Fuel 111 (2013) 223–228

Contents lists available at SciVerse ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Effect of reaction conditions on coke tumbling strength, carbon structure and mineralogy

Fenglei Shen [a,*], Sushil Gupta [a], Yang Liu [b], Qingbo Meng [b], David French [c], Veena Sahajwalla [a]

[a] SMaRT@UNSW, School of Materials Science and Technology, The University of New South Wales, Sydney, NSW 2052, Australia
[b] Sinosteel Anshan Research Institute of Thermo-Energy (RDTE), Anshan, Liaoning 114044, People's Republic of China
[c] CSIRO Energy Technology, North Ryde, NSW 1670, Australia

HIGHLIGHTS

- Reaction temperature has strong impact on coke tumbling strength.
- Effect of temperature on tumbling strength of low CSR cokes was high.
- Iron bearing minerals affected high temperature coke tumbling strength.

ARTICLE INFO

Article history:
Received 30 October 2011
Received in revised form 23 April 2013
Accepted 23 April 2013
Available online 9 May 2013

Keywords:
Coke
CSR
Coke strength
Carbon structure
Mineralogy

ABSTRACT

An experimental study was carried out to examine the effect of different reaction conditions on the changes in the tumbling strength of coke samples from two types of pilot-scale coke ovens. Cokes were reacted with different CO_2 concentration and different duration at the CSR test temperature of 1373 K and 1573 K. Tumbling strength of the reacted cokes was measured using a typical CSR test routine. Carbon structure and mineralogy of cokes was measured using X-ray diffraction. Under the test conditions, temperature is shown to have the most significant impact on the modification of coke properties when compared to CO_2 concentration or the reaction duration. The tumbling strength of cokes reacted at 1573 K were found to be higher than the CSR value of the original cokes. With increasing temperature of the tests, low CSR cokes indicated a greater improvement of the tumbling strength. High tumbling strength cokes indicated high ordering of carbon structure and lesser amounts of reactive iron-bearing minerals. The effect of temperature on the improvement of tumbling strength can be related to the adverse effect of increased ordering of carbon structure and decreased proportion of iron-bearing phases on the coke reactivity, both being more notable in case of low CSR cokes. The study has implications on the efficient utilization of low premium coal resources and for the true assessment of coke performance in a blast furnace.

1. Introduction

Coke is an essential and most important material for blast furnace ironmaking due to its multiple roles including thermal, reductant as well as mechanical. A number of approaches are used to assess the expected coke performance in an operating blast furnace. A variety of tumbling tests are commonly employed to characterize coke mechanical strength and coke strength after reaction [1–3]. Generally, high mechanical strength and coke strength after reaction (CSR) are preferred for smooth and efficient blast furnace operation, particularly during high productivity operations. The CSR value of coke is commonly used as a quality indicator despite concerns about the reliability of its association with actual performance in a working blast furnace. This is mainly related to the lower test temperature as well as the severe gas composition employed in the CSR test [4–6]. Coke experiences much higher temperatures in the lower zone of the blast furnace compared to that employed in the popular CSR test. In some cases, high fines were reported in off gases despite the use of high CSR coke [7]. Occasionally, the CSR test conditions are customized in accordance with individual and more realistic operating conditions [4,8]. However, there are uncertainties associated with the use of the CSR values of cokes, particularly those of low CSR cokes for the assessment of coke performance in a working blast furnace.

This paper aims to clarify the implications of different reaction conditions on the tumbling strength of different coke types. The modification of tumbling strength of cokes was related to the

* Corresponding author. Tel.: +61 2 9385 4433; fax: +61 2 8011 1286.
E-mail addresses: f.shen@student.unsw.edu.au (F. Shen), sushil@unsw.edu.au (S. Gupta).

0016-2361/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.fuel.2013.04.059

Table 1
Proximate, petrographic and fluidity data of coals.

	Coal samples					
	A1	A2	A3	C1	C2	C3
Proximate analysis (%, dry basis)						
Moisture, ad[a]	2.0	1.5	2.0	1.8	0.9	0.5
Ash	9.3	8.5	8.4	9.8	10.2	10.5
Volatile matter	18.7	25.3	27.2	22.2	25.8	28.3
Fixed carbon	72.0	66.2	64.4	68.0	64.1	61.2
Petrographic analysis (%)[b]						
Vitrinite	49.8	52.2	61.4	67.5	42.8	39.4
Liptinite	0.0	1.3	1.3	3.0	4.4	4.0
Inertinite	44.8	41.3	32.1	25.0	47.6	51.3
Mineral	5.4	5.2	5.2	4.5	5.2	5.2
$R_{o,max}$	1.52	1.21	1.10	1.40	1.12	1.05
Gieseler plastometer						
Initial softening temp. (°C)	440	400	410	427	386	400
Maximum fluidity temp. (°C)	460	450	445	459	448	440
logDDPM	1.00	3.62	2.90	1.20	4.11	4.18
Resolidification temp. (°C)	485	495	480	477	490	500
Plastic range (°C)	45	95	70	50	104	100

[a] Air dry basis.
[b] Petrographic data is based on semi-automated reflectance measurements (CSIRO, Brisbane).

changes in the carbon structure as well as the mineral transformations under different reaction conditions.

2. Experimental

2.1. Coke sample selection

Six cokes were selected for this study. Three cokes were prepared in a 400 kg pilot coke oven using Australian coals in an electrically heated movable-wall oven at ALS Laboratory, Brisbane. Three Chinese cokes were prepared in an electrically heated 40 kg pilot coke oven at RDTE, Anshan China. In both cases, the coal charge was similar such that 85% coal passed through a 3 mm sieve. Parent coal properties of cokes are provided in Table 1. Coke samples were secured from two separate projects involving two types of pilot coke ovens. Due to insufficient coal sample and transportation constrains, all cokes could not be prepared in the same coke oven. The CSR and M_{40} value of 400 kg and 40 kg coke ovens could vary depending on coal rank i.e. up to 5% in case of lower rank coals ($R_{o,max}$ < 1.2%) [9]. However, two types of coke ovens is not expected to affect the results of the present study, which aims to examine the effect of reaction conditions on changes of coke properties. Therefore, all coke reaction tests were conducted using the same test facility at RDTE, China. Mechanical strength (M_{40}) and coke strength after reaction (CSR) data was measured in accordance with ASTM standards [10]. The CSR test involves reacting 200 g of 19–21 mm coke particles at 1373 K with 100% CO_2 for 2 h. The percentage of coke particles retained on a 10 mm sieve after subjecting the reacted coke to a standard tumbling routine provides a CSR value.

2.2. Gasification tests

All the cokes were subjected to five reaction conditions including the CSR test conditions at the RDTE facility, China. The reaction temperature, duration and CO_2 concentration of each test is summarized in Table 2. The reacted cokes were subjected to the same tumbling routine as used in the standard CSR test. The tumbling data of the reacted cokes is also provided in Table 2. The tumbling of Test T1 represents the CSR values of the tested cokes.

2.3. Carbon structure

Carbon structure of all the tested cokes was measured by X-ray diffraction using a Philips X'pert Multipurpose X-ray Diffraction (MPD) at the University of New South Wales, Sydney. The special software was used to extract carbon structure parameters from the XRD diffractogram with emphasis on the stack height of carbon crystallite (Lc) of coke [11]. Lc value of all cokes is provided in Table 3.

2.4. SIROQUANT analysis

Mineral rich samples of the cokes were prepared using low temperature plasma ashing (LTA). Diffractograms of mineral-rich coke

Table 2
Summary of test conditions and the tumbling strength of the reacted cokes. M_{40} of original cokes is also indicated.

Test No.	Reaction test conditions			Tumbling strength (%)					
	Temperature (K)	Time (h)	CO_2 (%)	A1	A2	A3	C1	C2	C3
M_{40} (%)	–	–	–	68.6	76.0	73.6	65.6	70.2	78.7
T1[a]	1373	2.0	100	49.1	64.6	35.3	23.8	53.2	66.8
T2	1373	2.0	25	49.5	65.7	37.7	16.6	57.2	64.5
T3	1373	1.5	100	50.2	66.3	36.0	13.7	53.4	66.5
T4	1573	0.5	25	56.8	59.2	53.0	43.6	61.4	68.3
T5	1573	0.5	100	54.3	60.1	50.7	38.8	57.3	67.0

[a] Test T1 is the standard CSR test. Reaction time is approximated to half hour unit.

Table 3
Summary of test conditions and the Lc (nm) values of the original and reacted cokes.

Test No.	Reaction test conditions			Lc value (nm)					
	Temperature (K)	Time (h)	CO_2 (%)	A1	A2	A3	C1	C2	C3
Coke[a]	–	–	–	1.70	1.61	1.52	1.48	1.60	1.41
T1	1373	2.0	100	1.70	1.65	1.58	1.60	1.78	1.84
T2	1373	2.0	25	1.70	1.68	1.61	1.54	1.73	1.73
T3	1373	1.5	100	1.71	1.69	1.56	1.63	1.76	1.82
T4	1573	0.5	25	2.62	2.57	2.24	2.43	2.54	2.68
T5	1573	0.5	100	2.65	2.82	2.43	2.60	2.64	2.91

[a] Original coke before reaction.