On the Applicability of the Evaluation Techniques of the Properties of Iron-Ore Sinter

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Abstract. Referring to the hierarchical structure of sinter cake, the applicability of various methods for controlling sinter properties has been studied. The technique has been proposed for evaluation of quality yield and strength for sinter using the parameters characterizing structural fines yield and strength of macroblocks under destruction.

With the development of blast furnace production, the requirements to the quality of sinter have been increasing continuously, in particular the requirements to its physical-chemical properties (size, cold and hot strength) [1-3]. Sinter cake formed as the result of melting and shrinkage of charge materials in difficult and unbalanced conditions [4-6], is structurally a largely inhomogeneous polimineral polycrystalline fractured porous body which is in an internally stressed state. This definition formulated by S. V. Bazilevich [4], to the fullest extent possible reflects the physical essence of sinter cake and predetermines the complicated multifactorial dependence of the properties of sinter on its composition and structure.

Despite long-term production experience and many scientific studies, the production of high-quality sinter meeting all the requirements is still a difficult but at the same time important and relevant objective of science and technology. In these circumstances the system of the evaluation of the properties of sinter is of great importance and, in particular, the search for new quantitative methods of the evaluation of its quality indicators is important.

Taking into account the multiple stage process of destruction and the volume inhomogeneity of the distribution of substance in sinter cake, its structure can be presented as a particular scale hierarchy [7]: the systems of interconnected structural elements of diversified scale level: sinter cake, its lump fragments, blocks and mineral aggregates, separate grains of minerals, etc. The highest structural level of the hierarchy (sinter cake) has the most complicated structure, because it is presented with all diversification of the lower ones and the connections among the elements of lower structural levels which make it up. Any structural element of sinter cake is an element of the scale hierarchy, its structure is simpler and it does not have all of the same properties, but at the same time it is a component part of the sinter cake. In accordance with the sequence of destruction of sinter cake and the formation of consumer properties of sinter, 5 structural layers of the hierarchy can be identified depicted on Figure 1.

Every structural element of the hierarchy is responsible for the provision of a particular group of properties, corresponding to its scale. The structure of sinter cake must provide the optimal yield of sinter. The structure of lump products of crushing with the maximum size 100-200 mm should provide...
the acquisition of lumps size from 5 to 40 mm (blocks) with the minimum formation of fines 0-5 mm. The structure of lumps of size 5-40 mm should provide minimum destruction during both mechanical impact and restorative heat treatment, and also the lumps should have high physical-chemical properties.

The structure of sinter cake is a basic parameter which reflects the results of sintering and destruction. The analysis of the influence of the parameters of sintering process on the yield and mechanical strength of sinter by the microstructure of the lumps of yield stabilized sinter bypassing the complete macrostructure of the sinter cake is inefficient.

In accordance with the aforementioned, the existing methods of destructive control of yield and the strength of sinter are essentially correct, but they have significant drawbacks. In industrial conditions the yield is considered to be everything that is dispatched to the blast furnace shop or (at some enterprises) the yield of skip sinter. In these circumstances the yield sinter can include a significant amount of small (0-5 mm) and large (more than 40 mm) fractions depending on the efficiency of crushing and screening. The yield in research practice is considered to be the residual content of classes from +5 mm to +12 mm in the products of destruction of sinter cake after 1-3 drops onto a steel plate from 2 m height.

The indicator of the strength of sinter, as a rule, is considered to be the residual quantity of the class +5 mm (+6.3 mm) or the yield of the class 0-5 mm after the destruction (test) of the lumps of yield sinter of a particular size in a rotating drum. As the indicator of sinter strength during restoration we can take also either residual content of initial size classes in a tested sample, or the output of over-extreme (fine) classes.

The specified methods of evaluation of yield and strength of sinter are to a great extent formal, less informative and do not allow us to make conclusions about the reasons of the destruction of sinter during tests. Since the grain-size composition of the products of destruction depends both on the structure received after sintering and on the parameters of the destruction process, with the help of the existing indicators we cannot estimate the reasons of the decrease or increase of yield and strength of sinter.

As theoretical and experimental studies showed [8], in the process of multiple stage destruction of sinter cake by impact, which is applied in research practice and exists in real industrial conditions, the mass fraction of fines 0-5 mm in the products of destruction is connected to the work of the destruction by the dependence:

$$g_m = g_o + C \cdot U^{0.5},$$

where $g_m$ is the mass fraction of fines in the products of destruction of sinter cake (%); $g_o$, $C$ – coefficients; $U$ is the specific work spent for the destruction of sinter cake (J/kg).

The coefficient $g_o$ is not connected to the external mechanical energy spent for the destruction and depends on the macrostructure of sinter cake (total porosity, size, shape, specific surface area of interblock pores). The value $g_o$ determines the percentage of structural fines, present in sinter cake as links between blocks, and also it reflects all kinds of incomplete sintering (insufficient sintering). The strength of “open” lumps of sinter during disintegration of sinter cake is characterized by coefficient “$C$”.

**Figure 1.** The hierarchy of the sinter cake structure: $L$ – the size of a structural element; $S_i$ – the surface of destruction of connections among elements.
The equation (1) shows that the rate of incrementation of fines in the process of destruction is also connected to the work of destruction:

\[
\frac{dg}{dU} = 0.5C \cdot U^{0.5}.
\]  

(2)

If for the mechanical testing a sample of sinter is taken, which was preliminarily destroyed by the application of specific energy \( U_2 = U_1 + \Delta U \), where \( \Delta U \) is the energy spent on the destruction in a test, then the incrementation of fines in the process of testing (\( \Delta g \)) can be determined by integrating the equation (2) within the limits of the change of the work of destruction \( U_1 \) to \( U_2 \):

\[
\Delta g = C(U_1^{0.5} - U_1^{0.5}).
\]  

(3)

Equation (3) shows that the incrementation of fines in the process of testing depends both on the energy spent on the destruction in the process of testing, and on the energy spent on preliminary destruction. That is why the results of strength determination by existing accepted methods depend on the place over the route of the transfer of sinter from a machine to a blast-furnace shop where the sample for testing was taken from, on whether the destructive impact is chosen, on a test and also on the value “C”. In connection to that the determination of yield and strength of sinter by the existing formal indicators does not fully reflect the true results of sintering.

The scheme of technological analysis which allows to experimentally determine the coefficients \( g_0 \) and \( C \) and, together with that, the group of factors responsible for the acquisition of particular physical properties of sinter cake, is quite simple. The laboratory cake or a fragment of industrial cake of the volume 0.03-0.05 m\(^3\) is consecutively destroyed by multiple drops from a particular height (usually 2 m) onto a steel plate or by treatment in a rotating drum of 1 m diameter. In these circumstances the change of the output of small fractions (0-5 mm) is recorded depending on specific energy spent during destruction (minimum after three, five, seven and ten drops of cake from the height of 2 m onto a steel plate). By mathematical processing of the achieved experimental data in accordance with equation (1) the value of coefficients \( g_0 \) and \( C \) is determined. The determined values of the coefficients are compared with the control ones and in case of deviation a decision is made regarding the application of a certain correcting measure.

The determination of coefficients \( g_0 \) and \( C \) in industrial conditions is done by the control and analysis of the output of sintering products (return, yield sinter, the content of fines in sinter). Based on the results of control, the dependence of the output of fines 0-5 mm on the work of sinter destruction is determined, and the coefficients \( g_0 \) and \( C \) are calculated. The achievement of the maximum content of fines in sinter is ensured by the correct ratio of \( g_0 \) and \( C \), it can be corrected in any particular case by the change of the preparation of charge and the mode of sintering.

The methods of non-destructive evaluation of strength properties of sinter are known. Thus, the authors of [9] considering sinter as an object of a complicated mineral composition with physical-mechanical properties characteristic for every phase, proposed the following equation of cold strength (SI) of sinter:

\[
SI = K_{si}Q\sigma_0(1-\varepsilon)^2,
\]  

(4)

where \( Q \) is the amount of melt which connects the phases of sinter (the degree of melting); \( \sigma_0 \) is the strength of the matrix; \( \varepsilon \) is the porosity; \( K_{si} \) is the coefficient of proportionality. Values \( Q, \sigma_0 \) and \( \varepsilon \) are determined by calculation.

Low accuracy of the determination of the strength indicator of sinter per the specified model (the coefficient of correlation \( R=0.675 \)) is connected, firstly, with the use of the properties of a low level element of the hierarchy (\( \sigma_0 \)) for the determination of strength of a high level element. The strength of the matrix (\( \sigma_0 \)) is connected not only to its mineral composition, but also with its structure, in particular, with the parameters of the distribution of material in sinter, grain size, porosity and the character of porosity of the mineral skeleton.

In [10] the information about the close connection of the strength indicator of sinter with its chemical composition is given through a so-called module of microstructure:
Based on the data of the author, the strength indicator of sinter of sinter plant in CIS per GOST 15137-77 is basically linearly \((R^2 = 0.879)\) increasing with the increase of the module of microstructure, which contradicts the existing industrial and experimental results. If we consider that the strength of sinter increases when \(M_m\) is increasing, then the higher the content of \(\text{FeO}\) in the sinter, the lower its strength, which is not consistent with reality. The dependence of the strength indicator of sinter on its basicity is non-linear. Besides, the cold strength of sinter depends on the macrostructure of sinter cake, its porosity and the character of porosity (first and second levels of the hierarchy). The module of microstructure reflects the properties of the lower elements of the structural hierarchy of sinter cake and cannot account for the cold strength of sinter.

The hot strength of sinter is closely connected to the parameters of the chemical composition of sinter [11], presented on Figure 2, that the lower elements of the hierarchy of sinter cake account for.

Thus, the phase transition from hematite to magnetite influences the strength after restoration, which is accompanied by the change of parameters of the crystalline grid and the creation of internal stress [5]. The strength after restoration depends on the fraction both of primary and secondary hematite, the content of which increases when increasing the fraction of \(\text{FeO}\) and \(\text{SiO}_2\) in sinter and increasing \(\text{Al}_2\text{O}_3\) content. \(\text{Al}_2\text{O}_3\) can also cause disruptions in the magnetite grid, which is created after the restoration of hematite and it can increase the internal stress. The basicity can influence the strength after restoration, also the fraction of \(\text{MgO}\) in sinter and other factors [12]. The influence of the chemical composition on the strength of sinter after restoration is quite significant, which allows us to use the dependencies determined in [11] for the analysis and the prognosis of its hot strength.

Conclusions
Thus, for the evaluation of yield and the indicator of the mechanical strength of sinter it is reasonable to use the methods based on the destruction and control of the grain-size composition of the products of destruction of sinter cake. The most informative method is the one which allows evaluation of the
fraction of structural fines in sinter cake and the indicator which reflects the strength of the blocks. The connection of the properties of sinter with its chemical composition becomes significant only when evaluating its strength after restoration.

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