Ideal Behavior of Sinter Block Densification and Relation Thereof to Yield and Strength in Iron Ore Sintering

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The authors assumed an ideal manner of sinter block densification due to increase in melt volume, and explained thereby changes in sinter strength and yield with operational factors such as ore porosity, CaO/Fe₂O₃ ratio and coke content.

Based on knowledge of liquid phase sintering, they drew polygonal lines to describe the change of sinter block strength with melt volume, which comprised two line segments for rapid and slow densification regions, where the position of broken point and the slope of later line segment reflected ore porosity as more porous ores sifted the broken point to more melt volume side and less strength and allowed the slope to turn from negative to positive.

After assuming a block strength distribution in sinter cake, they illustrated that relative location of the distribution curve to a polygonal line was to determine a sinter strength and a sintering yield, and predicted a disaccording manner of sinter strength to sintering yield and overmelting phenomena as a result of pairing of distribution curve’s transformation to line segment’s slope in the slow densification region.

KEY WORDS: block; iron ore sinter; liquid phase sintering; porous media; strength; yield.

1. Introduction

Sintering is a major process for agglomeration of iron ore fines adopted in Japanese integrated steel mills.

Microscopic studies have advanced the understanding of sintering: Sasaki et al.¹ investigated and summarized sintering reactions occurring along temperature history; K. Sato et al.² examined relations of sinter microstructure with sinter qualities. In reducibility, Sakamoto et al.³ related the microstructure to reduction rate, while many researchers pointed out the importance of microscopic pores in sinter for the reduction kinetics. In reduction disintegration, Inazumi et al.⁴ found hematite grains of special morphology, skeletal rhombohedral hematite, initiated cracks in sinter matrix; Sakamoto et al.⁵ diagnosed the texture consisting of prismatic Ca-ferrite and grassy slag as pathways liable for cracks to propagate. In strength, Kamisaka et al.⁶ pointed out the importance of +0.5 mm pores; S. Sato et al.⁷ determined an equation describing sinter strength as a function of matrix strength and porosity.

Mesoscopic approaches have evolved parallel, where Vergman et al.⁸ used a ‘block’ model to express heterogeneity in a piece of sinter. The approaches succeeded in identifying a general make-up within blocks and a manner of their formation during sintering but no mention of how blocks are arranged in sinter.

Macroscopic understanding of sinter cake structure, especially pore structure, has also been required to explain sintering yield and productivity. Kasai et al.⁹ made a first step of observing the pores in pot-made sinter cake and found an anisotropic structure therein; however, which refused successors owing to their time-consuming measurement method. Kasama’s applying X-ray CT technology¹⁰ triggered researches of the art, leading to valuable findings on the pore structure in sinter cake¹¹ and to dynamic observation of sintering phenomena.¹²

The micro- and mesoscopic works have allowed to predict sinter mineralogical microstructure and also to explain the sinter qualities thereby; the macroscopic CT analysis has provided a lot of information of sinter cake structure. Nevertheless, there seems no generic view explaining overall pore transformation from pores in feed bed to ones in sinter cake and to ones in sinter, and no idea to explain sinter yield in connection with sinter cake strength.

Therefore, after resuming another block model modified on a base of liquid phase sintering, we aim in this paper to set up an ideal manner of sintering and link it to sinter yield and sinter particle strength. To achieve this, after preparing previous findings to start with concerning pore structure in sinter and a classical view of liquid phase sintering in chapter 2, we will relate sinter block strength to pore transformation process as a function of melt volume in chapter 3, estimate sintering yield and sinter particle strength based on the sinter block strength, and finalize the estimation with verification by experiments of others in chapter 4.

2. Preparation of Previous Knowledge on Liquid Phase Sintering and Iron Ore Sintering

2.1. Definition of Macroscopic Structure for Sintering

Iron ore sintering undergoes three typical stages as materials: sintering feed bed, sinter cake and sinter; sintering
machines make a porous sintered continuum (sinter cake) from sintering feed; subsequent crushers and sieves disinte-
grate the continuum into sinter particles (sinter).

Sintering reaction, iron ore sintering in narrow meaning, is a member of liquid phase sintering. Admixing coke and limestone to sintering feed discriminates iron ore sintering from sintering in powder metallurgy or ceramics (powder sintering): the coke burns inside the feed bed so as to heat up the material rapidly; the limestone reacts with iron ore to form melt to bond the ore particles. Such constituents permit iron ore sintering to use larger particles and to finish in shorter time, comparing to the powder sintering.

**Figure 1** shows definitions to be used hereinafter for parts of feed bed, sinter body and particle from a structural point of view: Sinter body comprises solid (S) and void (V). The void comprises an interconnecting pore (Pi) and many closed ones (Pc); the Pi is separated by the cross-sectional morphology to large horizontally-spread fissures (Pf) and open pores (Po). The solid bisects into solidified part from melt (M) and un-reacted relict ores (R); the discrimination is useful from the strength point of view; M is generally weak than R as Ca-ferrite has less strength than hematite.

The same definitions are available for sinter particles.

### 2.2. Previous Finding on Pore Formation in Sintering Process

Liquid phase sintering means a process of melt’s formation and flow; in reverse, a process of pore’s coalescence and extinction. **Figure 2** is a combination of porosimetry results on sinter cake by Haratoh *et al*.\(^{13}\) and on sinter by Kasama *et al*.\(^{14}\), which shows:

Sintering feed bed includes an intercommunicating pore between granules, the volume of which is approximately estimated to be 50% according to 1.9 t/m\(^3\) of bed bulk density on dry base and 3.6 t/m\(^3\) of feed true density. After adding some porosity by dehydration, calcination and coke combustion to a maximum, the bed turns to reduce the volume owing to melt formation;

Sinter cake decreases in total porosity from 65 vol% at upper layer to 40 vol% at lower layer while it increases in 1–5 mm porosity from 5 vol% at the upper layer to 10 vol% at the lower layer. The result suggests of a sintering manner that pores decrease in diameter as sintering proceed from the upper layer to the lower layer. **Figure 2** neglected –1 mm pores owing to the limit of X-ray CT’s resolution and tentatively regards 1–5 mm pores as Pc, despite of another result from X-ray 3D observation\(^{15}\) that the pores in sinter body included a single Pi and many Pc; the critical diameter dividing between Pi and Pc were around 2 mm;

Sinter particles have the same magnitude of Pc, Po and convex on surface, 10–15 vol%. The result bases on the assumptions that the vacuum mercury method indicates Pc; the difference of the water method from Pc indicates Po; the difference of PAC method from Pc+Po indicates the convex. Moreover, the three porosities are in positive proportion, which suggests both of an intercommunicating pore and closed pores reduced in volume at the same time in the part of sinter cake that remains to be sinter particles.

**Nushiro et al.**\(^{16}\) using X-ray CT to dynamically see through live sintering bed transition, have pursued paths from feed bed to sinter cake on a chart of pore density and pore size, and found that any ore followed the same path from an initial point of green bed for a final point of sinter cake but the final point showed different stops on midstream locations as porous ores stopped in short. This is construed that sintering process proceeds in a unique way of densification and the final degree of densification is only governed by an effective melt volume excluding such volume that intruded in pores.

### 2.3. General View of Liquid Phase Sintering for Powder Metallurgy

German\(^{17}\) has put together classical views of liquid phase sintering, 1) classifying it into three stages by passing time and driving force: (I) rearrangement, (II) dissolution-precipitation, (III) solid diffusion [see Fig. 1.4 in his book]; 2) adding sub-stages for the first stage in case of polycrystalline particles: (I-1) primary rearrangement, (I-2) infiltration-fracture, (I-3) secondary rearrangement [see his Fig. 4.10]; 3) regarding melt volume as the primary driving force for the first stage with an illustration that the shrinkage of volume increases in proportion to melt volume ratio, attaining to the maximum of 40 vol% around 30–35 vol% of the melt volume.
ratio, where the porosity reduced to zero [see his Fig. 4.16].

There has been established an equivalent picture in iron ore sintering: Hida et al.\textsuperscript{18} observed under their high temperature SEM that the melt formed over a porous ore readily intruded inside, and inferred that porous ores melted down as a solid-liquid mixed fluid including closed pores after some melt formation while non-porous ores still sustained open pores between relict ore particles at the maximum melt evolution.\textsuperscript{19} Hida’s picture can be interpreted in German’s words that non-porous ore halts within the (I-1) stage; porous ores get to the (I-3) stage as far as the short time allowance of iron ore sintering permits both types of ores to take only the first rearrangement process (I).

3. Developing an Ideal Relation of Sinter Block Strength to Melt Volume for Iron Ore Sintering

3.1. Bridging from Liquid Phase Sintering of Powder to Iron Ore Sintering

German’s third clause suggesting the dominance of melt volume on the first stage of liquid phase sintering as in his Fig. 4.16 offers valuable insight for iron ore sintering. Still there is a wide divergence between both: iron ore sinter body retains a 40 vol% Pi though it forms more than 50 vol% melt, much more than that filling the closed packing space; meanwhile, as German stated, 30–35 vol% melt is enough to bring powder sintering the full compaction.

To fill the gap, we assume, inspired by a large scale cross-sectional photo [Fig. 1(a)] taken by Kawachi et al.,\textsuperscript{20} based on a drawing of sinter structure by Yamaoka et al.,\textsuperscript{21} that the iron ore sintering goes in melting zone, a thin 10 mm width layer, along the following three processes:

- Fissure formation: The melting zone is to shrink by the force of liquid capillary effect while the sinter zone on the melting zone is to stand still supported by side walls; therefore, the interface is prone to tear to make a horizontal large fissure. A lower water condensation zone is also to shrink; the drying zone between them readily cracks;
- Open pore formation: The melting zone must contain some amount of open pores for air to pass through against melt filling the pores, where the balance of air’s momentum and liquid’s surface tension seems to govern the appearance of open pores in the melting zone. Kawaguchi proposed the same idea of pore formation in his review;\textsuperscript{22}
- In-block sintering: In the other part in the melting zone (defined as ‘block’ hereinafter) narrowly-defined sintering reaction proceeds under the general view of liquid phase sintering referred in §2.3.

The former two processes must be essential to sintering bed permeation and cause the difference in final porosities between iron ore sinter and powder sinter. The in-block sintering probably determines strengths of sinter particles and those of sinter cakes, and dominates sintering yield as the fissures and the most of open pores come out to surfaces on sinter particles during crashing and affect little on their strengths.

3.2. Derivation of the Ideal Relation between Block Strength and Melt Volume during Rearrangement Process

On the assumptions: 1) block strength determines sinter and sinter cake strengths as discussed above, 2) fill-up of a open pore inside a block is critical for the progress of iron ore sintering instead of perfect filling for powder sintering, we will set forth an idea on the transformation of sinter block structure and derive the relation of the block strength to melt volume in shape of a polygonal line as shown in Fig. 3, which comprises:

- Rapid densification: On the lower side of melt volume axis, melt formation reduces the diameter of solid part of granule and the melt pull the solid part each other into tight contact. This process results in the rapid shrinkage of sinter block, leading to the rapid increase in the strength thereof. Such manner of shrinkage in this region links directly increase in melt volume to increase in block strength, which provides front line segments with steep slopes;
- Slow densification: After open pores substantially disappear inside blocks, still some amount of space between particles may remain as closed pores. If more melt formation accelerated the removal of the closed pores despite of their

\begin{align*}
\text{Increase in melt volume} & \rightarrow \\
\text{Fig. 3. Ideal change in block strength with melt volume, featuring rapid and slow densification that the fill-up of open pore divides.}
\end{align*}
small mobility in melt, the densification would proceed in a visible degree as second line segment (i) in Fig. 3 shows. However, it seems more likely that other effects turn to be more dominant and make negative the slope of line segment as shown (ii) in Fig. 3; the possible phenomena are, for example, 1) more pore formation due to more limestone or coke dosage necessary for generating more melt, 2) decrease in matrix strength due to the R-to-M transformation accompanied with increasing melt formation;

Broken point: The change of shrinking mode puts a broken point (Bp) on the strength-melt volume line between the rapid and slow densification regions. This point means a critical point where controllers of sintering change from Po to Pc, and will show the optimum melt volume where the strength attains to maximum.

The polygonal line obtained above in Fig. 3 corresponds to a virtual plain ore. Natural ores have characters, the most important of which for liquid phase sintering must be porosity, dense or porous, and uniformity, homogeneous or heterogeneous across grains, as well as an effect of ore blending. Their effects will be:

Pore-in-ore effect: Pores in ores, absorbing melt, will sift a broken point to higher melt volume; some of them, remaining after assimilation, will lower the point in strength. Figure 4 gives ideal profiles for a homogeneous dense ore as (i) and a homogeneous porous ore as (ii);

Heterogeneity effect: Heterogeneity in grains or mixing ores is expected to present itself as an average of homogeneous ones. Fig. 4(iii) shows a line obtained as an average of dense (i) and porous (ii) ores. The line for mixture holds some transient region after a rapid densification. The slope of slow densification in case of homogeneous ores and that of relatively flat transient region in case of heterogeneous ores will act an important role on discussing yield-strength relations later in chapter 4.

### 3.3. Confirmation of Block Strength-melt Volume Relation

To confirm the block strength-melt volume relation discussed in §3.2, we experimentally examined three ores of various porosities for the effect of CaO amount on block strength. Following the method previously published, we prepared 1 cc test blocks made from 2–3 mm single ore particles coated with limestone powder in various CaO/Ore ratios and measured their strengths after firing at 1 527 K; the ore type of the three ores ranges from A: a dense hematite ore to B: a porous ore premixed of ores mined at different pits, to C: a goethite porous ore.

Figure 5 includes the results, which have in perfect agreed with the prediction shown in Fig. 4: the line for Ore A shaped as same as dense ore (i) in Fig. 4, which reasonably came from the fact that Ore A was really a dense ore; the line for Ore C shaped like (ii) for the porous though the broken point did not appear within the experimental range of CaO; the line for Ore B behaved like (iii) for the mixed, showing an averaged manner of Ore A and Ore C because Ore B was a mixture from various pits.

The agreement of the prediction to the experiment has verified the idea mentioned hereinafter related to change in sinter block strength with melt volume and ore porosity.

### 3.4. Other Practical Factors Affecting Block Strength

It is worth noting other factors than ore character and CaO/Ore ratio that affect block strength [Table 1]. Relational expressions relevant to liquid phase sintering are: 23)

For a capillary pressure ($\Delta P$),

$$\Delta P = \gamma \cos \phi \frac{r}{2}$$

For a rate of rearrangement ($d(\Delta L/L_0)/d\theta$),

$$d(\Delta L/L_0)/d\theta = V_M \Delta P / (2 R \mu)$$

For a distance of melt intrusion ($\chi$),

$$\chi_{ij}^2 \theta = \tau \gamma \cos \phi (2 \mu)$$

These equations suggest that the primary factor should be melt volume. Sintering temperature is the other factor than CaO/Ore ratio that determines the melt volume. The $Fe_2O_3$–CaO phase diagram informs both effects: A typical feed ($FeO_{10}$mass%CaO) could locally generate initial melt at 1 478 K; in equilibrium, it starts to melt at 1 499 K with 50 mass% melt; over the temperature the melt increases by 0.15 mass%/K. At the typical sintering temperature of 1 573 K, the amount of melt lineally increases from 0 mass% to 100 mass% as CaO content increases from 0 mass% to 28 mass%.

The secondary factors should be concerning melt character, i.e. $\chi$, $\phi$ and $\mu$. Nothing may be investigated on the

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**Table 1.** Substage in the rearrangement process I occurring first in liquid phase sintering and factors in formulae and in operation.

| Sintering Stage I | Factors | Operational |
|-------------------|---------|-------------|
| in formulae       |         |             |
| -1) Primary rearrangement | $V_M$ | Temperature |
| -2) Infiltration | $R$ | CaO/Ore |
| -3) Secondary rearrangement | Particle size of ore |
| Fracture          | $\mu$, $\chi$, $\phi$ | Porosity in ore |
|                    | $r$ | Gange in ore |
|                    | $\mu$, $\chi$, $\phi$ | (SiO$_2$, Al$_2$O$_3$) |
former two factors, but Machida et al.\textsuperscript{24} have measured the viscosities of melts for iron ore sintering and found negative effects of SiO\textsubscript{2} and Al\textsubscript{2}O\textsubscript{3} on the viscosities. The Al\textsubscript{2}O\textsubscript{3} and SiO\textsubscript{2} components are associated with ore gangue and coke ash in practice.

4. Estimation of Correspondence between Sinter Particle Strength and Sintering Yield

In sintering plant operation the strength of sinter cake or sinter block is far from direct measurement, whereas sintering yield is monitored and sinter particle strength is periodically measured as Ti/Sl. Linking sinter block strength to yield and Ti/Sl, therefore, is indispensable for practical use, which involves the next subject.

4.1. Linking Block Strength to Sintering Yield or Sinter Particle Strength

Hereinbefore sinter body was implicitly assumed to be homogeneous and to have a unique strength; hereinafter sinter body will be assumed to be aggregate of blocks having different strengths of the normal distribution due to the heterogeneity of melt formation reflecting the fluctuation of coke’s and limestone’s sizes and positions in feed bed. Additionally, another critical strength is introduced that separates sinter product and return fines (Sp); the yield-determining critical point (Sp) must locate just below the broken point (Bp), because sintering operators in rapid densification region will add and save coke due to large gain in yield while those in slow densification region will waste coke with the same action due to small gain in yield.

Figure 6 includes a polygonal line for the mean block strength on the melt volume-axis and a distribution curve of the local block strength on the same axis, both of which locate in a likely relative position as mentioned above. The horizontal dashed line denotes the strength separating product sinter and return fines, the two intersections of which with the mean strength line are the said Sp. The vertical dashed lines passing through the Sp divide the area under the distribution curve, the hatched portions of which meet the amount of return fines. The region till the front Sp is regarded as under-melting sintering; the region over the back Sp is as over-melting.

Finally, the discussion so far with conjunction of Fig. 6 will lead to the following equations linking block strength to yield ($\eta$) or sinter particle strength ($\sigma$).

$$\eta = \int_{x_1}^{x_2} D(x)dx$$ ................................ (4)

$$\sigma = \int_{x_1}^{x_2} P(x)D(x)dx/\eta$$ ................................ (5)

where $x_1, x_2$; melt volume at the front, back separating point

D(x): distribution curve for block strength

P(x): block strength as a function of melt volume (polygon line)

4.2. Variety in Yield-strength Correspondence

Subject to the above-said assumptions, various correspondences between yield and strength emerge as a result of pairing the slope of the second line segment to the change of distribution curve. Below shows a case study where the slope is set to be positive, neutral or positive, and the curve to change in the mean or the deviation of distribution. In practice, ore characters affect the slope as discussed in §3.2; operational actions can cause the change of curve, e.g. adding coke will sift the mean to more melt volume, modification of charging apparatus will narrow the deviation. Figure 7 includes typical cases as follows:

Case-1a: Fig. 7(a) shows a case in which a block strength’s line segment has positive slope and a distribution curve changes in the mean. When the distribution curve moves from (1) to (2) by an operational action for increasing melt volume, obviously, it increases the yield and the average strength of product sinter simultaneously;

Case-1b: Fig. 7(b) shows another case with a neutral segment. The like movement of the distribution curve by the like action increases yield; but it does not much change the product’s strength;

Case-1c: Fig. 7(c) shows another case with a negative segment. This case has a back Sp. The same movement of the distribution curve in this situation increases the yield at first, but turns to decrease it when the yield loss in the over-melting region becomes significant; meanwhile, the product’s strength gradually decreases as the slope of line segment is negative;

Case-2b: Fig. 7(d) is for narrowing the dispersion of a strength distribution with a neutral segment. The change in the distribution achieves a gain in yield; but it may lose the mean strength of product.

This section has predicted various correspondences between yield and strength in connection with ore characters (the shape of polygonal line) and operational actions (the change of distribution curve), all cases of which are summarized in Table 2.

4.3. Validation by Previous Pot-test Works

Many works have been carried out on the effect of CaO content or basicity on sinter yield and sinter particle strength, and will be available to confirm the linkage. It seems difficult to verify Eqs. (4), (5) directly with compar-
ing such data because it remains unknown of how to convert $\eta, \sigma$ to yield, SI/TI; otherwise, the qualitative yield-strength correspondence derived in §4.2 will be confirmed. The following references reported particular strength-yield corre-

spondences without explanation. This section will make an explanation how the correspondences appeared.

4.3.1. Ore Effect with Varying CaO Amount

Hida et al.\cite{25} have pot-tested three ores of low SiO$_2$ content, 1.0, 2.0 and 3.5 mass\%, with varying CaO amount in feed and investigated the effect of CaO on yield and SI strength. Figure 8(a) shows a skeleton remained after deleting data plots from their original figure. Wherein they have proposed $R_{CaO} = (CaO\% - 1.2SiO_2\%)/Fe\%$ as a universal index for melt volume and determined a unique bijection of yield on the $R_{CaO}$ or SI on the $R_{CaO}$.

Their SI curve appears with the exactly same feature as the Case-1c block strength line for non-porous ore of Fig. 7(c). The ore they employed is guessed to be Carajas; some may object to classifying the ore to non-porous ores, but they will agree that the progress of sintering lower the block strength as Carajas relict ore has larger strength than Ca-ferrite matrix.

Their yield curve has two bends tied by a segment of negative slope. The pattern is a natural consequence from the Case-1c; i.e. the negative slope of segment is right a prediction as the negative slope of block strength for non-porous ore; the sharp fall in yield beyond the later bend is recognized as the overmelting phenomena occurring with negative slope of slow densification.

Thus, our view has explained their case related to ore effect on sintering yield and SI.

4.3.2. Coke Effect with Varying CaO

Kawaguchi et al.\cite{26} have pot-tested CaO and coke effects on yield and TI strength, and showed that the yield linearly increased with the increase in CaO content, where coke content stratified the yield-CaO correlations in natural sequence. TI behaved in a somewhat strange manner: TI monotonically increased with increasing CaO and showed deceleration in higher CaO region; meanwhile the TI-CaO correlation was free of coke content [Fig. 8(b)].

The Case-1a line will meet to this case and explain the change in both yield and TI with CaO; however it seems difficult to explain the coke effect. The increase in coke con-

![Fig. 7. Typical paring of change in block’s densification profile to change in its strength distribution curve in sinter cake, offering various yield-strength correspondences.](image)

![Table 2. Yield-strength correspondence as a result of pairing of ore type affecting slope of transient region to operational action affecting distribution curve.](table)

| Change of distribution curve | Effect on (a) positive | Effect on (b) neutral | Effect on (c) negative |
|-----------------------------|-----------------------|----------------------|-----------------------|
| (1) Increase in melt volume | $\Delta \eta$ Increase Increase Increase then decrease |
| (2) Narrowing the dispersion | $\Delta \sigma$ Increase Unchange Decrease |

![Fig. 8. Previous pot-test results on yield and strength change by (a) ores and CaO, and (b) coke and CaO according to Hida and Kawaguchi, respectively.](image)
tent must primarily have increased melt volume, which was supported by the increase in yield; however, it did not affect TI at all though the same effect was expected. The contradiction is requesting to explore another negative effect of coke on TI such as Pc evolution, melt viscosity increase by SiO₂ and Al₂O₃ introduced from coke.

4.4. Comparison with Other Sintering Views

Both indices of yield and TI/SI represent physical strength. Everyone may expect that a single action will cause the both to move in the same direction though he is aware that the fact won’t be so simple from daily operations and some pot tests like above. Our view, if an idea, will explain the disaccordant manner of sinter strength and sintering yield, and overmelting phenomena, except the coke case on TI.

It is fair to refer to other views of sintering:

Inazumi et al. have showed the existence of critical coke content at 6 mass%, beyond which sintering yield and SI decreased despite of increasing coke content, and explained the fact by a percolation theory that excess bond making bipolarizes the size distribution of clusters. Their explanation well agrees the fact of decrease in yield over the critical, but seems out of way to explain the disaccordant manners of yield and strength.

Kasai and Kawaguchi have enlarged Hida’s idea of porous ore’s behavior and stated that the range of optimum melt volume is so narrow for the ores that less melt formation leaves no bond-contributing melt on them; more melt formation segmentalizes and fluidizes their relict ores resulting in no use to support the bed for permeation, comparing to non-porous ores. Such sintering view seems more suitable for coping with open pore formation rather than in-block sintering at issue, and therefore is capable of explaining the change in productivity and yield as Matsumura applied it to a pisolitic ore operation that excess melt for block sintering at issue, and therefore is capable of explaining the fact of decrease in yield over the critical, but seems out of way to explain the disaccordant manners of yield and strength.

The strength of sinter block on melt volume behaved as a polygonal line including rapid and slow densification regions, where the position of broken point and the slope of later line segment reflected ore characters. More porous was the ore, the broken point appeared to higher melt volume and less strength; ore heterogeneity introduced a transient region between rapid and slow densification regions, and affected the slope of the transient region.

Sinter strength and sintering yield were formulated in terms of product-return separating strength and relative location of the distribution curve of the local strength to the polygonal line, which explained over/under-melting manners during sintering. The paring of slope of transient region and change of distribution curve made various sinter strength-sintering yield correspondences.

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