of BPC-1A binder with consumption 7 kg/t led to the most essential strength decrease of dry pellets from 3.52 to 1.82 kg/pel. Lowering of dry pellets strength is considered as regular appearance connected with lowering of green pellets strength for compression and impact.

Thus, use of BPC-1A binder didn't reveal any essential advantages in comparison with the basic variant, relating to the indicators of green, dry and roasted pellets.

The obtained results of determination of "hot" strength according to ISO 13930-2015 are presented in the **Table 3.**

When using three BPC-1A amounts, the strength indicator LTD +6.3 increases while the maximal value 97.16 % was achieved for the amount 7 kg/t.

Wearing of pellets (output of the fraction -0.5 mm) did not vary practically for all experimental amounts in comparison with the basic value 1.81 %. The minimal value 1.72 % was also achieved for the amount 7 kg/t.

To determine reducibility of pellets, the GOST 17212084 was used, the results are reflected in the **Table 4**.

Reducibility of the samples of pellets, which were obtained using bentopolymer compositions, increases in comparison with the basic variant, and this increase is connected with decrease of binder consumption. These results correlate well with the previously obtained data on their physical and chemical properties (porosity, ductility, strength) for initial and roasted experimental pellets. The results of the researches of low-temperature intervals for experimental pellets are presented in the **Table 5**.

The obtained results testify on the comparative value of the starting softening temperature for all samples and on lowering of the softening temperature interval for the pellets using BPC-1A binder in comparison with the pellets of the basic variant. The softening temperature interval approaches to the minimal value 177 °C for the amount of BPC-1A 7 kg/t.

The data on metallurgical properties of the experimental pellets with BPC-1A binder testify on their superiority in comparison with the basic sample for all tested properties.

The obtained results correlate well with the data of actual results of domestic and foreign researches in the field of preparation of iron ore raw materials for blast furnace melting, in particular for porous structure, strength and reducibility of iron ore pellets.

Conclusion

It was established during experimental researches that the whole complex of metallurgical properties of pellets improves with use of bentopolymer composition and decrease of bentonite consumption. Thus, it can be concluded that use of bentopolymer compositions allows:

Table 3. The results of research of the index of low-temperature LTD destruction

Indicator	Bentonite 8 kg/t	BPC-1A 6 kg/t	BPC-1A 7 kg/t	BPC-1A 8 kg/t
LTD +6.3, %	95.16	96.26	97.16	96.14
LTD +3.15, %	2.57	2.48	1.87	2.56
LTD -0.5, %	1.81	2.07	1.72	1.91

Table 4. The results of reducibility researches for experimental pellets

Indicator	Bentonite 8 kg/t	BPC-1A 6 kg/t	BPC-1A 7 kg/t	BPC-1A 8 kg/t
Coarseness class, mm	–12+10	–12+10	–12+10	–12+10
Sample mass before reduction, g	500	500	500	500
Sample mass after reduction, g	381.7	375.04	375.52	379.4
Reduction degree, %	**83.67**	**88.14**	**87.97**	**85.42**

Table 5. The results of the researches of the temperature interval of softening for experimental pellets

Indicator	Bentonite 8 kg/t	BPC-1A 6 kg/t	BPC-1A 7 kg/t	BPC-1A 8 kg/t
Starting temperature of softening	1158	1160	1159	1158
Finishing temperature of softening	1400	1388	1336	1374
Softening temperature interval, °C	**242**	**228**	**177**	**216**

– to decrease of bentonite consumption during pelletizing and to increase of iron content in final pellets;

– to intensify the process of charge knurling in a pelletizer and to increase the degree of pelletizing ability;

– to increase “cold” and “hot” strength of roasted pellets;

– to improve metallurgical properties of finished pellets.

So, the bentopolymer composition presents the new kind of binder, its composition allows adjusting parameters of this binder itself and obtained pellets, what widens substantially possibilities of control and choice of the optimal production procedure for high-quality iron ore pellets.

Based on the complex of the obtained results of laboratorial researches, the bentopolymer composition BPC-1A with the amount 7 kg per ton of pellets can be recommended for pilot-industrial testing at Stoylensky mining and concentrating plant and for melting of the obtained pellets in blast furnaces, where the technical and economical efficiency, based on improvement of metallurgical properties of pellets, will be determined.

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