Comparison of the quality of the coke produced at different scales

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Abstract
A series of coking coals covering a wide range of coalification, thermoplastic properties and geographical origin were carbonized at two different scales. All the coals used are available in the international market and they are used by the cokemaking industry in blend preparation. The cokes were produced in two movable wall ovens of 15 and 300 kg capacity available at INCAR-CSIC facilities. The quality of the cokes was assessed by means of reactivity towards carbon dioxide and mechanical strength before and after the reaction with CO_2. The results obtained are very promising and a good correlation between the quality parameters of the cokes produced in the two ovens was found. The use of a semi-pilot oven against big-capacity ovens in the optimization of complex coking blends allows to obtain valuable results by using small amount of coal (15 kg vs. 300-400 kg) with the advantages that it is quicker, more flexible and of lower cost.

Keywords
Coal, Coking, Metallurgical coke

INTRODUCTION

For cokemaking industry a control of the coking coals to be incorporated in the blends is crucial. Different mathematical models based on coal characteristics have been developed to predict coke quality parameters, but their application to complex coking blends is limited by the diversity of the rank, thermoplastic properties and geographical origin of the coal constituents. Special-design ovens from 250 to 400 kg capacity are commonly used by the industry, but at the same time, it seems convenient to develop smaller ovens more flexible in operation and of a lower cost.

Metallurgical coke is a macroporous carbon material of high mechanical strength produced by carbonization of coals of specific rank or of coal blends at temperatures up to 1400 K. About 90% of the coke produced from blends of coking coals is used to maintain the process of iron production in the blast furnace where it has three major roles: fuel, chemical reducting agent and permeable-support material. Coke can be substituted in the blast furnace by oil, gas, plastics (Janz, 1996; Imai, 1999; Asanuma, 2000; Ohji, 2000), and coal (Cross, 1994) as fuel and chemical reducting agent. Such a substitution brings about a reduction in coke rates for the blast furnace (coke rate is the weight of coke required to produce 1 t of iron). However, there is no other satisfactory material available, which can replace, fully or partially, metallurgical coke as a permeable support of blast furnace charge. Thus, as coke rate diminishes, the quality of the coke needs to be higher (Lüngen, 1996; Terjung, 2000).

Among the physical properties of coke used to define its quality, resistance to size degradation at ambient temperature in a rotating drum (cold mechanical strength) is always considered of great relevance in coke performance in the blast furnace. The tests used are standardized in terms of drum design and dimensions, amount and size of the coke, operation conditions during the test (number of revolutions, rate) and indices which reflect the extent of the coke fragmentation by fissuration, cohesion and abrasion. All of these tests measure coke resistance to degradation when subjected to impact in mild conditions (ambient temperature and atmosphere); but they do not show how a coke will behave in the gas atmosphere and high temperatures of a blast furnace. Nippon Steel Corporation (NSC) demonstrated the need to introduce new quality parameters of coke based on the reactivity towards CO_2 at high temperature and the resistance to size degradation of the partially gasified coke (Ida, 1971). Afterwards, a new test was developed by NSC which is a combination of reactivity to CO_2 at high temperature (CRI index) and post-reaction mechanical strength (CSR index). This test has been widely accepted by the steel industry around the world (ASTM-D 5341).

The aim of this work was to establish relationships between the quality of the cokes obtained at two different scales, semi-pilot and pilot, by using two movable wall ovens (MWO) of different capacity 15 and 300 kg, respectively.

EXPERIMENTAL

Materials

Twenty eight bituminous coals of different rank (volatile matter content between 18.7 and 35.4 wt %), geographical origin (Australia, Canada, China and USA) and thermoplastic properties (Gieseler maximum fluidity from 6 to nearly 9000 ddpm) were chosen from those commonly used in the coking industry. The coals were carbonized individually and afterwards the cokes were characterized. Proximate analyses and sulphur determination of the coals were performed following the corresponding ISO standard procedures. The thermoplastic properties of the coals were tested in a R.B. Automazione Gieseler plastometer PL2000, following the ASTM D2639-04 standard procedure. Table 1 shows the main characteristics of the coals studied.

Carbonization tests at pilot and semi-pilot scale

Carbonization tests at pilot scale were carried out in an electrically-heated moveable wall oven of 300 kg capacity (MWO300) and the following dimensions: 915 mm length, 840 mm height and 455 mm width. The initial coke-oven wall temperature during charging was 880 ºC, raising at 14 °C/h and giving a temperature of 1200 ºC at the end of the process and 1050 °C in the centre of the charge. The coking time was 18 h.

Coals were also carbonised in a semi-pilot moveable-wall oven of 15 kg of capacity (MWO15) with electrical heating and the following dimensions: 150 mm length, 750 mm height and 250 mm width. During carbonisation tests, the temperature of the wall was maintained constant at 1010 ºC. The coking time was nearly 3 hours, reaching a temperature in the centre of the charge of 950 ºC. At the two-scale carbonizations tests, after pushing the coke from de oven, it was quenched with water. After drying and homogenization, a representative sample of each coal was taken in the conveyor charging belt of the MWO300 at different increments for its characterization and for the carbonization at the semi-pilot scale. The moisture of the coals to be carbonized in the two ovens was kept as close as possible ranging from 3 to 6 wt%.

Coke quality

Taking into account that by means of the semi-pilot oven (15 kg) it is not possible to obtain enough coke quantity to perform a conventional drum mechanical strength test, it has been necessary to develop another test in order study the relationship between the mechanical strength of cokes from the two carbonization scales used (INCAR abrasitivity test CS) (Díez, 2002). Briefly, 200 g of coke with a particle size between 19 and 22.4 mm was subjected to a mechanical treatment of 1200 revolutions at 20 rpm in the same drum as used for the determination of the CSR index by the NSC test. The two indices derived from this test reflect the cohesion (CS10) and the abrasion (CS1) of the cokes, calculated from the amount of coke > 10 mm and < 1 mm in size, respectively, after the mechanical treatment applied.

Coke reactivity towards CO_2 (CRI) and coke strength after reaction (CSR index) were assessed by the test developed by the Nippon Steel Corporation (NSC) and standardized afterwards by ASTM D5341-99. Briefly, a sample of coke (200 g) with a particle size between 19 and 22.4 mm is reacted at 1100 ± 5 ºC for 2 h with CO_2 at a flow rate of 5 L/min. The partially gasified coke is weighed and subjected to the tumbler test. The CRI is calculated as the percentage of weight loss. The mechanical degradation of the coke after CO_2 reaction (CSR) is measured as the weight of coke remaining on a 9.5 mm sieve after 600 revolutions at 20 rpm and it is calculated as the weight percentage of coke larger than 9.5 mm relative to the weight of the coke after the reaction with CO_2.

TABLE 1: Main characteristics of the coals studied.

Coal	VM (wt.% db)	Ash (wt.% db)	S (wt.% db)	MF[a] (ddpm)
USA1	18.7	5.0	0.77	31
USA2	19.2	4.9	0.68	6
USA3	20.4	8.9	0.54	249
USA4	26.1	8.8	0.72	2954
USA5	27.3	8.7	0.76	3703
USA6	29.1	7.6	0.89	1671
USA7	29.9	5.9	0.92	3003
USA8	31.0	6.3	0.96	4178
USA9	33.3	6.4	0.85	5225
USA10	35.4	6.5	0.79	8691
Au1	18.7	9.7	0.72	32
Au2	20.6	7.7	0.50	23
Au3	20.8	9.4	0.61	118
Au4	20.8	9.6	0.60	105
Au5	21.0	8.0	0.38	40
Au6	23.1	8.1	0.46	42
Au7	23.2	9.5	0.55	314
Au8	25.8	9.2	0.57	1613
Au9	25.8	9.0	0.88	1628
Au10	26.0	9.0	0.90	2874
Au11	32.8	8.3	0.95	4109
Au12	33.1	7.2	0.65	1647
Can1	22.5	9.1	0.38	42
Can2	26.9	8.9	0.27	147
Ch1	20.3	9.6	0.70	284
Ch2	21.3	9.4	0.91	301

Ch3	24.4	9.9	0.94	3894
Ch4	34.5	7.5	0.67	3019

[a] Gieseler maximum fluidity

RESULTS AND DISCUSSION

Indices derived from INCAR abrasivity test (CS10 and CS1) characterize both cohesion and abrasion resistance of coke. As it was established in previous studies, there is a relationship between indices derived from IRSID test and those obtained from INCAR abrasivity test CS (Díez, 2002). Figure 1 shows the relationship between the CS10 indices of the cokes produced at the two different scale ovens.

It is important to point out that the cohesion indices of the cokes produced at the semi-pilot oven did not numerically match those from the pilot oven, mainly due to wall effects and the different conditions applied during the coking process (i.e. coking rate). This is not only the case of cold mechanical strength, but also of the reactivity to CO_2 (CRI) and post-mechanical strength (CSR). Nevertheless, although there is not a good linear correlation between the two indices, a clear trend can be observed. The higher the cohesion of the cokes produced in the MWO15, the higher the cohesion of the cokes produced in the MWO300.

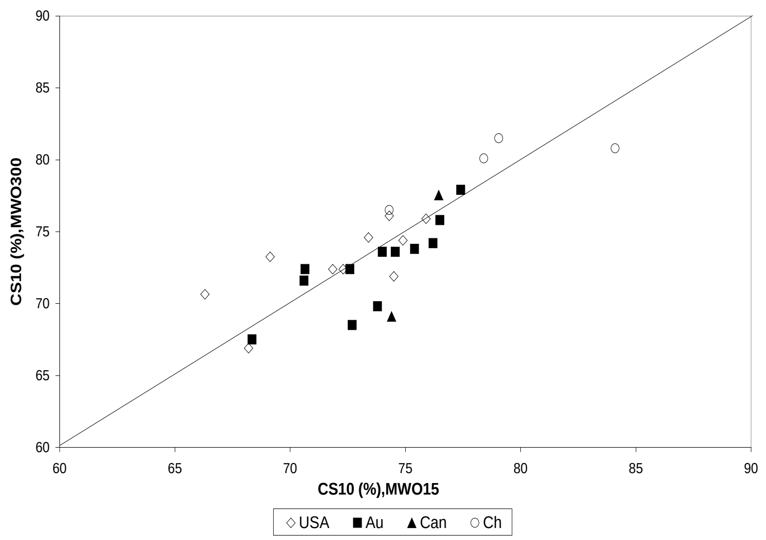

FIGURE 1: Relation between CS10 indices of cokes produced in the movable wall ovens of 15 and 300 kg capacity (MWO15 and MWO300).

Correlation between the two ovens improves when CRI indices of the cokes are compared (Figure 2). The relationship between the reactivity of the cokes produced in the two ovens presents a good regression coefficient of 0.957, being the values of MWO15 slightly higher than those from MWO300. With some exceptions, cokes produced in the semi-pilot oven are more reactive than cokes produced at a pilot scale.

The same trend was obtained in the case of the mechanical strength of the partially gasified cokes (CSR indices), being regression coefficient of 0.946 (Figure 3).

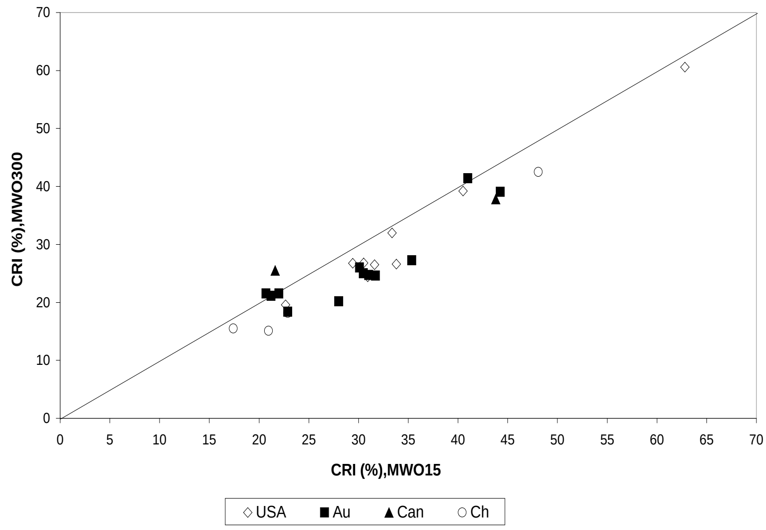

FIGURE 2: Relationship between CRI indices of cokes produced in the movable wall ovens of 15 and 300 kg capacity (MWO15 and MWO300).

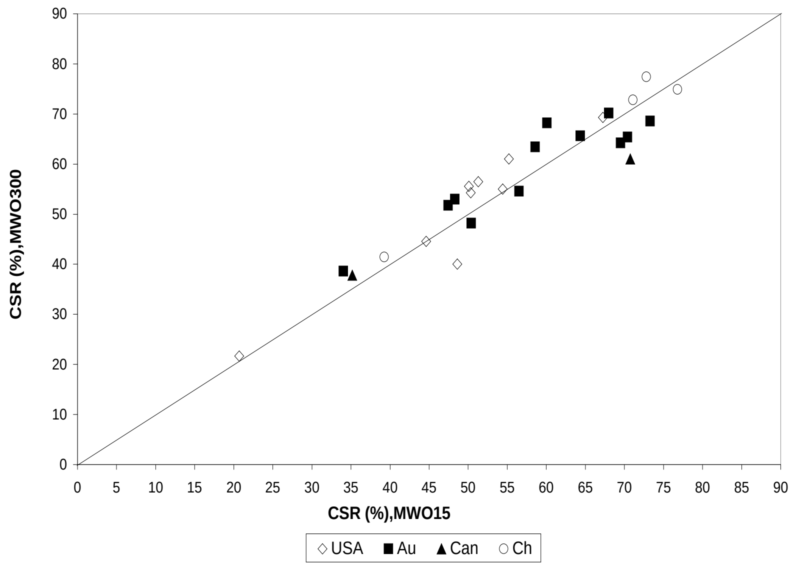

FIGURE 3: Relationship between CSR indices of cokes produced in the movable wall ovens of 15 and 300 kg capacity (MWO15 and MWO300).

CONCLUSIONS

The use of semi-pilot carbonization oven enables the determination of coke quality by means of reactivity towards CO_2 and coke strength after reaction, whereas results obtained for cold mechanical strength could act as a guide for determining this index at a larger scale. Furthermore, semi-pilot oven in the optimization of complex coking blends allows to obtain valuable results by using small amount of coal (15 kg vs. 300-400 kg) with the advantages of time and cost savings and a more flexible process.

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