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AN INVESTIGATION OF THE ABNORMAL SWELLING CHARACTERISTICS OF HIGH-AND LOW-SILICA IRON OXIDE PELLETS

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INTRODUCTION

Dominion Foundries and Steel Limited (DOFASCO) have considered the use of Itabira (Brazilian) iron oxide pellets in their blast furnaces. Tests done at DOFASCO revealed a wide variation in the swelling properties of both high-and low-silica Itabira pellets, some pellets swelling catastrophically (>100 per cent). This abnormal swelling was ascribed to heterogeneous lime distribution within the pellets, as revealed by microscope analysis. However, tests done by the pellet producer did not identify any abnormal swelling in their product. At the request of DOFASCO, MREC undertook to test the swelling characteristics of some of these pellets as they provide an interesting example of this type of pellet behaviour which may be relevant to direct reduction processes currently under consideration, as well as to blast furnace operation.

The tests done at MREC and reported herein showed swelling which was not catastrophic but was greater than normal for some of the pellets tested. The pellets were selected at random from the samples of high and low-silica pellets submitted by DOFASCO and results reported here pertain only to

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these samples and must not be construed as being indicative of the general swelling characteristics of Itabira iron oxide pellets.

The normal swelling (approximately 20 per cent) referred to above occurs during the hematite-magnetite reduction and is caused by microcracks formed by the directional growth of magnetite in hematite. Abnormal or catastrophic swelling occurs during the wüstite-iron reduction and has been explained by Lu* on the basis of impurities which may be either associated physically with the wüstite surface or chemically as solid solutions of wüstite with, for example, lime. Equilibrium conditions for metallization require a lower oxygen potential for wüstite reduction with carbon monoxide than for reduction of a contaminated wüstite (since the activity of wüstite becomes less than unity). Thus, at a certain time during the metallization, preferential reduction of uncontaminated wüstite starts and an iron whisker grows because of the faster transport to the particle surface of ferrous ions than oxygen ions together with the electrons created by removal of oxygen. These whiskers push apart the pellet and cause catastrophic swelling. Because such pellets disintegrate easily, the permeability of the blast furnace burden may be reduced, altering the smooth operating characteristics of the furnace and contributing to hanging and slipping conditions.

EXPERIMENTAL

DOFASCO recommended that the swelling of the Itabira iron oxide pellets be measured with the Japanese Industrial Standard Method for Measuring the Swelling Index of Iron Ore Pellets (JIS M 8715, 1968). Briefly, the method involves reducing three pellets for 60 minutes at 900°C in a silica boat in a

**Lu, W-K, "The Cause and Control of Abnormal Swelling of Iron Ore Pellets During Reduction", Presented at the 33rd Ironmaking Conference of A.I.M.E., Atlantic City, April, 1974.*

flowing reducing gas mixture of 30:70 carbon monoxide: nitrogen (500 ml/min). The swelling index is calculated using the formula:

$$Sw = \frac{V_2 - V_1}{V_1} \times 100$$

where Sw = swelling index (per cent)

V_1 = volume before reduction (ml)

V_2 = volume after reduction (ml).

The MREC swelling tests reproduced the JIS conditions as closely as possible with the available equipment. Three iron oxide pellets were reduced in a recrystallized alumina boat in a mullite tube (28 mm ID) with the reducing gas mixture supplied from a two-stream gas train. Carbon monoxide and nitrogen flows were monitored in capillary flowmeters (calibrated with the respective gases just prior to the tests with a soap-bubble flowmeter), pressure drops across the capillaries being maintained constant with bleed-off tubes in dibutyl phthalate. The two gases were mixed by turbulence in a tower containing glass balls before being introduced into the mullite tube. The reaction temperature was controlled to 900±10°C with an electronic temperature controller and the pellets were preheated to 900°C in a flowing nitrogen atmosphere for 30 minutes.

The volumes of the pellets before and after reduction were measured by mercury displacement. A glass chamber was attached by a ground-glass joint to the bottom of a 10-ml burette. The level of mercury in the chamber could be controlled by a calibrated reservoir attached to the chamber by a side arm. The mercury was brought to the zero mark in the burette and the level in the reservoir noted. The mercury level in the burette was then lowered and a pellet placed in the glass chamber. The mercury in the reservoir was then brought to the same level as previously, and the volume of the pellet read from the height of the mercury in the burette.

Four sets of tests were done with both the high- and low- silica pellets:

(i) At 900°C and 500 ml/min of reducing gas mixture (linear gas velocity = 81.2 cm/min)

(ii) At 900°C and 1000 ml/min (linear gas velocity = 162.3 cm/min). The conditions used for the DOFASCO tests were 900°C, 2000 ml/min in a 2-in ID tube (linear gas velocity = 98.6 cm/min).

(iii) At 1000°C and 1000 ml/min.

(iv) At 900°C and 1000 ml/min (linear gas velocity = 324.7 cm/min) with the pellets placed on indentations in refractory brick.

RESULTS AND DISCUSSION

The chemical analyses* of the high-and low-silica Itabira pellets is given below:

Table 1. Chemical Analysis of the Itabira Pellets

	High-Silica (per cent)	Low-Silica (per cent)
Fe	63.80	66.20
CaO	1.89	1.05
MnO	0.06	0.06
SiO_2	4.21	1.72
MgO	0.25	0.31
Al_2O_3	0.70	0.66
K_2O	0.06	0.01
Na_2O	not given	0.006
CaO/SiO_2	0.45	0.61

(*Supplied by DOFASCO)

Results are given in Table 2 for the swelling tests on iron oxide pellets selected at random from the samples submitted by DOFASCO.

Table 2. Swelling Test Results

Test Conditions	Swelling Index (per cent)	
	High-Silica Pellets	Low-Silica Pellets
$900^{o}C$, 500 ml/min reducing gas mixture, alumina boat.	11.9	9.1
	13.6	6.0
	6.0	7.3
	21.4	14.8
	20.0	5.0
	23.1	6.3
	34.5	17.4
	36.4	13.3
	26.7	12.0
Average	21.5	10.1
$900^{o}C$, 1000 ml/min, alumina boat	21.9	43.8
	45.5	33.3
	36.4	16.7
	50.0	13.3
	33.3	20.8
	22.7	25.0
Average	35.0	25.5
$1000^{o}C$, 1000 ml/min, alumina boat	37.5	41.7
	50.0	50.0
	62.5	30.0
Average	50.0	40.6
$900^{o}C$, 1000 ml/min, pellets exposed	30.0	23.0
	13.0	16.6
	30.0	31.5
	26.5	26.7
Average	24.9	24.5

In the first set of tests (in which the JIS conditions were reproduced as closely as possible with the available apparatus) the highest swelling indices recorded were 36.4 per cent for the high-silica pellets and 17.4 per cent for the low-silica pellets. The flow of reducing gas mixture (500 ml/min) was equivalent to a linear velocity of 81.2 cm/min in the reaction tube.

The results for some of the pellets tested by DOFASCO had shown greater swelling indices (>100 per cent) than reported in Table 1, but the linear reducing-gas velocity used was 98.6 cm/min (200 ml/min, 2-in ID reaction tube). The second set of results given in Table 1 used a higher flow of reducing-gas mixture (162.3 cm/min) than used by DOFASCO, and the maximum swelling indices recorded (50.0 per cent for high and 43.8 per cent for low-silica pellets) were higher than in the first test series, although well below 100 per cent. Increasing the reduction temperature to 1000^{o}C increased the maximum swelling indices to 62.5 per cent for high- and to 50.0 for low-silica pellets, respectively.

The DOFASCO test procedure did not use a boat for holding the pellets but placed them on a plate made from refractory brick. The possibility was thus diminished of local parts of the pellets below the top of the boat being exposed to a gas atmosphere influenced by the reduction thermodynamics, rather than to the 30:70 $CO:N_2$ mixture. Four pellets of each type were tested at MREC in the same manner in a reducing-gas flow of 1000 ml/min, but no excessive swelling was observed.

In conclusion, the MREC tests showed higher swelling indices for the Itabira iron oxide pellets than would be expected from normal pellet swelling, but the highest index obtained in any of the tests was 62.5 per cent, well below the indices obtained at DOFASCO. Test conditions did influence the swelling characteristics and the high-silica pellets generally gave the higher average swelling indices. This latter observation is perhaps surprising as the addition of silica is one method of reducing the abnormal swelling tendencies of iron oxide pellets, although the K_2O content of the high-silica pellets was six times greater than for the low-silica pellets.

The differences in the DOFASCO and MREC results indicate discrepancies in swelling test procedure and the proposed ISO test (Document ISO/TC 102/SC3 253E) as developed in Sweden, may provide an attractive alternative.