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Formation of the iron ore pellets structure with differentiated properties

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Abstract. The probable mechanism of the porosity appearance in pellets formed by the technology of forced nucleation is analyzed. A review on the problem of increasing the reactivity of a sintered metallurgical product is carried out. The conditions for optimizing the pore structure of the agglomerated dispersed iron-containing materials are formulated.

1. Introduction

Agglomeration of ore materials is necessary for obtaining a solid lump product, which is a raw material for the extraction of primary metal (cast iron) in blast furnaces or for metallization of raw materials in mine units [1, 2]. To form the porosity character of the agglomerated products in various branches of technology (metallurgy, construction and refractory production), various technical means and methods are used [3]. In metallurgy, pore-forming additives must have high surface-active properties and provide the necessary cold and hot strength at a minimum consumption of binder material. One of the structural problems of agglomerated metallurgical raw materials is the diffusion difficulties in the central part of the piece, due to kinetic constraints arising during transfer of gases from the surface, for example, pellets to their center. With such structure, at the stage of pellets drying, the central part of the pellet contains a certain amount of moisture; upon firing, a zonal structure is formed with underfiring and insufficient amount of hardening melt; during recovery, a long metallization is required [1, 2].

One of the ways to overcome these drawbacks is to obtain pellets using forced nucleation (nucleation by spraying and after-pelletizing NSA) technology, in which the germinal part and its pore structure are formed by heat-spraying a wet mixture onto the bottom crust of a pelletizer [1, 2, 4]. The scheme for the production of pellets according to the NSA technology is shown in figure 1.



Figure 1. The scheme for producing pellets by forced nucleation: 1 - spraying area (sprayed layer); 2 - zone of nucleation; 3 - embryos; 4, 5 – working and idle zones of a pelletizer; 6, 7- areas of moistening and after-pelletizing; 8 pellets.

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Formation of pellets according to the simplified NSA scheme begins with forced nucleation by spraying a moist mixture by compressed air in the blank area of the plate [2]. The structural diagram of such pellets is shown in figure 2.



Figure 2. The structure of the pellets formed by the NSA technology: a – scheme of the pellet with the embryo size $a_{ES} = 5$ mm; b – also with an embryo size $a_{ES} = 10$ mm. The shaded area 1 belongs to the embryos; the unshaded area 2 belongs to the shell of the pellets.

There is a scheme for the pellets production in which the wet mixture is sprayed onto the seeds obtained in the rerolling mode (nucleation, pelletizing, spraying NPS) [2]. The interaction scheme of the reducing gas with the ore skeleton of iron ore pellets obtained by the NSA and NPS technologies is shown in figure 3.



Figure 3. Scheme of the interaction of the reducing gas with the ore skeleton of iron ore pellets obtained by NSA and NPS technologies – a, b and NSA – c, d: in position: a, c – scheme of pellets with closed pores; b, d – scheme of pellets with open pores.

These technologies have been successfully tested in laboratory conditions and have shown high practical efficiency. However, the laws governing the formation of porosity of iron ore pellets and many other processes associated with the new technology remain poorly understood.

The aim of this work was to study the mechanism of nuclei porosity formation in the technology for the production of pellets based on the technique of forced nucleation.

2. Description of the experimental setup and methods of research

The experimental setup for video shooting the process of wet charge spraying onto a contrasting surface is shown in figure 4.

The sprayed charge with a moisture content of 8.4% contained iron ore concentrate of the Teysk deposit ($d_{ch} = 0.068$ mm) and 1% of bentonite. A wet mixture with a moisture content of 8.4% was sprayed by the compressed air at a pressure of 0.2 MPa and a flow rate of 0.6 m³/min. In each zone of the SL limited by a relative diameter δ equal to 0 ± 0.2 , 10–15 samples were taken with samplers (cutting ring) with a diameter of 10 mm. The compressive strength of wet – P_w and dry – P_d , kPa, samples was determined according to GOST 17245-79 and 26447-85. Some samples were used to

determine the density ρ_w , kg/m³, and the moisture content of the samples W, %. The relative distance L/d _{sa} = 1.5 was used in the work; 2.5; 5.0; 10.0; 15.0; 20.0 (where L is the distance between the nozzle SA and ShG, m; d _{sa} is the diameter of the nozzle SA, m). The angle of attack of the SA to the skull was 90 degrees. Using the nomogram developed in [2] and the experimental conditions, we determined the pressure of the internal combustion engine depending on the parameters of compressed air and the characteristics of the jet apparatus.



Figure 4. Scheme of the experimental setup for video recording of the spraying process of wet charge onto a contrasting surface -a, the field of jet pressures on the surface of the sprayed layer - b and the sampling scheme in zones I - III - c. In position a: 1 inkjet apparatus; 2 – charge hopper; 3 - gate; 4 - air charge jet; 5 sprayed charge layer; 6 – protective glass screen; 7 – contrast basis; 8 – support; 9 - video cameras. In position b and c: 1 - the boundaries of the zones; 2 - location of samples; 3 – places of photography.

3. Research results and discussion of the porogenesis mechanism

The analysis of the samples macrostructure (figure 5) showed that in each SL zone there are markedly pronounced structural features.



Figure 5. The macrostructure of the charge sprayed layer: a – charge skull; b – central zone NS $\delta=0$; $\beta=90^{\circ}$; c – $\delta=0,2$; $\beta=90^{\circ}$; d – $\delta=0,5$; $\beta=90^{\circ}$; e – $\delta=0,5$; $\beta=45^{\circ}$; f – $\delta=0.6$; $\beta=45^{\circ}$.

A feature of the macrostructure is the structural cavitations of NS, which are concentric, slightly sinuous channels formed by charge bursts and located along a circular path around the axis of the circular NS. This feature of sprayed coatings is noted by the authors in [4, 5]. As the parameters of the SL macrostructure, we used the relative value of the structural cavitations of the SL θ_{ho} and the relative number of structural cavities θ_N , amount/^{m2} (1/m²) on its surface.

The relative value of the structural recesses of the SL θ_{ho} on its surface was determined by the expression: $\theta_{ho} = h_o/h$, where h_o is the average value of the structural cavitations, mm; h is the average

height of the sprayed layer on its axis, mm. The relative number of structural grooves θ_N was calculated by the expression: $\theta_N = N/f_{sl}$, where N is the numerical value of the structural cavitations N, determined by the number of concentric shadow channels in each zone of SL; f_{sl} – the area of the sprayed layer with a diameter of d, m².

The parameters θ_{ho} and θ_N were estimated depending on the pressure of the NSA, the relative distance L/d s_a, and the humidity of the sprayed charge (figure 6).



Figure 6. Dependences of the relative magnitude of structural recesses – a and the relative number of structural recesses of the SL mixture – b on the pressure of ACM: mixture the moisture content: 1 - 5.5 %; 2 - 7.5%; 3 - 9.5%.

It was found that in the general case, the parameter θ_{ho} sharply decreases with an increase in the pressure of the ACM to 800 Pa, after which there is a slow decrease in its value (figure 6). A large role on the parameter θ_{ho} is exerted by the moisture content of the sprayed charge. When $W_c = 5.5\%$ and the pressure of the ACM less than 800-1000 Pa, low flows and small structural cavitations ($h_0 < 0.1$ -0.2 mm), inaccessible for instrumental measurement, are formed on the surface. At $W_c = 7.5$ and 9.5%, large charge flows of sufficient height and structural cavitations are formed, which are accessible for visual observation and instrumental measurement. The parameter θ_N characterizes the number of concentric structural recesses on the surface of the sprayed charge layer, depending on the P_{acm} Up to a pressure of 500-600 Pa, the parameter θ_N grows at a slower rate than at $P_{acm} > 600$ Pa (at $W_c = 7.5$ and 9.5%). This is explained by the fact that, with an increase in P_{acm}, the growth rate of the number of structural depressions significantly exceeds the increase in the area of the deposited layer f_{sl} and its diameter d. Moreover, with an increase in the charge moisture from 5.5 to 9.5%, the θ_N parameter increases almost 4 times at P_{ACM} = 1280 Pa. During the formation of SL obtained at a moisture content of the mixture $W_c = 5.5\%$ and a pressure of ACM less than 800-1000 Pa, the height of the structural recesses is practically impossible to measure and it was arbitrarily assumed to be 0.1 mm.

In the central part of the SL, the ACM pressure is maximal; in zone III, the ACM pressure is minimal. The dynamic pressure on the axis of the SL at an angle of incidence of the ACM of 90 degrees is zero, after which it increases to a maximum value at about half the radius of the SL (zone II), and then gradually decreases to a minimum in zone III [6] (figure 4).

A moving flow of gases and particles experiences resistance from the side of the surface of the SL due to friction when moving. For this reason, the surface zone of the NS experiences shear loads [2]. In the center of zone I of SL, with an ACM average pressure (in the range of 1000-2000 Pa), the maximum pressure is exerted on the charge, which squeezes moisture from the sprayed charge onto the surface of the SL, especially at $W_c > 7.5\%$.

As a result, a mobile charge pulp is formed with a moisture content $W = (1.25-1.50) W_c$, which impregnates the charge and actively participates in structure formation. In zone II of the SL, the

dynamic pressure of the carrier gas is maximal, and the static component of the total pressure is minimal (figure 4). In zone III of the SL, all components of the total pressure of the ACM have a minimum value. The sprayed layer of charge in this zone consists mainly of their loosely coupled charge conglomerates of low humidity $W = (0.85-0.95) W_c$, which are formed from partially destroyed crest ridges. The cross-sectional microstructures in different zones of the SL, annealed at 800 °C, are presented in figure 7.



Figure 7. The microstructure of fired SL (T=800 °C, τ = 20 min); W= 10 %; Magnification 120^x: Positions: a, b, c – zone 1; d, e, f – zone 2; g, h, i – zone 3; Coordinates : h = 0.5, δ = 0.15 (a); h = 0.7, δ = 0.1 (b); h = 0.3, δ = 0.15 (c) h = 0.3, δ = 0.5 (d); h = 0.2: δ = 0.4 (e); h = 0.2, δ = 0.5 (f) h = 0.2, δ = 0.65 (g); h = 0.1, δ = 0.7 (h); h = 0.2, δ = 0.9 (i).

Analysis of the SL microstructure in different zones of the thin section showed the presence of extended, small, sinuous pore channels of various depths and densities, both in the SL height and in its diameter. Moreover, the channels are located mainly vertically or with a slight inclination towards the attack of the jet. Since the entire SL array experiences power loads from the dynamic pressure of the air flow, a characteristic inclination of the pores towards the jet attack appears.

In zone 2 (d = 0.2-0.6), the width and depth of the pore channels increase, the length decreases significantly, the tortuosity and density of the channels increase. In this zone, a small number of closed-type pores of irregular shape appear. In zone 3 (d = 0.6-1.0), the porosity of SL is noticeably higher, the number of channel-type pores sharply decreases, and they are observed only at the beginning of the zone.

The mechanism of porosity formation is based on the overlapping of charge bursts at each other under the dynamic pressure of the ACM. The air cavity (pore) is most likely to form at the base of the structural cavity, where the strongest adhesion of the charge flow to the base is. The forces that prevent separation of the influx from the base are capillary and interparticle interaction forces, viscous friction forces [1, 2]. The influx crest, which is under the ACM dynamic pressure, on the contrary, has higher mobility and deformation due to its special geometric shape and therefore can block the void in the area inaccessible to the pressure of the IDL.

This mechanism is probabilistic, since fixing it in a dynamic state is quite problematic. If charge bursts do not have sufficient mobility necessary for the development of the first mechanism of pore formation, then a mechanism for the formation of voids by mechanical overlapping of structural recesses with a sprayed charge is possible. Since the deposition mechanism is layered in nature, in the process of SL compaction in the depth of the layer, pore formation can continue along the path of decreasing pore size, elongation, spheroidization, etc. In view of the complexity of these processes that occur in a dynamic state and in a closed system, the described mechanisms are probabilistic character.

4. Conclusion

As a result of the studies, a probable mechanism of pore formation in the structure of iron ore pellets was formulated and methods for influencing the nature of the porosity of the embryos using gas-jet spraying of a wet charge on the surface of a charge skull of a plate pelletizer were shown. It was established that the porosity of the germinal centers can be controlled by the selection of moisture, fractional characteristics of the charge and the dynamic parameters of the jet apparatus.

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