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Characterization of different origin coking coals and their blends by Gieseler plasticity and TGA

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Abstract

Twenty-five bituminous coals of different rank and geographical origin together with seventeen blends (binary, ternary and quaternary) prepared with these coals were studied in terms of their thermoplastic properties, which were determined by means of the standardized Gieseler test. The influence of the geographical origin of the coals on maximum Gieseler fluidity is discussed. Pyrolysis was carried out in N_2 up to 1000 °C in a thermobalance. It was found that the effect of particle size on the results of the thermogravimetric analysis was negligible. The degree of additivity of the parameters derived from the thermoplastic and thermogravimetric analysis was also studied.

Keywords: Coking coal; Gieseler fluidity; Thermogravimetric analysis

1. Introduction

Steel is essential for every day life and coal is essential for iron and steel production. About 64% of steel production worldwide comes from iron made in blast furnaces which use coal as a raw material [1]. Coking coals when heated in the absence of oxygen soften (around 375–400 °C) and then, as heating progresses, resolidify (around 500 °C) into hard and porous pieces of coke. This temperature range, normally referred to as the plastic range, is extremely important for coals used in cokemaking. Furthermore, the development of the microtexture and microstructure of coke takes place essentially within the plastic stage [2,3]. From the chemical point of view the transformation of coal into coke involves two coexisting types of reactions with opposite effects: on the one hand cracking reactions and on the other aromatization and condensation reactions, so that there is a balance in the transfer of hydrogen. Coking coals need to have specific physical and chemical properties. Such coals are scarce and more expensive than the coals used in electricity generation. Consequently the use of coal blends is normal practice in industrial coking. Coking coals of excellent quality are mined in China, Australia, the USA or Canada. About 60% of this coal is then exported to Japan and Europe [4]. Coals of different geographical origin present coking properties that are different to those of other coals of the same rank (volatile matter content). For instance, Australian coals with a high inertinite content (around 50%), usually produce metallurgical cokes of a better quality than might be expected from their plastic properties due to the different behaviours of the macerals that constitute coals [4,5].

The coal plastic stage is usually described by cokemakers by means of the Gieseler test and parameters derived from this test are normally included in the models used to predict coke quality. Taking into account that coal thermoplastic properties have already been described by means of thermogravimetry [6–9], the study of the degree of additivity of the parameters derived from this type of test (TG) would appear to be important when trying to include them in the models normally used to predict coke quality. Considering that the coking industry normally uses blends of coals as raw materials, the use of additive properties should facilitate the obtaining of a successful model [4,10].

The aim of this work was to investigate the degree of additivity of the parameters derived from a thermoplasticity and thermogravimetric analysis of coals, and to study the influence of particle size on coal thermogravimetric analysis.

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2. Experimental

2.1. Materials

Twenty-five coals chosen from those normally used by the coking industry were selected for the present study. The most important characteristics have been previously reported [10]. In addition, 17 coal blends were prepared (Table 1). Six binary coal blends (CB1–CB6) with a volatile matter content between 22.7 and 30.8; six ternary coal blends (CT7–CT12) with volatile matter content between 22.5 and 27.3; five quaternary coal blends (CQ13–CQ17) with a volatile matter content between 23.3 and 28.4. The coals were named according to their origin. Thus, Am is used for American coals, Au for Australian coals and Ch for Chinese coals, the first number corresponding to different coals and the second to the same coal received in a different period of time. As in the case of individual coals, ash and sulphur were maintained within the limits normally used. The blends were subjected to proximate analyses (ISO562 and ISO1171 standard procedures for volatile matter and ash content, respectively), vitrinite reflectance (ISO7404/5), and Gieseler plasticity (ASTM D2639-74). All these tests have been described in detail in a previous work [10].

TG measurements were performed in a TA Instruments SDT 2960 thermoanalyser. Approximately, 12 ± 2 mg sample was analyzed in the temperature interval 30–1000 °C with a constant heating rate of 10 °C/min, under a nitrogen flow of 100 ml/min. For individual coals, two particle sizes were used, <0.212 mm, the same size used in the standardized proximate analysis of coals and blends and <0.425 mm, the size used in the standardized Gieseler plasticity test. The thermogravimetric parameters used in the present research work were described in detail in earlier works [9,11–17] (Table 2).

3. Results and discussion

The coals selected from different geographical origins are of different rank (VM content between 19.1 and 34.7 wt.% daf), the ash and sulphur contents being lower than 10 and 1 wt.% db, respectively, which is characteristic of coals used for metallurgical coke production.

3.1. Thermoplastic properties of coals and blends

For coals normally used in cokemaking, Gieseler plasticity increases with decreasing rank as in the case of the coals used in the present study [10]. This behaviour is related to the cross-linking density and the size of the planar macromolecules which constitute the coals [18]. The plastic properties of the blends were also assessed by the Gieseler test (Table 2). Fig. 1 shows the variation of maximum Gieseler fluidity (MF) expressed as a logarithm to the base 10, together with the volatile matter content of the coals. The blends have also been included in Fig. 1 and they appear to behave like a single coal of corresponding rank. Maximum fluidity decreases from 18,500 to 39 ddpm for American coals with a volatile matter content that varies from 34.7 to 19.1 wt.%. In the case of Australian coals the trend is similar although, in general, Australian coals present a lower maximum Gieseler fluidity than American coals of the same rank, e.g. Gieseler maximum fluidity of coal Am4.1 doubles that of Au2.1 (volatile matter 22.4 and 22.9 wt.% daf), 269 and 122 ddpm, respectively. The thermoplastic properties of coals depend on their rank, but the degree of coalification (rank) is not the only factor that influences the thermoplasticity of a given coal. It is well known [19,20] that the petrographic composition as well as the thermal behaviour of the petrographic components that are dependent on geographic location are also important factors to be considered. There is a tendency for Permian coals of the Southern Hemisphere to have

Table 1
Composition and main characteristics of the blends studied

Blend	Composition				VM (wt.% daf)[a]	Ash (wt.% db)	S (wt.% db)
CB1	75Am1.1	25Am7.1			22.7	5.0	0.75
CB2	50Au2.2	50Ch2.1			23.1	9.8	0.77
CB3	50Am1.1	50Am7.1			25.4	5.2	0.74
CB4	50Au5.2	50Au7			28.3	9.5	0.73
CB5	25Am1.1	75Am7.1			28.5	5.7	0.92
CB6	15Am1.1	85Am7.1			30.8	6.1	0.97
CT7	50Au1	25Ch2.2	25Ch3		22.5	8.9	0.80
CT8	25Au1	25Ch2.2	50Ch3		24.3	9.2	0.86
CT9	40Am4.2	40Au7	20Ch1		25.8	10.0	0.82
CT10	25Am1.2	25Am4.1	50Am7.2		26.6	6.4	0.78
CT11	25Am1.1	50Am7.1	25Ch2.1		27.1	6.1	0.97
CT12	50Am7.1	25Au2.2	25Ch2.1		27.3	8.1	0.83
CQ13	25Am1.2	25Am4.1	25Au7	25Ch1	23.3	7.8	0.74
CQ14	25Am1.1	25Am7.1	25Au2.2	25Ch2.1	23.5	7.6	0.73
CQ15	25Am4.1	25Am6	25Au2.1	25Ch3	24.0	9.1	0.7
CQ16	25Am4.2	25Au5.2	25Au7	25Ch1	25.4	9.2	0.64
CQ17	25Am7.2	25Au2.2	25Ch2.2	25Ch3	28.4	8.4	0.84

[a] VM, volatile matter content of the blend on a dry ash free basis (daf).