

Coal Characterization for Cement Production: Key Combustion Indices and What They Mean

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Introduction

Coal is the main fuel used in cement production in China, and one of the key indicators of the consumption of raw fuel in cement production. Coal quality affects not only the yield and quality of cement clinker production, but also its costs as high-quality coal with a higher calorific value can enable higher process temperatures or reduce coal consumption at the same process temperature, thereby lowering fuel costs. Advanced testing means and strengthening the quality management of coal are the important parts to ensure the reduction of coal consumption and the improvement of the quality of cement products.

The combustion behavior of coal in the cement industry is complex. Traditional industrial analytical evaluation methods [1] are no longer applicable. One example is the adiabatic calorimeter method where the coal is placed in an adiabatic container, and its heat content is calculated by measuring the temperature change inside the container. While this method uses simple equipment, the measurement results are relatively inaccurate.

In this work, the material characterization of coal is carried out using a NETZSCH STA *Jupiter*® simultaneous thermal analyzer. Thermogravimetric (TGA) and differential scanning calorimetry (DSC) curves were used to determine key combustion parameters, including the exothermic onset and end temperatures (T_{onset} , T_{end}), initial mass-loss temperature (T_i), maximum mass-loss rate (V_{max}), total exothermic heat (q), and average combustion rate (v). Based on these parameters, three evaluation indices,

- combustion intensity (I),
- average heat-release intensity (Q) and
- the combustion characteristic index (S)

were calculated. These indices provide a quantitative basis for assessing the performance of coal combustion. In the cement industry, coal with optimal combustion behavior is characterized by low combustion intensity (I), high average heat-release intensity (Q), and a high combustion characteristic index (S), reflecting a favorable balance between ignition behavior, heat output, and overall reactivity.

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Measurement Method

For the experimental series, two coal specimens – coal A and coal B – were selected. Each specimen had a mass of approximately 10 mg. The applied temperature program extended from ambient temperature (RT) to 1000°C. Heating was conducted at a constant rate of 10 K/min under an air atmosphere. Table 1 shows all important parameters of the TGA and DSC curves along with the corresponding symbol, unit and definition.

Establishment of Evaluation Index Parameters

Using the basic parameters of the thermal analysis curve, the following three evaluation index parameters can be defined [2] (see table 1 for abbreviations).

a) Burning Intensity (I)

The burning intensity of coal indicates the intensity of the instantaneous heat release in the exothermic process. It is defined as:

$$I = \frac{H}{W} \quad [\text{mW/mg} \cdot \text{min}]$$

b) Average Heat Release Intensity (Q)

The average exothermic intensity of coal expresses the amount of heat released per unit mass of coal per unit temperature during the period from the beginning to the end of the coal's exothermic activity. It is defined as:

$$Q = \frac{q}{(T_{\text{end}} - T_{\text{onset}})} \quad [\text{J/g} \cdot ^\circ\text{C}]$$

c) Combustion Characteristic Index (S)

The combustion characteristics of coal are a comprehensive index of coal, including the flammability of coal, the ignition point of coal, the burning intensity of coal and the burning time of coal. From these perspectives, combined with the corresponding literature [3-4], it can be

$$S = \frac{(V_{\text{max}})^{-1.2} \cdot v}{(T_i)^2 \cdot T_{98\%}}$$

Table 1 Important parameters of the TGA and DSC curves with symbol, unit and definition.

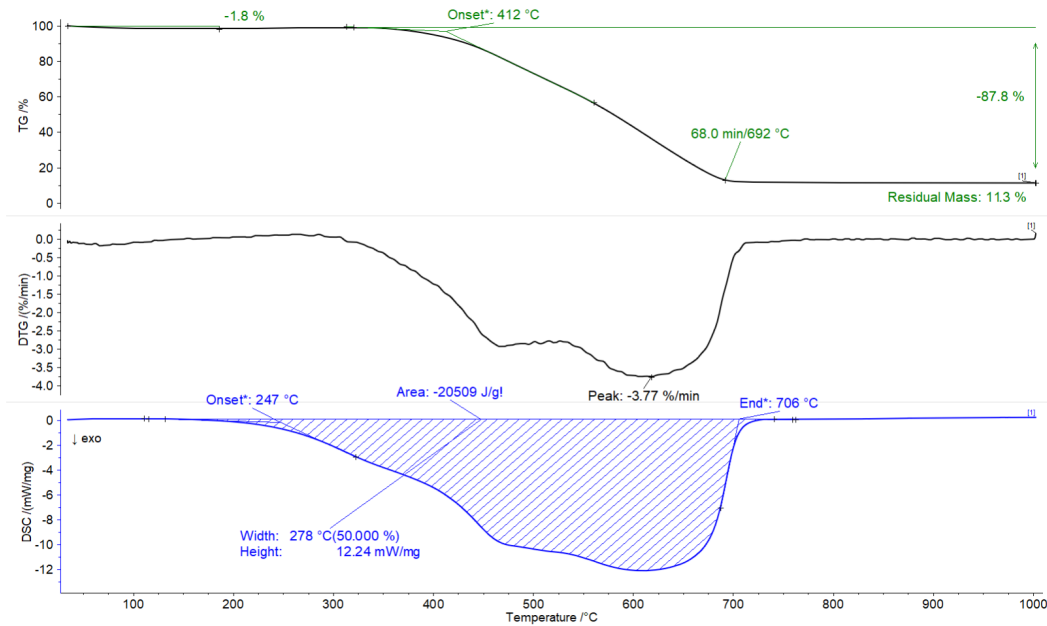
Parameter	Unit	Definition
Thermogravimetry (TGA)		
Onset temperature of the mass loss	T_i °C	The temperature at which the coal begins to lose weight (ignition temperature).
Burnout time	$t_{98\%}$ min	The time required to burn 98% of the fuel.
Burnout temperature	$T_{98\%}$ °C	The temperature corresponding to burning 98% of the fuel.
Average combustion rate	V %/min	Total weight-loss percentage divided by the burnout time.
Differential Thermogravimetry (DTG)		
Maximum mass-loss rate	V_{max} %/min	The maximum mass-loss rate.
Heat Flow (DSC)		
Onset temperature of the exothermal peak	T_{onset} °C	Temperature of the coal at the beginning of the exothermal effect
End temperature of the exothermal peak	T_{end} °C	Temperature at the end of the exothermal effect
Area of the exothermal peak	q J/g	Exothermal capacity of coal
Peak height of the exotherm	H	Height of the exothermal peak relative to the DSC baseline
Half-peak width of the exothermal peak (width)	W min	Time corresponding to the peak width at half of the exothermal peak height.

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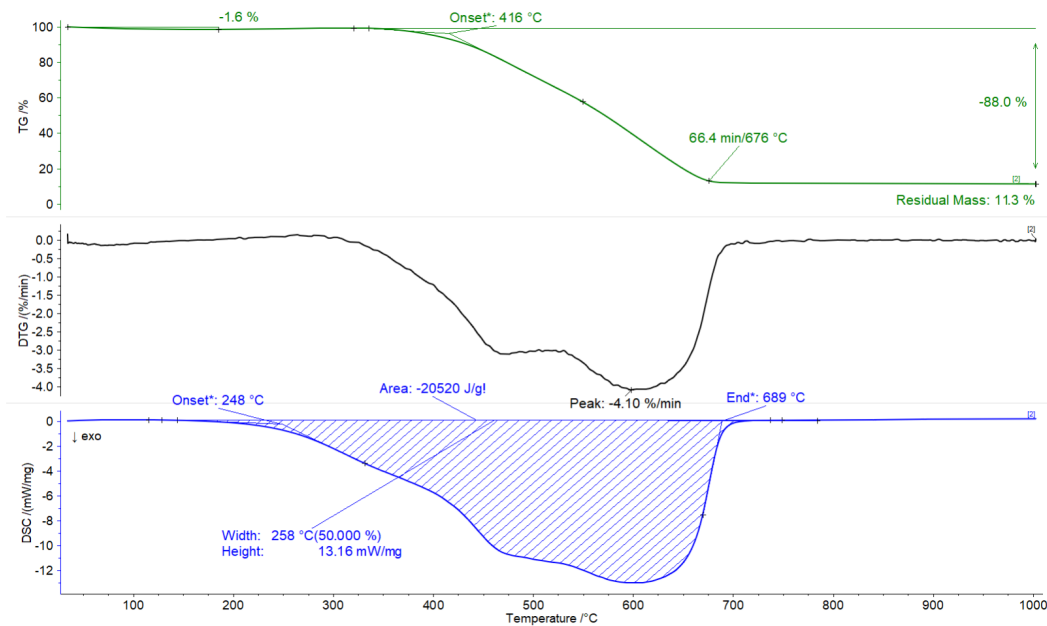
Results and Discussion

The STA curves of coal A and coal B are shown in figures 1 and 2, respectively. As you can see, both samples show two mass-loss steps. The first up to 150°C which is due to the release of moisture. The corresponding mass

losses for coal A and coal B are 1.8% and 1.6%, respectively, indicating comparable moisture contents. The second, substantially larger mass-loss step corresponds to the thermal decomposition and combustion of the coal samples.



1 Mass loss (TGA), mass-loss rate (DTG as well as heat flow (DSC) curves of coal A.



2 Mass loss (TGA), mass-loss rate (DTA) as well as heat flow (DSC) curves of coal B.

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From the STA curves, the basic parameters of the thermal characteristics of the two kinds of coal can be obtained, which are listed in table 1.

As can be seen in table 1, the ignition temperatures of the two kinds of coal in decreasing order is as follows: coal B > coal A. The ignition temperature reflects the degree of difficulty of the coal ignition. The lower the ignition temperature, the easier it is to ignite the coal. The exothermic capacity of the two coals in decreasing order is as follows: coal B > coal A; the higher the exothermic capacity, the better the coal quality. The burnout time of the two coal samples in descending order is as follows: coal A > coal B. In general, the longer the burnout time, the worse is the burning out performance.

The three evaluation index parameters of the two kinds of coal are listed in table 2. For the cement industry, the

larger the combustion characteristic index (S), the better the combustion performance of the coal and the better the coal quality. However, the comprehensive combustion performance of coal cannot be determined by this single index. We should also consider the size of the burning intensity (I) and the average heat release intensity (Q). Only coal with a low burning intensity (I), a high average heat release intensity (Q) and a high combustion characteristic index (S), features superior comprehensive performance.

As can be seen in table 3, coal B has a higher burning intensity and average heat release intensity than coal A. However, its combustion characteristic index (5.35×10^{-9}) is lower than that of coal A (5.46×10^{-9}). In general, coal A possesses superior comprehensive combustion performance.

Table 2 Measurement results of the TGA and DSC measurements on coal A and B.

Parameter	Samples	Coal A	Coal B
	°C	412	416
T_i	m/W/mg	12.24	13.16
H	min	27.80	25.80
W	J/g	20509	20520
q	°C	247	248
T_{onset}	°C	706	689
$t_{98\%}$	min	26.8	24.8
$T_{98\%}$	°C	692	676

T_i : Ignition time; H : Height of the exothermic peak; W : Half-peak width of the exothermic peak; q : Area of the exothermic peak; T_{onset} : Onset temperature of the exothermic peak; T_{end} : End temperature of the exothermic peak; $t_{98\%}$: Burnout time; $T_{98\%}$: Burnout time; v : average combustion rate; V_{max} : Maximum mass-loss rate

Table 3 Three evaluation index parameters of coal A and B.

Parameter	Sample	Coal A	Coal B
Burning intensity, I	mW/mg·min	0.440	0.525
Average heat release intensity, Q	J/g·°C	44.721	46.594
Combustion characteristic index, S		5.46×10^{-9}	5.35×10^{-9}

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Conclusion

The combustion characteristics of coal samples can be studied by the NETZSCH STA *Jupiter*®. The basic parameters of coal samples during the heating process can be obtained from the TGA, DTG, and DSC curves, such as ignition temperature, heat release, and burnout time.

Based on the derived thermal parameters, additional comprehensive indices – i.e., burning intensity, average heat-release intensity, and combustion characteristic index – can be calculated. These evaluation indicators provide an integrated description of the combustion behavior of coal and allow for a more reliable comparison between different coal samples, thereby supporting the selection of the most suitable coal for a given application.

Reference

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