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Solving the Problem of Silicon Dioxide Melting Based on Deviation Model

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ABSTRACT

In order to reveal the dissolution behavior of iron tailings in blast furnace slag, we studied the main component of silica in iron tailings. First, edge contour features need to be established to represent the melting process of silica. We choose shape, perimeter, area and generalized radius as objects. By independently analyzing the influence of these four indexes on the melting rate, the area and shape were selected as the characteristic parameters of the edge contour of the silica particles. Then, the actual melting rate of the silica is estimated by the edge contour feature index. Finally, we can calculate the melting rate of the first second of three time periods of 0.00010312mm³/s, 0.0002399mm³/s, 0.0000538mm³/s.

1. Introduction

Background

Silica has stable physical and chemical properties, it has a high melting point and boiling point, it doesn't react with acid. And hot strong alkali solution, molten caustic soda, reaction to silicate and water. At high temperature, it reacts with a variety of metal oxides, silicate formation. Therefore, in the tailings waste of various mines, silica often occurs. Let's take iron tailings as an example, in China, the content of silicon dioxide in some iron tailings can reach 75%. As a result of silica has high melting and boiling point, highest than others. Therefore, when people are smelting metal ore, so melting behavior of silica expresses melting behavior of iron tailings tank^[1]. But, the temperature of high temperature melting pool exceeds 1500 °C, when measuring the temperature of silica

in the high temperature melting pool by direct contact, will lead to shorter instrument life. Therefore, relevant research groups utilization system, which a CCD video shooting system with magnification effect. Analyzed the fixed value rate of silica in time series, tracked the process of silicon dioxide heating and melting.

In order to analyze the melting behavior of silicon dioxide better, the index which can describe the edge profile of silicon dioxide is established.

According to the characteristic index of silica edge profile, a three-dimensional model of silica particles is established. The volume of silicon dioxide particles is determined by the establishment of three-dimensional model, and the actual melting rate of silicon dioxide is determined by the reduction of the volume of silicon dioxide particles in the photos taken by the CCD video shooting system^[2].

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2. Problem Analysis

According to the requirements of the topic, we need to set a series of indicators, to characterize the edge profile of silica. Find out the relationship, which the relationship between index and silicon dioxide melting process. Finding indicators, which index having decisive influence on the melting rate of silica. Physical properties of four kinds of silica particles, which shape, perimeter, area and generalized radius, to analyze the change of perimeter. By building lattice on time series graph, analysis of silica particles, which area and radius^[3]. Also, high temperature treatment to silica, analyzed the relationship, which shape and melting rate. Through the comparison of four indexes, determined the edge contour feature index.

From the fact that the known mass is proportional to the three-dimensional volume, the density of silica is a constant value. Therefore, we turn complexity into general. also, we have replaced silicon dioxide of unknown shape and size with exact shape. In the second question, number of small squares, it represents the area index with the largest correlation coefficient. Then, we divided the picture into three stages. Using SPSS regression, fitting method, drawn the function curve, which melting rate and area of silica. Lists the corresponding function expressions, to obtain the actual melting rate of silica.

3. Assumptions

- (1) Assumed the air resistance is not considered during the movement of silica.
- (2) Assumed the static friction with the crucible will not be taken into account when the silica particles move.
- (3) Assumed that the viscous force produced by the relative motion of silica with air is not taken into account.
- (4) Assumed that the polymerization between silicon dioxide and oxygen molecules is not considered.
- (5) Assumed that when corundum crucible heats silicon dioxide, the heating temperature of silicon dioxide does not change.

4. Determination of Edge Contour Index

To determine indicators, which the profile of silica that can represent the melting process. We chose four indicators, that shape, perimeter, area and generalized radius. Research separately, that whether these indexes are related to melting rate^[4].

4.1 Shape

In the melting process, shape of silica, which from irreg-

ular shape to approximate cylinder, and then gradually approach to the sphere. For the sake of study, whether the melting process is related to shape, we can do experiments to verify it. In the experiment, we make the slag into a cylinder, as the temperature increases. Liquid volume will increase, sample shape will change, cylindrical specimen is sintered and shrinks. And then gradually melt, the height of the sample keeps decreasing^[5]. As shown in Figure 1.

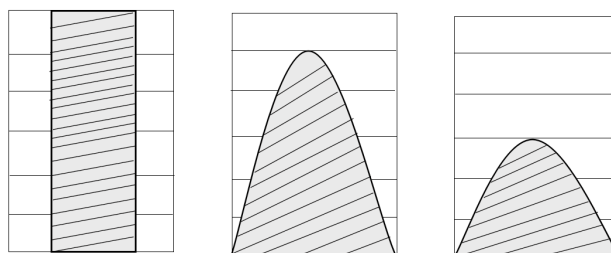


Figure 1. Specimen height change during melting

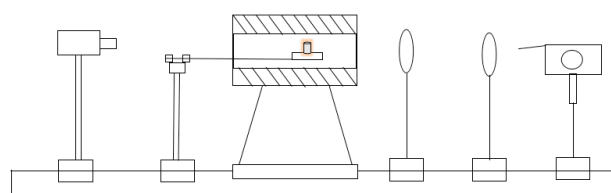


Figure 2. Melting point and melting temperature measuring device

As shape changes, like that, this experiment verifies the impact, which solid shape vs. melting rate. With the aid of the instrument shown in Figure 2, by adjusting the position of the objective and eyepiece, make the sample image on the screen, which clear magnified image. Then adjust the up and down positions on the left and right of the screen, place the magnified image of the sample, between the six horizontal scale lines of the screen. To observe the melting characteristic temperature. At a certain heating rate, continuously record the remaining area of melting. Then we can get the curve, which melting rate changes with time. It can be seen from the curve, that when the solid shape changes from cylinder to mound, increase of melting rate^[6]. Similarly known, in the melting process of silica, when the shape changes from irregular objects to regular objects, increase of melting rate.

4.2 Area

In the melting process of silica, from start to end, silicon dioxide area is decreasing. To explore the relationship, which between melting rate and area, we can calculate the area of silica in 1s. Then, put silicon dioxide melting diagram on grid line, use small grid to express area. As

shown in Figure 3.

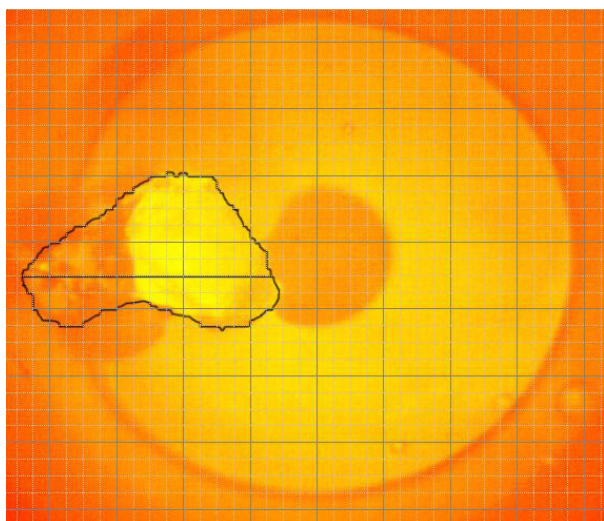


Figure 3. Calculation diagram of area, perimeter and generalized radius

Thus, we can calculate the residual area of silicon dioxide at each time. Select three melting stages, each segment of 10s. The first stage is the initial stage of melting, from 497 to 506. The second stage is the intermediate melting stage, from 550 to 559. The third stage is the final melting stage, from 592 to 601. As shown in Table 1 (Data from the following tables, is phase I and phase II. In the molten state, area, perimeter and diameter's data. See the appendix for the data of the third stage.) According to unit time, reduction of area. Can obtain the relationship between area and melting rate.

Table 1. Edge profile index data

Stage one	Area	Perimeter	Diameter	Stage two	Area	Perimeter	Diameter
497	130	49	16	550	38	34	10
498	123	53	18	551	28	26	8
499	113	54	17	552	26	25	7
500	111	53	19	553	23	18	6
501	109	43	13	554	19	23	7
502	95	45	14	555	20	22	7
503	81	40	15	556	22	22	7
504	78	38	14	557	18	20	8
505	74	42	10	558	16	17	6
506	60	48	12	559	14	14	5

The area reduction rate, of the three stages is shown in Figure 4. Can be found, melting rate of the third stage, significantly less than the first stage. Therefore, we can come to a conclusion, the smaller the area, less contact

with the outside world. So less heat absorption, the slower the cooling rate^[7].

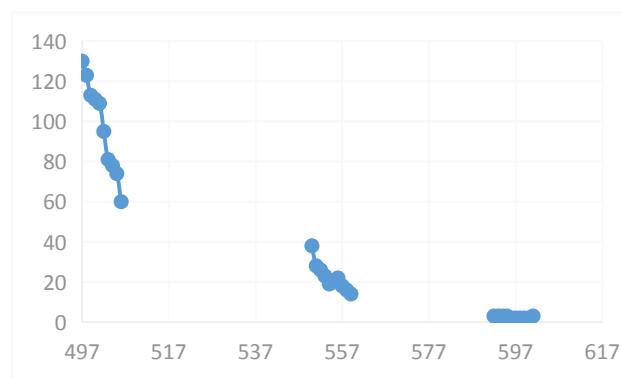


Figure 4. Area change with time

4.3 Perimeter

To explore the process of melting, relationship, that circumference and melting rate. We still choose three stages, to when exploring the area. Circle silica, the number of small lattices surrounding silica is the perimeter length. As shown in Figure 3. According to the change of perimeter in Table 1. We can come to a conclusion: Because of the uneven melting in some places, cause circumference not to change linearly. As shown in Figure 5. So the perimeter does not represent the melting process of silica.

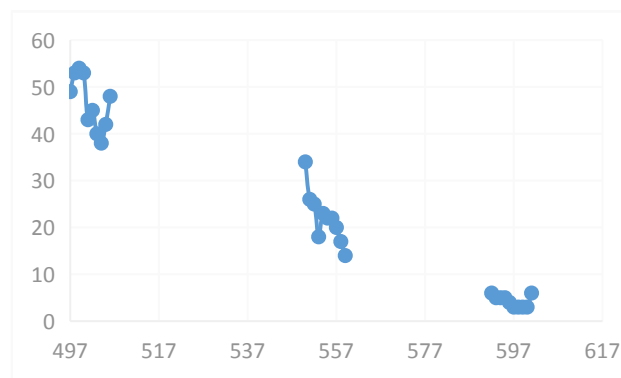


Figure 5. Variation of circumference with time

4.4 Generalized Radius

Redefining the melting state, the longest radius of silicon oxide is the generalized radius. Empathy, the above three stages are still selected, calculating the length of the generalized radius. To reduce the error, we chose the diameter and length here. As shown in Figure 3. And organize the data into table 1. From what we can get, according to figure 6, the relationship between generalized radius and time. So generalized radius can not represent process, which the melting process of silica.

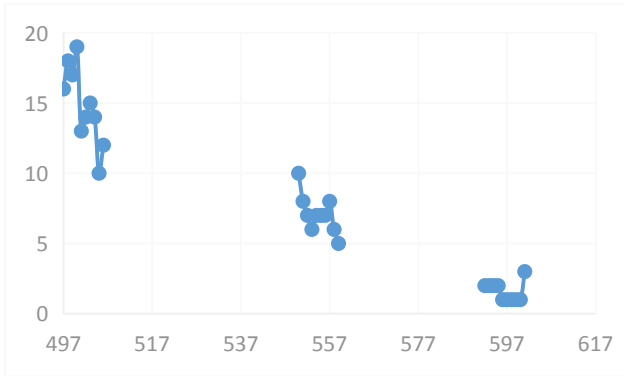


Figure 6. Generalized radius versus time

5. Deviation Model based on Melting Rate

5.1 Model Preparation

The mass is directly proportional to the 3D volume, indicating that the density of silicon dioxide is constant. It can be seen from the review that the density of silicon dioxide is 2.2 ~ 2.66g/cm³. Generally, in the heating process, the volume of drugs will not exceed 2/3 of the total volume, so the density of silicon dioxide can be taken as 2.4g/cm³, and the volume V=64mm³, so it can be seen from $m = \rho V$, $m = 0.1536g$, the mass m is 0.1536g. We know that the shape and area can represent the edge contour characteristics of the silicon dioxide melting process [8]. Because the shape of silicon dioxide will change randomly with the melting process, the shape is an unstable parameter. Therefore, we can choose regular prism as the initial solid in this topic.

5.2 Establishment and Solution of the Model

Taking the prismatic silicon dioxide crystal with mass of 0.1536g as an example, according to the influence of the area on the melting rate, SPSS can be used to fit the change of the area of three stages with time, that is, the melting rate of silicon dioxide in unit time. Because the key parameter of silicon dioxide melting rate is mass, and the melting rate is directly proportional to mass, if there is no influence of area on the melting rate, the corresponding relationship between them should be linear function. Now, the actual melting rate of silicon dioxide is estimated by the edge profile characteristic index of silicon dioxide.

Analyze the impact of the first phase, which influence of area on melting rate. Fitting with SPSS, get the function of area changing with time. Establish deviation model. It is found, that the fitting degree of cubic function is the highest $R^2=0.978$. As shown in Figure 7. According to the fitted coefficient, get the relationship between area and time: $x=0.198t^3-0.597t^2-0.589t$, this is the effect of area on

melting rate. Plus, the effect of mass on melting rate. So, the relationship between melting rate and these two factors is

$$V_1=am+b(0.198t^3-0.597t^2-0.589t)$$

$R^2=0.978$. Fair and reasonable, the second melting rate is

$$V_2=am+b(3.866t^3-7.133t^2-2.584t)$$

$R^2=0.681$. As shown in Figure 8. The third melting rate is

$$V_3=am+b(10.135t^3-14.170t^2+3.878t),$$

$$R^2=0.936. \text{ As shown in Figure 9.}$$

Therefore, in the three stages, the relationship between melting speed and time is as formula (1).

$$\begin{cases} V_1=am+b(0.198t^3-0.597t^2-0.589t), R^2 = 0.978 \\ V_2=am+b(3.866t^3-7.133t^2+2.584t), R^2 = 0.681 \\ V_3=am+b(10.135t^3-14.170t^2+3.878t), R^2 = 0.936 \end{cases} \quad (1)$$

This formula is actual melting rate of melting rate. When the mass is 0.1536g, three stages first second, which instantaneous melting rate.

Namely: 0.00010312mm³/s, 0.0002399mm³/s, 0.0000538mm³/s.

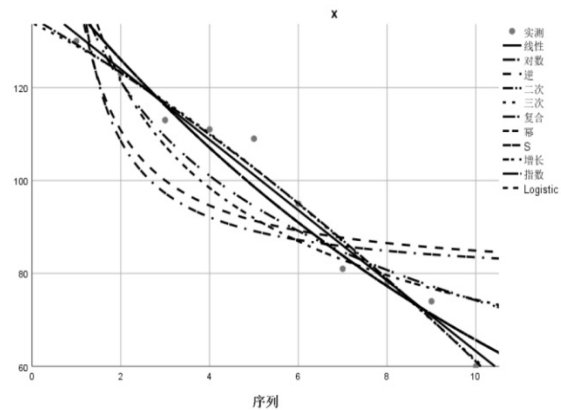


Figure 7. First stage fitting function diagram

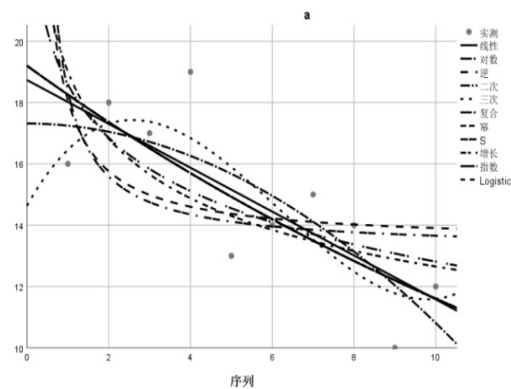


Figure 8. Second stage fitting function diagram

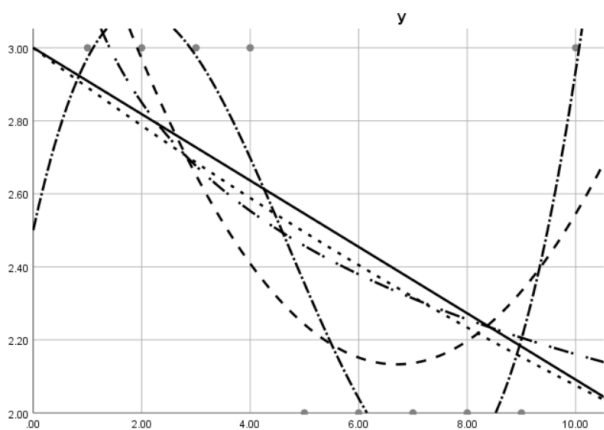


Figure 9. Third stage fitting function diagram

6. Conclusion

From the above analysis we can obtain the relationship between shape, area, perimeter and generalized radius and melting rate. The area has the greatest relationship with the melting rate. The smaller the area, the smaller the contact with the outside world, the smaller the heat absorption, and the slower the cooling rate. There is a certain correlation between the shape and the melting rate. During the melting process of silica, the melting rate increases when the shape changes from irregular object to regular object. However, the influence of shape on the melting rate is not as great as that of area. Perimeter and generalized radius have no or little correlation with melting rate and have no decisive influence on the change of melting rate. Therefore, area is selected as the characteristic parameter of the edge contour of silica particles, and the shape of silica particles is taken as a reference, while perimeter and generalized radius are not suitable for the characteristic parameters of the edge contour of silica particles.

We use the image overlay technology of MATLAB to process 114 pictures. Then 10 photos are selected from three stages for regression analysis, and the most characteristic index area of edge contour is used to solve the melting rate of silica. After SPSS regression fitting, the fitting curve of three stages can be drawn. When the mass is 0.1536g, the instantaneous melting rates in the first second of the three stages are 0.00010312mm³/s, 0.0002399mm³/s and 0.0000538mm³/s.

7. For Inspection of the Models

The actual melting rate of silica based on the best fitting degree selected by SPSS fitting, according to the fitting function $p(x) = a + bx^j$, three functions are fitted out, and that:

$$a = \left(\sum_{i=1}^m y_i \sum_{i=1}^m x_i^2 - \sum_{i=1}^m x_i \sum_{i=1}^m x_i y_i \right) \left(m \sum_{i=1}^m x_i^2 - \left(\sum_{i=1}^m x_i \right)^2 \right)$$

$$b = \left(m \sum_{i=1}^m x_i y_i - \sum_{i=1}^m x_i y_i \right) \left(m \sum_{i=1}^m x_i^2 - \left(\sum_{i=1}^m x_i \right)^2 \right)$$

$$R = \frac{\sum_{i=1}^m x_i y_i - \frac{1}{m} \sum_{i=1}^m x_i \sum_{i=1}^m y_i}{\sqrt{\left[\sum_{i=1}^m x_i^2 - \frac{1}{m} \left(\sum_{i=1}^m x_i \right)^2 \right] \left[\sum_{i=1}^m y_i^2 - \frac{1}{m} \left(\sum_{i=1}^m y_i \right)^2 \right]}}$$

In general, $R > 0.95$ can be considered to have a good correlation. According to the calculation of the third question, the R index obtained ($R_1=0.989$, $R_2=0.825$, $R_3=0.935$) can indicate that the first stage conforms to the fitting function. This is the actual melting rate of silica.

References

- [1] Hong Zeng, Jian He, Lin Wu, Songquan Zhang, Daiyin Zhao, Zhaohong Yang, Xiufang Gong, Gongxian Yang. Application of amorphous silica in investment casting[J]. Dongfang turbine, 2019(01): 55-57.
- [2] Jianping Xu, Zhaoxiong Zhang. Determination of total silicon, silicon dioxide and other impurities in industrial silicon by melting sample preparation-x-ray fluorescence spectrometry[J]. Physical and chemical examination (chemical volume), 2019, 55(02): 187-192.
- [3] Ningning Wang. Study on polylactic acid copolymerization and nano silica composite modification[D]. Henan University, 2012.
- [4] Jingzhi Zheng. Dispersion and properties of polypropylene / micro and nano silica composites[D]. Huazhong University of science and technology, 2010.
- [5] Wei Zhou. Study on the preparation of nano and micro silica particles by melting[D]. Wuhan University of technology, 2010.
- [6] Xi Liu. Preparation and properties of nylon 6 grafted on the surface of nano silica[D]. Hunan University, 2010.
- [7] Jing Qian, Ruixia Yang, Chao Li. Determination of silica in fluorspar[J]. Metallurgical standardization and quality, 2009, 47(03): 41-43.
- [8] Chen Minjie, Tian Guohua, Zhang Yong, Wan Chaoying, Zhang Yinxi. Effect of silica on crystallization and melting behavior of isotactic polypropylene and copolymerized polypropylene[J]. China plastics, 2005(10): 30-34.