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Improving the efficiency of the preparation of agglomeration charge

Improving the efficiency of averaging of agglomeration charges containing finely dispersed materials and reducing fluctuations in the chemical composition of the agglomerate is an actual topic since sintering plants do not have enough equipment for the complete preparation of the agglomeration charge, namely averaging. In addition, the supply of finely dispersed components of iron ore concentrate and iron-containing sludge to the warehouse for averaging and the processes of stack formation and disassembly are accompanied by disorganized structure formation. Solving this issue will improve agglomerate quality and increase agglomeration machines' productivity.

A method of preparing agglomeration charge is proposed. This method involves averaging the mixture after equalizing its granulometric composition, which minimizes material segregation during stack formation and disassembly.

The leveling of the granulometric composition of the mixture is carried out by processing it in mixers at natural humidity, which leads to the destruction of locally over-moistened micro volumes of sludge and concentrate and finishing the mixture at optimal humidity, which contributes to the preferential formation of granules of class 1.6…10.0 mm. A component for crushing is added to the mixture in the amount of 10 …40 % of the weight of the mixture to intensify the process of crushing in the mixer.

Granulation of the charge before averaging and storage in the warehouse contributes to eliminating the phenomenon of caking, the unorganized formation of macrostructures in the process of loading the material. This ultimately improves the quality of the agglomerate in terms of strength indicators.

The method will reduce fluctuations in the agglomerate's chemical composition in terms of iron content and basicity while increasing the productivity of sinter machines and strengthening the heat. Taken together, this allows us to conclude about its feasibility and the possibility of its introduction into industry.

Keywords: *iron ore concentrate, iron-containing sludge, granulometric composition, structure formation, segregation, averaging, quality.*

Introduction. The process of including a multicomponent mixture in the composition of the agglomeration charge is associated with significant fluctuations in the chemical composition of the agglomerate due to significant differences in the chemical and grain composition of the components of the charge, as well as the segregation of raw materials in the averaging process. In addition, since the supply of finely dispersed components of the concentrate and sludge to the warehouse for averaging, as well as the processes of formation and disassembly of the stack, are accompanied by unorganized structure formation (granules of different fractional composition), segregation of the materials being averaged occurs. The ratio of the linear sizes of lumps in a stack formed from similar materials is more than 400 times, and the formed granules have a different material composition. As a result, lamination of the mixture occurs. Its subsequent storaging in the warehouse leads to a significant strengthening of the granules.

The inhomogeneity of the chemical composition of the material formed during the stack formation is poorly leveled at the following stages of charge processing (dosing, mixing, stacking on stacking carts) and only increases during these operations. This fact leads to the deterioration of the agglomerate strength indicators due to the presence of raw charge inclusions formed from the specified micro-structures and did not pass the agglomeration stage.

This process significantly develops when lime and sludge, which have an increased tendency to structure formation, are added to the concentrate.

Analysis of literature sources. One factor that intensifies the process of agglomeration of the charge with a simultaneous increase in heat strength is the strengthening of granules during the granulation of the charge. It was established [1] that as the granules' strength increases, the sintering plant's specific productivity increases, and the yield of fines (0-5)×10^{-3} m from the cake decreases. The reduction in fines yield when the shrinkage of the sintering layer is reduced is explained by the fact that the compaction is already implemented at the microlevel — in the granules during their formation.

As can be seen from the analysis of equation [2]:

$$F_{\max} = F_{\text{cap}} - F_{\text{wed}} + F_{\text{mol}} = A^{`}\left(\frac{1-\varepsilon}{\varepsilon\cdot d_4}\right) - B^{`}\left(\frac{1-\varepsilon}{\varepsilon\cdot d_4}\right)^2 + C^{`}\left(\frac{1-\varepsilon}{\varepsilon\cdot d_4}\right)^3 = A\cdot\frac{1}{h} - B\,\frac{1}{h^2} - C\,\frac{1}{h^3}, \qquad (1)$$

where $F_{\max}$, F_{cap}, F_{wed}, F_{mol} respectively: total, capillary, wedging, and molecular adhesion forces of particles in granules; ε — actual porosity of the granule; d_4 — average diameter of material particles; h — distance between particles in granules; A, B, C are constant coefficients that depend on the nature of the material and the external compacting effect, the total strength of the granules is determined by the ratio of positive capillary, molecular and negative wedging forces.

Calculations according to equation (1) showed [2] that during the granulation of thin magnetite concentrates, the leading role in ensuring the strength of the granules can be assigned to the molecular mechanism.

The only available and effective way to control the development of the molecular mechanism of adhesion of heterogeneous particles in granules is to influence the nature of the granules. However, it occurs not due to the modification of the surface of the particles but by the selection of components in a granulating group with similar natural properties since, according to Debroy's rule, the maximum force of molecular attraction is observed for the same hydrophilicity (nature) [3]. This direction is being developed today by researchers, practitioners, and technologists [1, 2, 4-6]. From what has been said, in the conditions of a significant number of components, which include finely divided materials, the preparation should be carried out by group method.

Suppose we assume that the rate of increase in the mass of the granule formed in the overflowing layer is proportional to the mass of the granulated materials. In that case, we can obtain an equation describing granule increase kinetics [7]:

$$d_\tau = \sqrt[3]{d_f^3\left(d_f^3 - d_z^3\right)\cdot exp\left[-\frac{1}{3}\mu\cdot n\cdot\varphi(\vartheta)\cdot\tau\right]}, \qquad (2)$$

where: d_f, d_c, d_z are the average diameters of final, current, and nucleus granules, respectively; μ — a coefficient that depends on the ability of the material to form granules and the activity of their nuclei; n — the speed of rotation of the granulating drum; $\phi(\nu)$ — time.

So

$$d_z \le d_c \le d_f. \qquad (3)$$

The mathematical model of the formation of nuclei based on over-moistened micro volumes during drop-jet humidification of the charge is represented by the equation:

$$d_z = \sqrt[3]{\frac{6V_{dr}}{P\cdot\varepsilon}}\cdot\sqrt{K_o\,\frac{\varepsilon}{1-\varepsilon}\cdot d_4\cdot\frac{\theta}{\delta}\cdot ln\tau}, \qquad (4)$$

where: d_z — the diameter of the nucleus of droplet origin; P — porosity of the nucleus; K_o — shape coefficient of average diameter particles; θ, δ — surface tension and viscosity of the moisturizing liquid; V_{dr} - volume of a drop of water; τ — time.

At the same time, the strength of the nucleus and granules formed at the initial moment is represented by the equation [2]:

$$M_z = k\cdot\frac{1}{d_4}\sqrt[3]{(1-\varepsilon)^2\frac{\varepsilon_r}{d_r}}, \qquad (5)$$

where k — a coefficient that depends on the type of arrangement of particles in the nucleus and its shape; ε_r — the relative volume of cavities in the resulting structure (nucleus) occupied by liquid (water).

Based on the analysis of formulas (2-5), the mechanism of compaction and strengthening of granules with solid nuclei and over-moistened micro volumes is clarified. During compaction, granules are formed immediately strong, because they have mainly elastic properties, while the hardening of granules requires certain processing and time, being compacted due to plastic deformation. Deformation determines the necessary length of the drum-type granulator.

As can be seen from the Table 1, in all cases, granules formed based on solid nuclei have increased strength compared to granules from concentrate. The strength is determined according to the method described in [1]. It should be noted that limestone particles cannot be recommended as nuclei since the granules formed on their basis are destroyed in the zone of intense heating due to carbonate decomposition. Of the remaining two types of solid nuclei, preference should be given to the reverse fraction of the agglomerate (return). Similar conclusions (Table 2) were made in [8].

Experimental sintering of the same charge containing 85 % lime concentrate in the iron ore part, prepared by the usual method and with nuclei in granules (mainly in the form of particles of sintering ore and the reverse fraction of agglomerate (Table 3), confirmed that the best results are achieved when using the concentrate and reverse fraction of agglomerate. With an increase in the gas permeability of the layer, the increase in the specific productivity of the installation was 32.8 %.

Authors of the works [4, 8-10] obtained similar results during preliminary granulation of fine-grained materials. The best result was achieved when the concentrate and lime were stored together [8, 11]. According to [7], the strength of raw briquettes from Kryvyi Rih concentrate containing 3 % lime increased by 1.5 times after 24-hour storage, and the productivity of the sintering plant increased by 28.8 %. However, the most significant results are achieved by averaging and storing lime and reverse fraction of agglomerate in one stack concentrate [8].

Formulation of the problem. In order to obtain a chemically homogeneous agglomerate from multi-component charges containing finely dispersed concentrates and sludge, a technology is required in which the components of the agglomeration charge that are uniform in grain composition are averaged. After the destruction and fixing of the micro-complex, the size should be 1.6-10.0 mm.

The purpose of this work is to increase the efficiency of averaging sintering charges containing finely dispersed materials, reduce fluctuations in the chemical composition of agglomerate, which will increase its strength, and increase the productivity of sintering machines.

The basic content of the paper. In order to determine the rational parameters of the charge preparation technology, an analysis of industrial studies (in the conditions of the Ilyich metallurgical plant) of the granulometric composition of the iron ore mixture was performed, the results of which are presented in Fig. 1. It was established that after feeding the mixture of magnetite concentrate, iron-containing sludge, lime and a series of overloads, the yield of structures with a size of > 5 mm and > 10 mm was 81.0 % and 65.4 %, respectively. Such a significant amount of these fractions of the material before its averaging inevitably causes segregation during stack formation. As a result, most of the lime was concentrated near the bottom of the iron ore stack.

The process of unorganized structure formation, a complex phenomenon, is primarily associated with locally over-moistened micro-volumes in the mixture of charge components and fine-grained material (concentrate, sludge, and other iron-containing materials). At the same time, a single load is enough to form granules with a size of mainly 20-40 mm from particles < 0.1 mm in the mixture of wet components.

Thus, to prevent the harmful effects of the unorganized strengthening of small components of the agglomeration charge into aggregates, it is necessary to take measures to prevent the formation of micro-structures before averaging or their destruction. The mixing process, which can lead to segregation when developing from a

Table 1

Compressive strength (kg/granule; kg/cm²) of wet granules of sintering charge with a diameter of 5-6 mm and briquettes obtained by various methods depending on the nature of the nucleus centers

The material of the shell and the nucleus of the granules	Compressive strength			
	kg/granule			kg/cm²
	The method of obtaining briquette granules			
	Granulation d_b = 0.3 m V_{rt} = 30 rpm	Granulation d_b = 0.5 m V_{rt} = 24 rpm	Granulation d_b = 3.8 m V_{rt} = 5.9 rpm	Pressing P = 63.7 kg/cm² S = 3.14 cm² h = 8 mm
Concentrate with lime and reverse agglomerate	0.317	0.419	0.720	4850
Concentrate with lime and limestone	0.257	0.281	0.520	3750
Concentrate with lime and agglomerated ore	0.189	0.278	0.490	3700
Concentrate with lime	—	—	0.300	2950

Note. d_b; V_{rt} — the diameter of the drum and its speed of rotation, respectively; P, S, h — pressure, cross-sectional area, and height, respectively

Table 2

Effectiveness of using granular components of the charge as the center of formation of micro-granules

Component	The number of grains that serve as the centers of formation of micro-granules pcs/1 kg	Amount of concentrate, that is rolled on the surface of the grains, which serve as centers of formation of micro-granules, kg/kg
Return of agglomerate by size:		
3-6 mm	7300	2.34 [1]
3-10 mm	3700	1.54
The iron ore of the Kryvyi Rih deposit by size:		
3-6 mm	7600	1.17
3-10 mm	4750	0.92

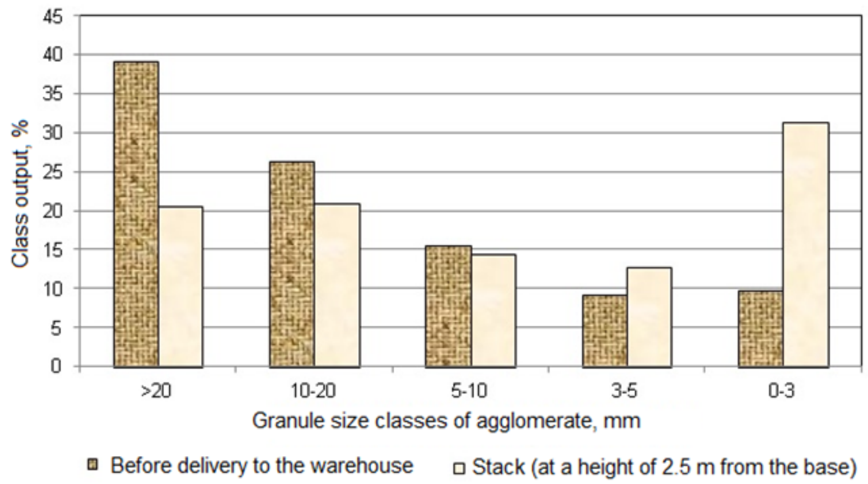

Fig. 1. Granulometric composition of the iron ore mixture (magnetite concentrate with sludge) and lime in different areas of the sintering plant

stack, is a significant challenge. The drop of significant volumes of material accompanies the development of the stack. According to equation (1), the minimum forces of adhesion between particles are achieved by maximizing the wedging effect in the material layer:

$$\left(\frac{dF_{max}}{dh} = 0\right) \quad (6)$$

and the equal action of capillary and molecular mechanisms in the formation of total strength, or when ensuring inter-structural adhesion only due to the capillary force field. These conditions correspond to the size of particles or aggregates of 0.07-0.10 mm and more than 1.0 mm. However, in the first case, the surface forces are still quite large and exclude agglomeration.

Thus, an effective means of combating fusion is strengthening powdery particles, which can be implemented by granulation.

The set goal is achieved by the fact that the entire middle group of components of the sintering charge (for example, finely dispersed concentrate, sludge, lime, and others) are subjected to processing in mixers under waterfall mode and natural humidity before being sent to the warehouse for averaging. This fact leads to the crushing of locally over-moistened macro-volumes. After that, the mixture is granulated in drum-type granulators at optimal humidity in the rotation mode which leads to the preferential formation of granules, preferably of the 1.6-10.0 mm class.

Crushing of granules consisting of iron ore concentrate and iron-containing sludge is carried out in the mixer under the action of increased loads on the structures characteristic for the waterfall regime, as well as during interaction with the coarse-grained components of the sintering charge (reverse of agglomerate, limestone, sintering ore).

To strengthen the crushing process of the lumps, 5-40 % of the mass of the mixture of material that performs the role of the crushing body is introduced into the charge. The selection of the component for crushing the formed structures is carried out from the coarse-grained materials in the charge. At the same time, the crushing material should not have the ability to granulate on its own. But its particles can be centers of nucleation of granules. From the set of components of the sintering charge, the reverse fraction of the agglomerate and the sintering ore most fully meet these requirements.

After processing in mixers, the charge is granulated in drum-type granulators at optimal humidity in the rotation mode which contributes to the development of processes of granule formation mainly of the 1.6-10.0 mm class [12]. Then, the sintering charge, adjusted according to the granulometric composition, goes to the raw material warehouse, where it is subjected to averaging and storing. As a result, the granules are strengthened [13]. In addition, granulation of the material before delivery to the warehouse contributes to the elimination of fusion and the formation of micro-structures in the process of further overloading of materials due to the reduction of the contact area between particles. The mode of movement (waterfall, rolling) of materials in the drums is regulated by changing the speed of the drum or the degree of filling [12]. Addition of a component that acts as a body of a destructive body beyond the specified limit is impractical due to the shortage of coarse-grained materials. In addition, the necessary time for processing the charge for the destruction of granules is reduced, which decreases the efficiency of the method. Additions of the same component below the specified limit will contribute to the fact that the degree of destruction of granules during processing will be insufficient.

Thus, the group method of preparing the sintering charge intensifies the sintering process when only crushed materials and the reverse fraction of the agglomerate are combined into a separate group.

In laboratory conditions, experiments were conducted to determine the strength of wet granules obtained by various methods, depending on the nature of the nuclei centers. The results are given in the Table 1. It was established that the highest strength of wet granules of sintering charge, 5-6 mm in diameter, and briquettes obtained by various methods, depending on the nature of the nucleus centers, has the composition "concentrate with lime — reverse agglomerate".

Table 3

Results of laboratory experiments on granulation and sintering of the sintering charge prepared by the standard method according to the proposed method

Methods of preparing the charge	Output of classes (%) by size, mm						Crushing strength of wet granules with a size of 5...6 mm		The resistance of the charge layer with a height of 200 mm at the speed of air filtration 0.3 m/s		Sintering Time[1]	Vertical sintering speed	Output suitable	Specific productivity	Content of fines 0...5 mm in agglomerate	The average diameter of the agglomerate	The maximum temperature of the outgoing gases
	>10	**5-10**	**3-5**	**1.6-3.0**	**1.0-1.6**	**<1.0**	g/gran	%	mm water col.	%	min	mm/min	kg	т/(m2×h.)	%	mm	°C
Basic variant (SC)	4.7	24.7	19.7	20,4	19.3	11.2	259.8	100	284	100	14.5	20.6	22.5	1.34	18.9	18.51	507
K1	4.1	29.7	28.6	28.2	9.1	0.5	278.4	107	66	23.2	13.9	21.7	23.6	1.46	19.6	18.72	555
K2	5.1	33.1	30.8	32.8	4.5	0.2	487.7	188	50	17.6	11.5	26.1	23.9	1.78	16.9	17.86	570

[1] The height of the layer of sintering charge is 0.3 m, the moisture content of the charge is 8.0 % speed.

Laboratory studies were carried out using the reverse of agglomerate of various sizes and iron ore from the Kryvyi Rih deposit to determine the effectiveness of using granular components of the charge as centers for the formation of micro-granules. The results of the research are given in Table 2.

It was established that both the agglomerate of the reverse fraction and the iron ore with a grain size of 3-6 mm form a more significant number of grains that serve as centers for the formation of micro-granules per 1 kg by 97.3 % and 60 %, respectively, than with the grain size of the specified materials of 3-10 mm.

Three series of experiments were conducted to determine the influence of preparation methods on the parameters of the sintering process: the basic version using the usual method of preparing the sintering charge (SC), using concentrate treated with lime and pre-granulated with sinter ore (K1) and concentrate treated with lime and pre-granulated with the reverse fraction agglomerate (K2). The moisture content of the charge was maintained at 8 % in all experiments. The results of the research are given in Table 3.

Four series of experiments were conducted to determine the efficiency of the proposed method of averaging the sintering charge. The basic indicator is taken as 100 %. The height of the sintering charge layer is 0.3 m, and the moisture content of the charge is 8.0%. The mixture, granulated at optimal humidity, was received for processing.

Experiment № 1. In laboratory conditions, a stack weighing 200 kg was formed traditionally, consisting of slag ore (10 % of the entire charge), (Novokryvorizsky Mining and Processing Plant) NMPP sludge (10 %), lime (5 %), and concentrate (75 %). Stacking was carried out layer by layer in six layers. After keeping for 7 days, the stack was reloaded twice from place to place, which allowed averaging. Then the charge was granulated in a drum-type granulator with a diameter of 0.340 m and a rotation speed of 16 rpm, in the rotation mode at optimal humidity. After that, scattering and chemical analysis of each sample was carried out for iron content and basicity. The results of the experiments are summarized in Table 4, from which it can be seen that the iron content fluctuations were ±1.5 % and ±0.15 % in basicity. The grain composition of the charge was heterogeneous: the class < 1.6 mm content was 12 %, while the content of micro-volumes with a size of 12.0-40.0 mm was 8 %.

Experiment № 2. The charge of the same composition and amount as in experiment No. 1 was pre-mixed in a drum at a rotation speed of 44 rpm (waterfall mode), then, it was granulated at optimal humidity and drum rotation speed of 16 rpm, rotation mode, and placed in a stack, where it was kept for 7 days. Previously, in a ribbed drum with a diameter of 0.220 m and rotation speed of 40 rpm, granulated charge for 120 s was tested for strength. The class content < 1.6 mm in the charge after the test was 18 %. After keeping the charge, as in the previous case, it was subjected to averaging and scattering after completion and determination of chemical analysis. The content of the class <1.6 mm in the charge was reduced to 2 %, and the amount of the class 12-40 mm was 2 % (Table 4). After storing, the granules' strength increased: the class's content < 1.6 mm after the test in the drum was 9 %.

Experiment № 3. The results of the experimental verification of the possibility of adding and optimizing the

Table 3

The results of laboratory studies of sample scattering and determination of chemical composition

Experiment №	Content in class charge, %				Fluctuations in chemical composition		Note
	<1.6	1.6-10.0	10.0-12.0	12.0-40.0	Fe, %	CaO/SiO_2	
1	12.0	70	10.0	8.0	±1.50	±0.15	After keeping
2	12.0	70	16.0	2/18[1]	±1.00	±0.12	Before keeping
3	2.0	80	16.0	2/9[1]	±0.26	±0.025	After keeping

[1] The denominator indicates the content of the class <1.6 mm after the strength test of the charge in a ribbed drum.

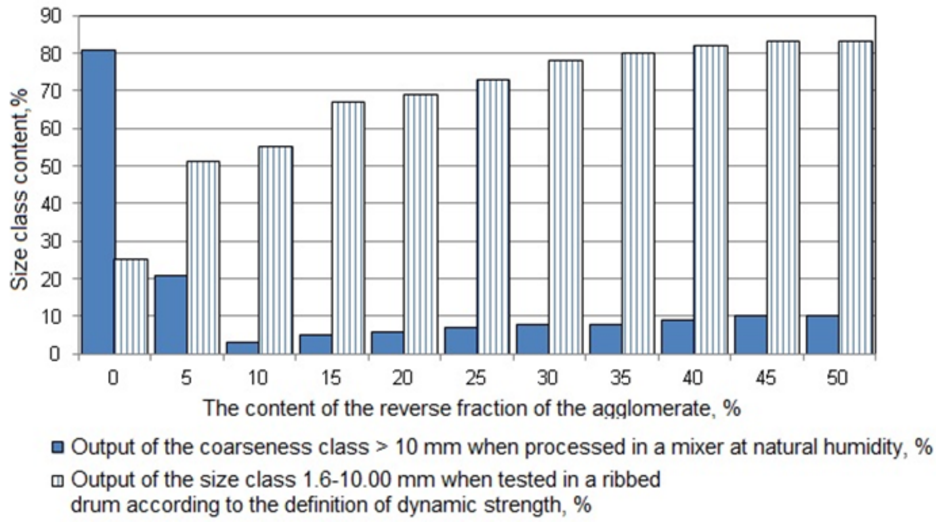

Fig. 2. Changes in the structure (output of size class >10 mm) and strength characteristics (output of size class 1.6-10.0 mm) of concentrate, sludge and lime depending on the content of agglomerate reverse during processing in a mixer and testing in a ribbed drum, respectively

consumption of coarse-grained material were performed using a group of components — from the lime-treated NMPP concentrate and agglomeration production sludge taken in the ratio specified in the previous examples. In studies No. 3 and No. 4, the granulated charge was not subjected to stacking and storing but was immediately processed in a drum-type mixer with a diameter of 0.340 m and a rotation speed of 44 rpm (waterfall mode).

The consumption of the reverse fraction of the agglomerate for crushing granules was varied from 0 to 50 % of the mass of the specified group of components with an interval of 5 %. Presented in Fig. 2, the results of the experiments show that even 5 % of the reverse fraction of the agglomerate is sufficient for the destruction of granules larger than 10 mm, but the duration of processing the materials in the mixer was 7-8 minutes. When adding 40 % of the reverse fraction of agglomerate, the processing time is reduced to 2-4 minutes. The following portions of the reverse fraction of agglomerate (> 40 %) slightly reduce the necessary time of processing the mixture to destroy granules. Based on these data, the limits of the content of coarse-grained additives in the mixture are established.

Experiment № 4. Since the granulated mixture is subjected to destructive loads in transporting, overloads, and stacking, the number of granules obtained was estimated by their dynamic strength, which was determined using a ribbed drum with a diameter of 0.220 m. The test results shown in Fig. 2 (curve 2) showed that the granules have sufficient strength with the reverse agglomerate fraction content in the mixture range of 5-40 %.

Conclusions

The developed method of preparing the agglomeration charge involves averaging the mixture after equalizing its granulometric composition, which minimizes the phenomenon of material segregation during the formation and disassembly of stacks.

It was established that the inclusion of materials with different granulometric, chemical composition, and physical properties in the composition of the multicomponent agglomeration charge leads to increased fluctuations in the chemical composition of the agglomerate. Moreover, this deficiency is not only not eliminated at the following stages of charge processing (dosing, mixing, stacking on stacking carts) but also increases during these operations. In addition, the supply of finely dispersed components of iron ore concentrate and iron-containing sludge to the warehouse for averaging and the processes of stack formation and disassembly are accompanied by disorganized structure formation.

Equalization of the granulometric composition of the mixture by processing in mixers at natural humidity leads to the destruction of locally over-moistened micro-volumes of sludge and concentrate, as well as the formation of a mixture at optimal humidity, which contributes to the formation of granules mainly of the 1.6-10.0 mm class. A component for crushing is added to the mixture in the amount of 10-40 % of the mass of the mixture to intensify the crushing process in the mixer.

Granulation of the charge before averaging and storing in the warehouse helps to eliminate the phenomenon of agglomeration and unorganized formation of macro-structures in loading the material, which ultimately increases the quality and strength of the agglomerate.

The proposed measures will reduce fluctuations in the chemical composition of the agglomerate in terms of iron content and basicity while increasing the productivity of sinter machines and strengthening the cake.

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Підвищення ефективності підготовки агломераційної шихти

Підвищення ефективності усереднення агломераційних шихт, що містять тонкодисперсні матеріали, зменшення коливання хімічного складу агломерату є актуальною темою. Оскільки агломераційні цехи не мають в достатній кількості устаткування для повноцінної підготовки агломераційної шихти, а саме усереднення. Крім того, подача дрібнодисперсних компонентів залізорудного концентрату і залізовмісного шламу на склад для усереднення, а також процеси формування та розбирання штабелю супроводжуються неорганізованим структуроутворенням. Вирішення цього питання дозволить покращити якість агломерату та збільшити продуктивність агломераційних машин.

Запропоновано спосіб підготовки агломераційної шихти, що передбачає усереднення суміші після вирівнювання її гранулометричного складу, що зводить до мінімуму явище сегрегації матеріалу при формуванні та розбиранні штабелів.

Вирівнювання гранулометричного складу суміші проводиться за допомогою її обробки в змішувачах при природній вологості, що призводить до руйнування локально перезволожених мікрооб'ємів шламу і концентрату, а також оздоблення суміші при оптимальній вологості, що сприяє переважному утворенню гранул класу 1,6...10,0 мм. Для інтенсифікації процесу дроблення в змішувачі, до суміші додають компонент для дроблення у кількості 10 … 40 % від ваги суміші.

Грануляція шихти перед усередненням та витримуванням на складі сприяє усуненню явища злежування, неорганізованого утворення макроструктур у процесі навантажень матеріалу, що в кінцевому підсумку сприяє покращенню якості агломерату за показниками міцності.

Спосіб дозволить знизити коливання хімічного складу агломерату за вмістом заліза та основності при збільшенні продуктивності агломашин та зміцнення спеку. У сукупності це дозволяє зробити висновок про його доцільність та можливість впровадження у промисловість.

Ключові слова

Залізорудний концентрат, залізовмісний шлам, гранулометричний склад, структуроутворення, сегрегація, усереднення, якість.