TECHNOLOGICAL CHARACTERIZATION OF COALS FOR COKE PLANTS[1]

Odilon José da Silva [2]
Poliana Cristina Araújo [3]
Nayara Franciele Silva [3]
Fernando Bueno Guerra [3]
Paulo Santos Assis [4]

Abstract

The process of coke production is directly related to the coal quality, since not all coals produce coke of desired quality and in some cases they can damage the ovens of the coke plant. To compensate for the deficiency of individual coals with all the necessary properties, blends of multicomponent coals are used currently in the blast furnace coke production. These coal blends are managed to optimize the quality of the coke and to reduce the raw material cost, that is, the interrelationships of these innumerable factors with those related to the coal nature contribute for the final quality of the coke. Therefore, a developed methodology to characterize the coals becomes an important tool in the selection and blend of coals for blast furnace coke production, aiming at operational stability with higher productivity in the blast furnaces and reduction of the cost of pig iron, since it represents 30% of the plate cost or 40% of the pig iron. A methodology for evaluating the intrinsic characteristics of the coals was developed, aiming at the creation of a model to predict the quality of the coke. For this, the study examined the conventional characterization and analysis of 14 types of individual coals and mixtures that had been collected from the annual planning of coal blend of ArcelorMital Tubarão. It was concluded: - Comparing the coke quality results from INCAR and ArcelorMittal Tubarão, no significant differences were encountered– The biggest differences were restricted to the “M” and “N” blends and to the CSR parameter.

Key words: Coal; Quality of the coke; Coke plant.

1 *Technical contribution to the 3rd International Meeting on Ironmaking, September 22 – 26, 2008, São Luís City – Maranhão State – Brazil*
2 *M.Sc. in Materials Engineering at REDEMAT, Brazil*
3 *Grad-Stud at Escola de Minas, Ouro Preto, Minas Gerais, Brazil*
4 *Full professor at Escola de Minas, Prof. at REDEMAT, Brazil; Honorary Professor by Hebei Technology University, China; Researcher at CNPq, Brazil*

1 INTRODUCTION

A stable start-up of the blast furnace is intensely connected to the consistency of the chemical, physical and metallurgical properties of the raw material, especially of the coke´s, which are therefore a result of the coal properties from where they originated. The consistency of properties of the blast furnace coke is related to the condition that it displays, over time, values of moisture, ash, sulfur, alkalis, phosphorus, size, size distribution, cold resistance and resistance after reaction, adequate to a high quality coke production in terms of metallurgical efficiency.

The challenge of the coke production is in devising blends of coals that produce low cost and high quality coke. The ArcelorMital Tubarão measures the coke quality using two indicators, the index DI^{150}_{15} (percentage in weight of the coke15mm bigger in size after tumble mechanical treatment) and CSR (coke´s mechanical resistance after reaction). The factory aims at working with DI^{150}_{15} over 85% and CSR over 65.50%, and at assuring the extension of the coke plants useful life to at least 53 years, since the aim is to optimize the blast furnaces productivity reducing the consumption of coke, as well as allowing an increase in the rate of injection of the pulverized coal.

The most important stage in coke production is related to the selection of coal based on the data from the suppliers, considering that the parameters for coal quality are usually determined with various analytical techniques. The identification of the intrinsic coal characteristics is intended, such as the rank analysis and maceral composition to the related properties to reactivity and coke´s mechanical resistance to cold and heat. The development of a valuation methodology is also intended, aiming at the creation of a predicting model of coke quality.

2 OBJECTIVES

To develop a reliable method of selection and prediction of coke quality so that to ensure the adequate coal purchases to obtain the coke quality specified by the blast furnace 1 of ArcelorMital Tubarão.

To define parameters of coke quality through the technological characterization of coke plants coals through the existing techniques such as the analysis of volatile material, ash content, moisture, sulfur content, ash chemistry, plasticity, plastometry and petrography, or the ones to be developed in this study.

3 DEVELOPMENT

The mineral coal is a complex substance. Due to the complexity of its physical and chemical properties and various application methods, there are plenty of ways to classify the coal that date back to 1931 and that use of a variety of parameters and reference terms. The most used method in ironmaking is the rank´s, which determines the degree of carbonizing, and it is used for technological and classification purposes of this fossils fuel, which is based on the volatile content and heat-producing power and that we will call class.

The coking properties of the coal are related to their petrographic constitution. This constitution, determined with the use of optical microscopy, selects the coal according to its content into reactive and inert macerals. The coal is not a uniform particle, but a blend of uniform components called macerals.

The classification system most used in siderurgy is the one standardized by the ASTM. The current version of this system is displayed in Table 1. As mentioned, the coal is classified by its content of volatile matter and heat-producing power normalized to d.a.f. (dry-ash-free), that is, the heat-producing power is calculated free of moisture and of coal ash content.
There is an important connection between the microscopic structure of the bituminous coals and certain physical and chemical properties of this fossils fuel, therefore the possibilities of empirical application of coal petrography in the fields of coke production, mining, washing and combustion.
The vitrinite maceral usually contribute more significantly to the coal fusibility during the coal transformation into coke. The fusible coals, with its volatile matter between 18% and 35%, have coking power too high combined to its swelling power and its strong plasticity, result of the high number of relatively weak van der Waals forces between the hydrogen and oxygen present in this maceral group.

Table 1- ASTM classification of the coals by class (Coal Petrography)

Class	Group	% of the limit of fixed carbon (dry-ash-free)		% of volatile matter (dry-ash-free)		Heat-producing power (Btu/pound) (dry-ash-free)		Bonding characteristics
		≥	<	≥	<	≥	<	
I-Anthracite	1.meta anthracite	98	-	-	2	-	-	Non bounding
	2.anthracite	92	98	2	8	-	-	
	3.semi-anthracite	86	92	8	14	-	-	
II - Betuminous coal	1.low volatile	78	88	14	22	-	-	Usually bounding
	2.medium volatile	69	78	22	31	-	-	
	3.high volatile A	-	69	31	-	14.000	-	
	4.high volatile B	-	-	-	-	13.00	14.000	
	5.high volatile C	-	-	-	-	11.500	13.000	
III – Sub-bituminous	1.coal A	-	-	-	-	10.500	11.500	Non bounding
	2.coal B	-	-	-	-	9.500	10.500	
	3.coal C	-	-	-	-	8.300	9.500	
IV – Lignite	1.lignite A	-	-	-	-	8.300	8.300	
	2.lignite B	-	-	-	-	-	6.300	

The exinite is the richest material in volatile matter, of highest swelling power, the worst to be ground, the richest in tar and hydrogen. It interferes in the coking of coals with more than 25% of volatile matter, as the richest element in sub products and gasification. Adversely, the inertinite is the most dense and less rich fraction in volatile matters, has high carbon value and low hydrogen content. It has no coking power, but it has an important role in coke production controlling, in the coking blends, as it is perceived that, to a certain coal class, there is an optimum relation of fusible and infusible components to obtain the maximization of the coke´s resistance.
Certainly the empirical application more developed of the coal petrography is on the prediction of the coking properties of coal blends. The determination of the reflecting power associated to the quantitative analysis of the macerals, qualified into reactives and inerts, allow the coke producer to fully comprehend the maceral composition of the coals available to charging, being able to correct their blend according to this composition, aiming at obtaining, in all cases, the best possible siderurgical coke.
As explained previously, the coal macerals have physical and chemical properties extremely different. The volatile matter content, of hydrogen, the density and swelling vary between macerals groups. The structure of equivalent cokes is a reflection of these properties, the coke cavities are as extensive and as open as its vitrine and exinite contents are high. This specific structure relates to a strong release of gas (volatile matter) during the fusion zone or plastic phase. The fusion is not enough to cause the swelling and if the fused matter is too fluid and very little adhesive, the gases escape without swelling production, and this is the imperative factor for obtaining the coke.
The coking in conventional coke plants is the phenomenon that occurs when the coal is submitted to high temperatures, in the absence of oxygen, causing the release of gases and the appearance of a solid and porous product, the coke. In this case, the coal softens and expands until it finally condenses.
The softening point depends almost fully on the petrographic composition, being lower as the vitrine percentage of the coal rises. The expansion is mainly caused by the resistance offered to the release of gases; the resolidification is the consequence of the volatilization and decomposition of fluid products. After de resolidification, the remaining volume suffers the loss of weight and increase in density, what causes its contraction.
The coal is heated in conventional coke plants at temperatures between 1100ºC to 1350°C in the absence of oxygen and cleaves forming:

a) Tar, light oils and cook plant gases;

b) Coke, that is the final product, solid, porous, essentially carbon formed, whose properties should be compatible to the quality requirements imposed by the blast furnace, availability of coals and the coke plant production methodology.

Various prediction methods of mechanical resistance indexes for the coke were developed in Russia, USA, Europe and Japan, based on the results of: petrographic analysis, statistical analysis of industrial data and/or pilot scale coking. The predicting methods of resistance can be divided in two large groups: in one it is predicted the value of a resistance index and in the other one the methods define a "window of adhesive properties" to the blends that originate resistance indexes similar or superior to the minimum required.
The mechanical resistance of the cold coke is defined as being its capacity to resist to fragmentation by mechanical request, impact and/or abrasion, in a rotating drum. The extension of its granulometric reduction can be determined after being submitted to a fixed number of revolutions in a drum of standardized characteristics.

The importance of characterizing the coke resistance to high temperatures, mainly, the determination of the coke resistance after reaction with $C0_2$ (CSR), was revealed in basic researches and in the dissection of blast furnaces performed in Japan. The operational practice showed that the CSR displayed some influence in the performance of the blast furnace (load permeability was improved with the raising of CSR). Kojima and Sakurai showed that not only the coke´s resistance to cold could be predicted with the coal petrography, but also the CSR from the volume of inerts and of the medium reflectance (Ro).

4 MATERIALS AND METHODS

For the development of predicting models of the metallurgical coke quality based in the individual coal characteristics, in the period of January 2006 to April 2008, 22 individual coals were studied, one blend prepared in laboratory and 16 industrial blends with their correspondent cokes. The study comprehended the conventional characterization of 14 types of individual coals and blends and those were analyzed.
The individual coal samples and blends were collected from the universe of coals from the annual planning of blend of ArcelorMital Tubarão. The industrial blends were collected from the output of the system of coal preparation after the dosage and crushing of the blend and industrial coke after the screening in the 25mm mesh of the coke treatment system. The chosen blends had a distinct composition compared to the others. All the tests were performed at the INCAR (Instituto Nacional del Carbon/ National Carbon Institute – Oviedo/Spain).
Coke samples were sent to INCAR to be analyzed and compared to coke analysis of the same blend performed at ArcelorMittal Tubarão, and the indexes of $DI^{150}{}_{15}$ and CRI/CSR were determined.

5 RESULTS AND DISCUSSION

The characterization of the industrial coke produced at ArcelorMittal Tubarão and analyzed at INCAR presented few differences of $DI^{150}{}_{15}$, being inferior to one point in most of the cokes. One exception worth mentioning is one coke from one of the blend, with a difference of 2.2 percentage points, as displayed in Table 2. Therefore the results were very satisfactory.

Table 2 - Comparative between the DI^{150}_{15} results of industrially produced coke at the Coke-Oven Battery of ArcelorMittal Tubarão and analyzed at INCAR.

Coke	INCAR DI^{150}_{15} (%)	ArcelorMittal Tubarão DI^{150}_{15} (%)	Difference (%)
A	84,5	85,5	-1
B	84,3	85,7	-1,4
C	85	85,5	-0,5
D	85,2	85,3	0,1
E	84,4	85,3	-0,9
F	85,5	85,4	0,1
G	85,2	85,2	0
H	86	85,4	0,6
I	84,1	85,2	-1,1
J	84,6	85,3	-0,7
K	84,4	85,2	-0,8
L	84,8	85,2	-0,4
M	87,6	85,4	2,2
N	84,3	85,4	-1,1
O	84,9	85,2	-0,3
Maximum Value	87,6	85,7	2,2
Minimum Value	84,1	85,2	0
Difference	3,5	0,5	--

Concerning the values for reactivity and resistance after reaction (CRI and CSR respectively), these also presented relatively small differences between the analysis results at INCAR and ArcelorMittal Tubarão, excepting two of the blends with differences of 4 and 5 percentage points respectively, which are fully acceptable, as displayed in Table 3.

Table 3 - Comparative between the CRI and CSR results of coke analyzed at ArcelorMittal Tubarão and at INCAR.

Coke	CRI INCAR (%)	CRI ArcelorMittal Tubarão (%)	Difference (%)	CSR INCAR (%)	CSR ArcelorMittal Tubarão (%)	Difference (%)
A	24,2	24,9	-0,7	66,5	66,7	-0,2
B	27,0	24,9	2,1	63,7	66,7	-3,0
C	25,7	25,0	0,7	65,2	67,0	-1,8
D	27,2	24,9	2,3	62,5	66,6	-4,1
E	24,8	25,7	-0,9	66,5	66,2	0,3
F	22,9	24,6	-1,7	67,5	66,6	0,9
G	25,0	24,9	0,1	64,4	66,0	-1,6
H	24,2	25,0	-0,8	65,6	66,2	-0,6
I	23,0	25,4	-2,4	67,6	65,7	1,9
J	25,3	24,7	0,6	64,5	66,3	-1,8
K	23,3	24,7	-1,4	66,0	66,1	-0,1
L	24,8	24,7	0,1	65,8	65,8	0,0
M	29,9	25,0	4,9	59,7	66,0	-6,3
N	29,4	25,0	4,4	61,6	66,5	-4,9
O	29,9	24,9	5,1	62,5	66,7	-4,2
Maximum value	29,9	25,7	5,1	67,6	67,0	6,3
Minimum value	22,9	24,6	0,1	59,7	65,7	0,0
Difference (%)	7,0	1,1	--	7,9	1,4	--

From the experimental values of DI, CRI and CSR of individual coals that form part of the blends, it is possible to estimate with a certain degree of success the parameters of complex blends. Considering that the coke quality parameters are additive and that the contribution to these parameters, due to the coal interactions that form part of the complex blends, is minimum, mathematical models that include the coal characteristics that are also additives should be used. The predicting models of coke quality parameters $DI^{150}{}_{15}$ e CRI/CSR presented by various authors define as a rank function (volatile matter, vitrine reflectance), maceral composition, fluidity (rheology) and of impurities (ash, ash composition and sulfur).
The quality parameters of the coke produced in pilot coke-oven of capacity of 300 kg from the individual coal samples and industrial blends are displayed in Table 4.

Table 4 Results of DI^{150}_{15}, CRI and CSR of individual coal samples and industrial blends tested at pilot coke-oven.

Carbonization in pilot coke-oven		DI^{150}_{15} (%)	CRI (%)	CSR (%)
Individual coals	A	79,3	46,4	42,8
	B	73,8	42,3	34,6
	C	83,0	30,1	51,0
	F	76,3	43,0	39,5
	H	75,8	31,4	47,8
	I	79,6	28,5	53,9
	J	82,9	23,7	63,3
	K	73,7	43,3	18,5
	L	78,8	27,2	56,5
	O	81,3	30,1	52,6
	P	79,7	14,3	70,8
	Q	82,7	24,1	60,9
	S	79,3	25,5	56,6
	T	80,3	40,5	33,9
Coal blends	A	80,2	31,2	54,0
	B	79,8	29,5	56,6
	C	78,8	33,8	48,9
	D	75,5	38,0	41,6
	E	78,4	32,7	55,8
	F	80,3	29,8	52,4
	G	77,7	30,8	53,1
	H	79,2	28,5	56,2
	I	79,9	31,1	52,9
	J	79,8	30,6	53,9
	K	77,4	31,0	50,3
	L	79,4	31,7	54,0
	M	80,0	34,7	50,8
	N	80,8	36,9	49,1
	O	78,7	35,1	52,4

It can be noted that the result of coke quality in pilot scale are always less than the ones obtained in industrial scale. This difference can be due to the following factors:

- the density of the loading of coal blend that affect the coke porosity;
- the heating rate, varied temperature conditions, the fuels for the heating of the industrial coking chambers;
- the differences in coke quality along the length and width of the oven;
- the quality and quantity of the produced coke;
- Stabilization practices.

6 CONCLUSIONS

It can be concluded, from the research performed:

- Comparing the results of the coke quality industrially produced analyzed at INCAR and at ArcelorMittal Tubarão, no significant difference were found.
- The main differences found are restricted to the “M” and “N” blends and for the CSR parameter, still in the variations accepted by the ASTM D5341 norm.
- Comparing the industrially produced coke and the pilot scale no correlation was found, to the data base studied. And invariably the pilot oven coke presents higher reactivity and lower mechanical resistance than the industrially produced coke.
- It was not possible to establish, from the data base studied, the additive function of the coke quality, that is, the interactions between the complex molds of coal blends cannot be ignored.
- Among the study of individual coals of different sources and rank and complex coal blends, varying the interval of volatiles, ash and coking properties, it was not possible to create from the technological characterization of coal and blends, a model considering the conventional parameters, to predicting the coke quality that would support the decision of choosing the coals.

Acknowledgments

The authors thank ArcelorMittal Tubarão for its support to the current Technical Contribution, to FAPEMIG and CNPq by the support to the researches of professor Paulo Assis and his group, as well as to FAPEMIG for the help given to the researchers to take part on the screened seminar.

REFERENCES

1 CALDEIRA, J.G.; Figueiredo, N. Teoria da Coqueificação (Coking Theory). In: Programa de educação continuada (Programme of continued education), São Paulo, ABM, p.2-48, June 2003
2 NAHUYS, J.; DUARTE, N. M. Petrografia de carvão e suas aplicações (Coal petrography and its applications). In: Programa de educação continuada (Programme of continued education), Rio de Janeiro, ABQUIM , p.319-329, April 1980.
3 COELHO, Robson Jacinto. Modelos de Previsão de Qualidade Metalúrgica do Coque a Partir da Qualidade dos Carvões Individuais e do Coque Obtido no Forno Piloto de Coqueificação da CST (Predicting Models of Coke Metallurgical Quality from Individual Coal Quality and the Coke Obtained in CST Pilot Coke Oven). 2003. 130 pages. Dissertation (Master in Materials Engineering) – REDEMAT/UFOP, Ouro Preto, 2003.
4 SAMPAIO, R. S. et al. Avaliação de Carvões e Minérios de Ferro Para os Novos Processos de Produção de Ferro Primário (Coal and Iron Ore Avaliation for the New Processes for the Production of Primary Iron). In: Novos Processos de Produção de Ferro Primário (New Processes for the Production of Primary Iron). ASSIS, P. S.; SAMPAIO, R. S., Ed. ABM, 1995, p.115-145.