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Coke graphitization and degradation across the tuyere regions in a blast furnace

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HIGHLIGHTS

- Coke graphitization can estimate the tuyere region temperatures.
- Coke reactivity correlated with graphitization degree and adsorbed potassium.
- At tuyere level, feed coke experienced more than fifty percent size reduction.
- Coke fines generation correlated with coke graphitization and anisotropy.

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ABSTRACT

Changes in particle size distribution and in the degree of graphitization of coke samples from various locations across the tuyere entrance of a blast furnace were examined. X-ray diffraction and a fixed bed reactor were used to measure carbon structure and reaction rate of the coke. The feed coke size was observed to decrease by more than 50% in the descent to the tuyere in the majority of the tuyere-level locations. About 60 wt.% of the core matter from the "bosh" and "raceway" locations consisted of less than half-size feed coke particles. The percentage of −3 mm and −0.45 mm size fractions observed in the recovered drill core material were less than 10 wt.% and 3 wt.% respectively particularly around the raceway locations. The graphitization degree of half-size coke particles is shown to be a suitable indicator of the temperature profile of tuyere-level regions of a blast furnace. The degree of graphitization of tuyere-level coke samples showed an inverse relationship with amount of potassium adsorbed as well as with the apparent reaction rate. The carbon structure as well as anisotropic texture of coke fines indicated higher ordering of carbon compared to the half-size cokes from the similar locations. The −0.45 mm size fraction of fines displayed a large proportion of graphite crystals. The study has confirmed the contribution of surface graphitization of cokes on the fines generation particularly in the "raceway" and "birds nest" regions. The study has implications for using the bench-scale assessment of coke performance and modeling of coke behavior to provide an understanding as to what is likely to occur in an industrial blast furnace.

1. Introduction

Coke is one of the most critical and probably the most expensive raw material used for steelmaking via the blast furnace route. Therefore, efficient utilization of coke must be considered as a major priority of iron producers. Consequently, coke replacement by supplementary fuel injection by means of pulverized coal specifically, but also oil, natural gas and some waste synthetic polymer materials, has become a major driver of cost reduction and up to 50% replacement has been successfully achieved. Coke plays multiple roles in a blast furnace by providing reducing gases, carburization source, permeable medium and also burden support. At high injection rates, the coke quality becomes more pertinent as less coke is available to fulfill these roles.

Ideally, coke is desired to gasify without any degradation during the descent from top to bottom in a working blast furnace. However, coke size decreases during the descent in a blast furnace and generates some fine material and the extent to which this occurs is related to its inherent strength. A high reactivity as measured for coke in the commonly employed Nippon Steel reactivity test, is frequently attributed to a high degree of degradation in a blast furnace [1,2]. In this widely used bench-scale test, about 200 g of 19 mm −20 mm sized coke particles are reacted with 100% CO_2 at 1100 °C for 2 h. The weight loss of coke after completion of the test provides the so-called Coke Reaction Index

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Table 1
Blast furnace operation, production and coke quality data for the drilling campaign.

Operation data		Production data		Coke data	
Injected fuel (heavy bottom oil)	Oil	Hot metal (t/m^3/d)	3.50	CSR (%)	65.8
Flame temperature (°C)	2287	Hot metal carbon (%)	4.32	CRI (%)	21.9
Blast temperature (°C)	1196	Hot metal silicon (%)	0.383	Irsid$_{10}$ (%)	19.6
Blast volume (Nm^3/h)	137	Hot metal sulphur (%)	0.076	Irsid$_{40}$ (%)	50.4
Oxygen enrichment (Nm^3/h)	10905	Coke (kg/thm)	352	AMS[a] (mm)	62
Blast pressure (bar)	2.52	Oil (kg/thm)	102	Ash (%)	10.51
Heat loss (GJ/h)	55.5	Reducing agent (kg/thm)	454	SiO_2/Al_2O_3	2.09
Top dust (kg/thm)	4.43	Slag rate (kg/thm)	215	Basicity[b]	0.13

[a] AMS: Average Mean Size.
[b] Basicity: $(Fe_2O_3 + CaO + MgO + K_2O + Na_2O)/(SiO_2 + Al_2O_3)$; thm: ton hot metal.

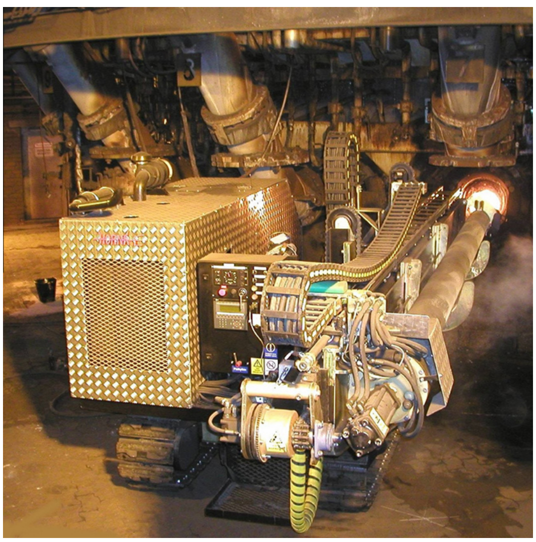

Fig. 1. Mobile tuyere drilling probe.

(CRI), and the percentage of coke particles retained on +10 mm sieve after tumbling for 600 revolutions in a standard drum configuration provides the measure of strength known as the Coke Strength after Reaction (CSR) value of coke. The CSR test conditions are considered by many as harsher than the actual blast furnace reaction environment [3,4].

The current coke quality parameters are empirically based and as such are constrained by their inability to simulate some of the critical high temperature phenomena of a working blast furnace, such as graphitization and coke reactions that occur in the very active zone adjacent to the tuyere-level. Due to the complexity of blast furnace, such as large scale of operation, high temperatures and pressures, etc., it is often not possible to extract representative coke samples from operating blast furnaces. However, in recent times, a tuyere drilling technique has enabled technologists to effectively extract coke samples from an operating blast furnace thereby providing a source of potentially useful information about various important phenomena that occur [5–9]. Despite this innovation, understanding of the modification of coke behavior as it reaches across tuyere regions is still limited. Therefore, there is continuing interest to further clarify the impact of blast furnace conditions particularly those in tuyere-level regions on the transformation of coke properties. In this paper, tuyere core samples obtained from a medium size European blast furnace have been examined to characterize coke size degradation and graphitization behavior at various locations around tuyere-level. The implications of coke graphitization on the modification of reactivity and fines generation are also discussed.

2. Materials and methods

2.1. Tuyere drilling

In this study, coke samples were obtained by tuyere drilling of blast furnace (#1) of Ruukki Oyj, Rahee. The drilling for this study was carried out on 7 June 2007 [10]. Blast Furnace configuration and operating data during the drilling period are summarized in Table 1. The hearth diameter and the effective volume of the blast furnace was 8 m and 1086 m^3 respectively, and was equipped with 21 tuyeres for injecting preheated heavy distillation residue oil. In this campaign, a typical high strength metallurgical coke was introduced in the burden using two bells with a twin chambers charging system. Total coke rate was 352 kg/thm including 48 kg/thm of 12–36 mm size nut coke (Table 1). Average mean size (AMS) of feed coke was 62 mm, and approximately 80% particles larger than 40 mm. The percentage of +80 mm, 63–80 mm and 40–63 mm size particles in the coke charge was 14.4%, 29.7% and 40.7% respectively. Coke quality including mechanical coke strength (I_{40}) based on the weekly average of +20 mm coke from the sampling point at the coking plant remained steady during the drilling periods.

Fig. 1 shows the mobile drill used for tuyere coke sampling. In the drilling procedure, a steel tube of 5.6 m length and 205 mm diameter is inserted from one of the opened tuyeres during the stoppage. The actual length of drill penetration in the furnace is determined by the physical conditions of tuyere regions. In the

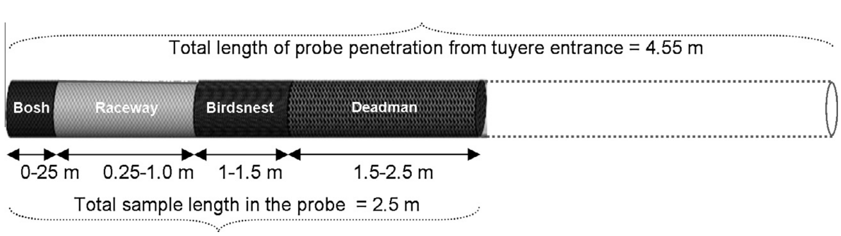

Fig. 2. Schematic representation of different tuyere level zones in the core.