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Research article

An index of fluidity-temperature area for evaluating cohesiveness of coking coal by Gieseler fluidity characterization

Yang Guangzhi[a,b,*], Shi Ting[a], Zhang Qifeng[c], Cao Yinping[d], Zhang Weiji[a], Wu Xinci[a,d], Li Jing[a,b], Yang Junhe[a,b,*]

[a] *School of Materials Science and Engineering, University of Shanghai for Science and Technology, Shanghai 200093, China*
[b] *Shanghai Innovation Institute for Materials, Shanghai 200444, China*
[c] *Manufacturing Management Department, Baoshan Iron & Steel Co. Ltd., Shanghai 200941, China*
[d] *Iron-making Department, Baoshan Iron & Steel Co. Ltd., Shanghai 200941, China*

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ABSTRACT

Gieseler fluidity characterization is an important method to evaluate the fluidity of coal which highly influences the cohesive properties of coke formation. A concept of fluidity-temperature area S_{lgF} instead of maximum fluidity lgMF was put forward to be used as the index of Gieseler fluidity characterization. Thirty-five coal samples were tested by Gieseler characterization and the sensitivity for identifying coal cohesiveness by S_{lgF} and lgMF were compared. It was found that S_{lgF} has a more sensitive resolution of coal fluidity than lgMF and it could give a correct result for judging coal cohesiveness in accordance with the comprehensive cohesiveness in most cases, especially for coals having almost same lgMF values.

1. Introduction

In iron-smelting industry, coke is one of the basic raw materials and plays essential and irreplaceable roles for blast furnace (BF) of fuel, reductant, carbon source and frame-supporting [1]. With the development of large-size for BF and the introduction of injecting pulverized coal, less coke is used to support the burden and a longer residence time is lasted [2]. Some roles of coke may be partially replaced by pulverized coal while the supporting role becomes increasingly important because of heavier burden on per unit coke with more reaction gases and retaining time. Therefore, there is an everlastingly strict demand for coke quality, especially tumbling strength. So, the blending coals used for coking should be chosen carefully by considering many properties, such as proximate analysis, mineral analysis, caking property and so on [3–5].

In general, enough cohesiveness of coal is essential and it ensures a good caking property for coke formation. Coal cohesiveness is usually evaluated by four indexes, which are maximum thickness of Y, cohesive index value of G, Audibert-Arnu dilatation of a + b and indexes of Gieseler fluidity. They evaluate the quantity or quality of coal cohesiveness more or less from different aspects and some studies have tried to study the relationship between Gieseler fluidity and other cohesiveness indexes [6–9]. Maximum thickness of Y is the index for indicating the quantity of coal cohesiveness. Cohesive index of G characterizes the bonding strength of coal and the lumpiness of coke formed. Audibert-Arnu dilatation of a + b reflects the thermal expansion of pyrolyzed products and the pressure of generated gas of coal, which has a preferable ability to distinguish the strongly caking coal [10]. Gieseler fluidity documents the fluidity of coal, which is adopted as a key parameter in the evaluation of feedstocks for coking [11]. There have been many papers on evaluating coal cohesiveness by Gieseler fluidity. Yuuki Mochizuki et al. [12] found that the addition of S-containing compounds, such as elemental sulfur, FeS_2, diphenyl disulfide and dibenzothiophene will decrease coal fluidity. Francisco Gayo et al. [11] studied the plastic behavior of coal when mixed with multicomponent wastes containing five most common thermoplastics in household streams and developed a mathematical model to estimate the extent of fluidity reduction as a function of the composition of plastic waste. T. Yoshida et al. [13] showed that dynamic viscoelasticity could be successfully measured by using a rheometer for coking coals and the obtained viscoelastic properties were compared with the Gieseler fluidity parameters.

Generally, lgMF value is used to evaluate the fluidity characteristic of a coal in Gieseler fluidity testing. In this paper, the fluidity curve of Gieseler testing was analyzed and it was found that lgMF as a single data was insufficient to represent the whole fluidity of coal which had a successive and complete fluidity curve. What's more, sometimes it was difficult to distinguish coals of different cohesiveness with similar lgMF

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* Corresponding authors at: School of Materials Science and Engineering, University of Shanghai for Science and Technology, Shanghai 200093, China.
E-mail addresses: yanggzh@usst.edu.cn (G. Yang), jhyang@usst.edu.cn (J. Yang).

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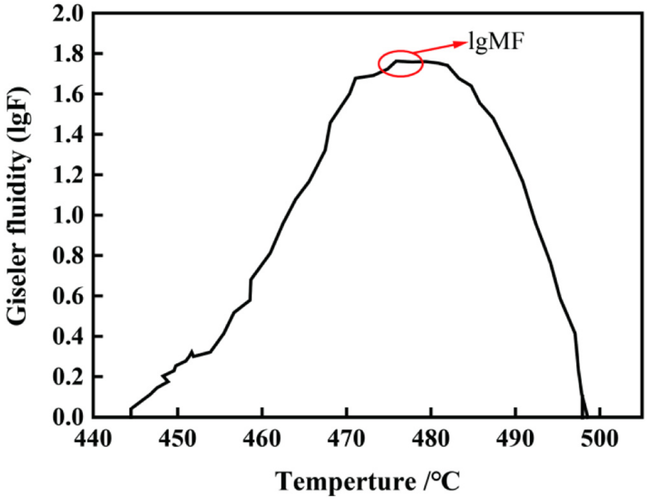

Fig. 1. Gieseler fluidity curve of a coal sample.

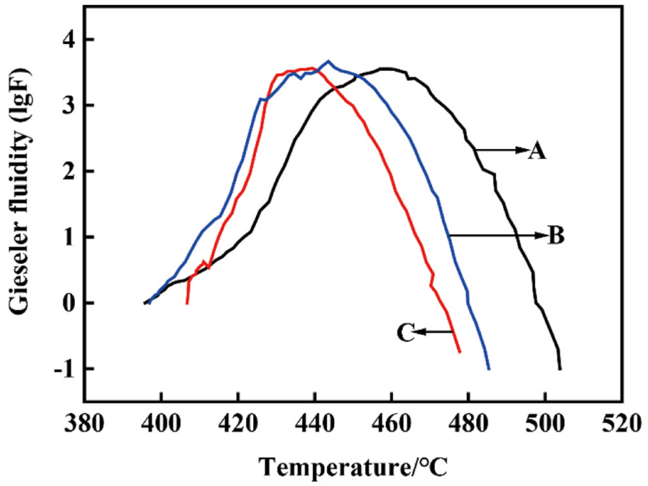

Fig. 2. Gieseler fluidity curves of coal A, B and C with similar lgMF.

Table 1
Cohesiveness indexes of coal A, B and C with similar lgMF.

Coal sample	a + b/%	G	Y/mm	lgMF
A	149	96	24	3.55
B	117	91	17.5	3.67
C	70	85	13.5	3.56

values. A fluidity index of S_{lgF} as the area of fluidity-temperature curve was put forward. It was found that compared with lgMF, S_{lgF} had a higher correlation with comprehensive coal cohesiveness and a more sensitive resolution for coal fluidity. Besides, S_{lgF} can generally distinguish well for many coals which have almost the same values of lgMF.

2. The introduction of fluidity-temperature area index and experimental

2.1. *The introduction of fluidity-temperature area index*

Gieseler fluidity is used to testing the fluidity properties of coal during softening process, which can reflect the adhesion ability of coal metaplast. A fluidity curve is often shown and the collected data are maximum fluidity (lgMF), soft-solid temperature range (T_r-T_s, °C), temperature of maximum fluidity (T_f, °C), temperature of onset softening (T_s, °C) and temperature of solidification (T_r, °C). Generally, lgMF is singly used for characterization the Gieseler fluidity properties which is the value at the apex of fluidity curve, representing the maximum fluidity during the whole softening period.

Fig. 1 is the Gieseler fluidity curve of a coal sample and the position of lgMF is labeled as red circle which represents the single point data of maximum value on the curve. However, the fluidity curve is a serial and successive curve which contains a huge amount of fluidity-temperature data. It is incomplete to evaluate coal cohesiveness by only using one point of the fluidity curve which contains so much information.

In theory, the whole fluidity curve comprehensively represents the behavior of a coal and there is a possibility that coals with different fluidity curves may have similar lgMF values, which may lead to the fact of having tested the difference of coals by fluidity curves but not indicating correctly with lgMF.

In fact, there are many examples of the above possibility. Fig. 2 shows the fluidity curves of coal A, B and coal C (the three coals are all used in a factory), and all the cohesiveness indexes of the three coals are presented in Table 1, including a + b, G, Y, and lgMF. It seems that the three coals have basically similar lgMF values of 3.55, 3.67 and 3.56, which shows the differences between them are small and not obvious. While the fluidity curves of the three coals are very different except for similar apex values, the fluidity-temperature areas of curve A, B and C decrease sequentially. Furthermore, their other cohesiveness index values of a + b, G and Y also decrease in the same sequence.

That is, Coal A, B and C have the cohesiveness properties decreasing in sequence according to indexes of a + b, G and Y. They have different fluidity curve features from each other, but it is difficult to be indicated by the value of lgMF. Since the area of fluidity contains all the fluidity information of the whole coal softening scope, here a new fluidity index of fluidity-temperature area for S_{lgF} is put forward to evaluate coal cohesiveness. The value of S_{lgF} is calculated by formula (1) as followed:

$$\mathrm{SlgF} = 0.4\int_{\mathrm{Ts}}^{\mathrm{Tr}} \mathrm{f(x)} \tag{1}$$

where, S_{lgF} is the fluidity curve area of coal, lgF is the logarithmic value of fluidity, f(x) is the fitting formula of logarithmic fluidity curve, T_s and T_r are the softening and resolidification temperatures of coal respectively. The coefficient of 0.4 is used to decrease the value to a moderate range, just like the use of logarithmic fluidity instead of fluidity itself.

2.2. *Experimental*

2.2.1. *Coal samples*

For examining the practicability of the new fluidity index of S_{lgF}, 35 coal samples were selected in the Gieseler fluidity test. All the samples were provided by Baosteel Company in China. The main characteristics of the coal samples are shown in Table S1 (see in the Supplementary material).

2.2.2. *Gieseler test*

The fluidity of the coal samples was tested by an Automazione Gieseler instrument JS-2010-2 from Nanzha Thermal Meter Co. Ltd., following the GB/T 25213-2010 standard procedure of China. Coal samples were firstly crushed to fine powders of < 0.425 mm and the ratio of size < 0.2 mm couldn't exceed 50%. 5 g of sample was charged into a stainless-steel crucible with a stirrer and placed into a lead solder bath in a plastometer. Fluidity was documented with a constant heating rate of 3 °C min^{-1}. lgMF, T_f, T_s and T_r values were given automatically after the procedure was completed.