

Implementation of Coke Stabilization at ArcelorMittal Dofasco

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ABSTRACT

ArcelorMittal Dofasco has three coke plants that feed two blast furnaces. Coke Plants No. 1 and 2 are 4 meters in height and Coke Plant No. 3 is 6 meters in height. Coke that is produced from these plants undergo different number of drops, drop heights and total drop distances starting from the wharf as the coke makes it way to the blast furnaces.

Coke from all three coke plant wharfs, sampling locations and blast furnace stockhouses were sampled originally to establish the level of stabilization of our current coke. Laboratory experimentation trials conducted on cokes at CanmetENERGY provided attainable levels of stabilization at industrial coke plants. With these values determined, two coke stabilization units were installed. The first location was to service Coke Plant No. 1 – Blast Furnace No. 2 and the second location was to service Coke Plants No. 2 and 3 – Blast Furnace 4.

This paper will describe the level of stabilization prior to the stabilizer installation, the laboratory work conducted, the changes effected in the plant and the net result of implementing coke stabilization on coke quality at the blast furnace.

INTRODUCTION

Coke stabilization is the practice of taking coke that is produced and allowing it to break by impact along pre-

existing fissures along its structure. It is preferable to have the coke break down along these fissures prior to being charged into the blast furnace. The product coke may be smaller in size, but its size distribution will be tighter and the coke will not further break down due to impact allowing for a higher permeable coke bed and therefore enhanced efficiency in the blast furnace. Coke from all three coke plant wharfs, sampling locations and blast furnace stockhouses at ArcelorMittal Dofasco were sampled originally to establish the level of stabilization of our current coke. With these values determined, two coke stabilization units were installed. Samples were obtained after these installations were completed and changes in coke stabilization and coke quality were quantified.

DISCUSSION

As ArcelorMittal Dofasco moves towards a low coke rate, high productivity blast furnace operation, a higher and less variable coke quality is required. Besides high cold strength, high hot strength and tight size distribution, an additional requirement is a well-stabilized coke product. Stabilization can lead to higher cold coke strength and a tighter size distribution, although smaller mean coke size.

Coke Stabilization:

When coal transforms into coke during the coking process, fissuration occurs in the semi-coke mass with the dramatic loss of the parent volatile matter. The rate of contraction itself will govern the amount and extent of fissuration throughout the semi-coke mass. The coke mass will fall from the oven when pushed into the quench car, initially breaking along the major fissures. These fissures cause the coke particles to be irregular in size and shape. The coke will continue to break down on handling from the wharf to the blast furnace. With this break down, the coke product will be variable in both size and shape. It will have a wide size distribution and be physically inhomogeneous. The coke physical properties can change especially size and size distribution if the coke still contains these naturally occurring fissures at this point. In order to minimize variability in coke strength, coke size, size distribution and coke bed permeability, coke should be stabilized prior to being charged into the blast furnace.

Coke size reduction between stockline and tuyere will depend on the degree of coke stabilization of the feed coke. Low levels of coke stabilization will mean that the fissures that pre-exist in the coke lumps will further break down in the furnace on handling, charging and descent resulting in smaller coke at the bottom of the blast furnace. Coke degradation can be broken down into two stages:

- The first stage is due to mechanical stabilization of the coke prior to being charged into the blast furnace,
- The second stage occurs in the blast furnace where coke is subjected to severe mechanical, chemical and thermal conditions.

The intention of stabilization is to break the coke along these natural fissures and ideally bring the coke to its Fissure Free Size (FFS). When a coke is fissure free it is said to be 100% stabilized. The fissure free size represents an estimate of the coke size following size degradation due to fracture, independent of abrasion. Stabilization does not mean to degradate the coke by crushing the coke.

ArcelorMittal Dofasco has chosen to use a coke “flinger” or “sizer”. This apparatus ⁽²⁾ throws the coke, creates less fines that the other methods and yield loss is minimal as the material that is too small can provide a source of nut coke to the blast furnace (Figure 1). These flinger units can be installed in-line with the existing belt systems.

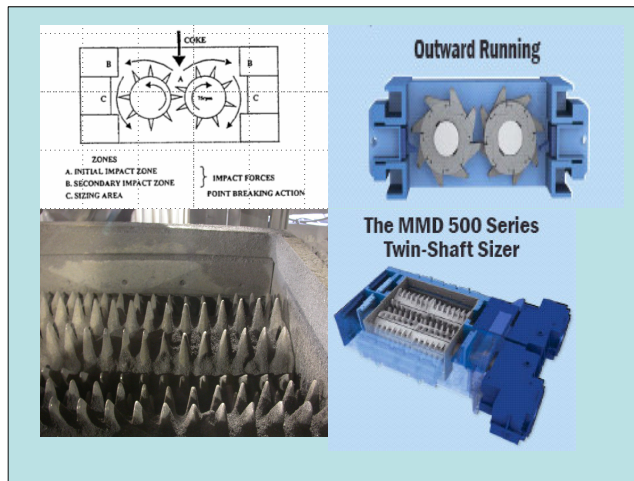


Figure 1: Coke Stabilizer ⁽¹⁾, ⁽²⁾ (Flinger or Sizer)

ArcelorMittal Dofasco has installed two such coke stabilization (sizer) units ⁽²⁾ (Appendix 1 – Figure 1). The first unit (South End) is located at the end of the wharf at Coke

Plant No. 1 (M1). Blast Furnace No. 2 stockhouse has adequate deck screening, so no additional screening capability was installed at this location. The second unit (North End) is located at the M204/M205 junction and serves both Coke Plants No. 2 and 3. Because of the limited deck screening capability at Blast Furnace No. 4 stockhouse, a screening station was installed in-line after the stabilization unit at the M204/M205 location.

Method:

Coke stabilization is determined using the ISO IRSID I₄₀ drum test. Stabilization is defined as the Fissure Free Size (FFS) divided by the Mean Coke Size (MCS) that is put into the tumble drum.

$$Coke\ Stabilization = FFS/MCS \times 100 \quad (i)$$

The stabilization calculation is based on the BCRA method of plotting 1/MCS² versus the number of drum revolutions (Appendix 1 - Figure 2). Each coke sample was subjected to 0, 500, 1000 and 2000 revolutions in order to perform the stabilization measurement. Coke is removed and the coke size distribution is measured after each of these revolution targets. This method removes coke size reduction caused by abrasion rather than cracking.

The parameters measured or calculated are mean coke size, size distribution, ASTM stability, IRSID I₄₀, fissure free size, and level of stabilization. Other parameters such as M₄₀ and micum slope were also measured or calculated and are reported. It should be noted that standard coke size measurements are carried out using square screens, but IRSID tests and stabilization values use round screens for the analysis as per ISO standards.

Base Case (Pre-Stabilization)^{(3-8):}

Originally, coke stabilization was initiated at Coke Plants No. 2 and 3 – Blast Furnace No. 4. Coke was collected at the wharfs, sampling stations and the blast furnace stockhouse.

Table 1 Pre Stabilization Results

Sample Location	Coke Plant No. 2		Coke Plant No. 3		BF#4 Coke	
	Wharf	Sampling Station	Wharf	Sampling Station		
Mean Coke Size (square screen)	mm	67.5	53.1	67.7	49.7	56.3
100 mm sieve	%	10.0	1.9	11.2	1.0	1.0
75 mm sieve	%	34.8	13.2	35.4	10.7	13.6
50 mm sieve	%	73.0	50.9	71.6	41.7	55.4
37.5 mm sieve	%	90.1	77.3	88.7	71.9	87.4
25.0 mm sieve	%	96.4	91.4	95.5	90.4	98.3
19.0 mm sieve	%	97.5	94.3	96.7	93.7	99.1
12.5 mm sieve	%	98.0	95.7	97.4	95.1	99.2
passing 12.5 mm sieve	%	2.0	4.3	2.6	4.9	0.8
-75mm+25mm	%	61.6	78.2	60.1	79.7	84.7
ASTM Stability	%	58.2	62.0	58.6	61.3	60.2
ASTM Hardness	%	69.4	70.1	69.5	69.5	67.6
M ₄₀ (20mm)	%	69.1	69.5	71.8	64.8	74.2
M ₁₀ (20mm)	%	8.1	6.2	7.5	6.3	6.5
Micum Slope		0.0069	0.0063	0.0058	0.0061	0.0058
IRSID I ₄₀ (20mm)	%	46.2	48.4	51.1	46.5	52.8
IRSID I ₂₀ (20mm)	%	76.4	78.7	77.5	78.1	78.5
IRSID I ₁₀ (20mm)	%	20.9	19.2	20.2	19.2	19.6
IRSID Fissure Free Size	mm	48.4	52.9	49.9	50.8	52.1
IRSID Stabilization	%	66.9	86.4	69.9	85.2	81.6

The original level (pre-stabilization) of stabilization showed the following:

- Mean coke size at Coke Plant No. 2 and No. 3 wharfs are similar at 68mm.
- %-75mm+25mm size fraction is 61% at the wharf and 85% at Blast Furnace No. 4.
- IRSID fissure free size is ≈50mm and is independent of sample location.
- The level of stabilization at the coke wharfs is 67%-70%.
- The level of stabilization at Blast Furnace No. 4 is 82%.

The blast furnace stockhouse samples were then further subjected to continuous drops to determine if stabilization can be increased for the ArcelorMittal Dofasco coke. A summary of these tests are shown in Figure 2. This figure indicates there is the potential to increase the level of stabilization and also increase coke stability values, although there would be less 50mm sized coke.

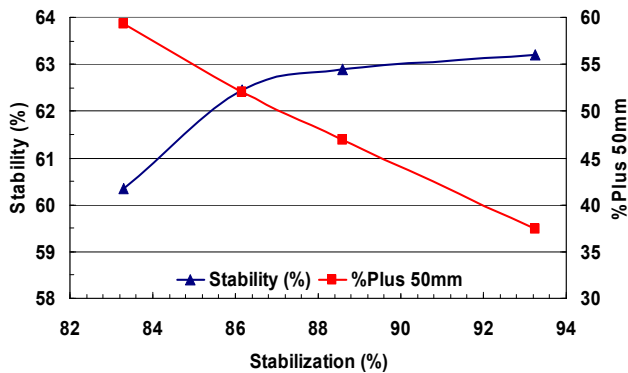


Figure 2. Stability and %Plus 50mm versus Degree of Stabilization

Daily Coke Sample Locations:

The sampling stations were included during the pre-stabilization period because it was important to show how the sampling locations used influenced daily coke quality results due to degree of stabilization the coke sample was experiencing. It was shown that due to the excessive drop into the collection barrels, the daily coke samples were stabilized to a higher degree (86%) than what was delivered to the blast furnace (82%). Coke size was also smaller in size at the sampling location than at the blast furnace. Based on this information, coke is now sampled at the respective coke plant wharfs. For the purpose of this paper, there will be no further discussion on coke sampling locations.

Sampling for the Commissioning of the Stabilizer Units:

Daily composite coke samples were collected at the wharfs of Coke Plants No. 1, 2 and 3 and at the stockhouses of Blast Furnaces No. 2 and No. 4 on the same respective days. These coke samples were then sent to CanmetENERGY for determination of their stabilization values and other physical characterizations.

Daily composite coke samples were taken from the following locations over a ten day period:

- South End Stabilization:
 - Coke Plant No. 1 wharf (M1),
 - Blast Furnace No. 2 stockhouse (after screens).
- North End Stabilization:
 - Coke Plant No. 2 wharf (M101),
 - Coke Plant No. 3 wharf (M201),
 - Blast Furnace No. 4 stockhouse (after screens).

It should be noted that the coke sampled at Blast Furnace No. 4 is an unknown coke mixture supplied by both Coke Plant No. 2 and Coke Plant No. 3. Samples were only taken when both coke plants were supplying coke to the system.

Post Stabilization:

After the North (CP's No. 2 and 3 – BF No. 4) and South (CP1 and BF No. 2) stabilization stations were installed, coke was sampled at the respective wharfs and blast furnace stockhouses over several days. The results are summarized in Table 2.

Table 2 Post Stabilization Results

Sample Location	South Stabilizer		North Stabilizer			
	CP #1	BF #2	CP#2	CP#3	BF #4	
Mean coke size, mm (square screen)	mm	69.2	51.0	65.9	57.5	51.1
100 mm sieve cum	%	11.7	0.0	7.6	2.4	0.0
75 mm sieve cum	%	36.2	3.7	32.4	18.2	6.0
50 mm sieve cum	%	76.5	46.0	72.0	58.2	44.4
37.5 mm sieve cum	%	90.7	80.0	88.0	82.1	77.4
25.0 mm sieve cum	%	95.9	96.4	95.6	94.4	97.6
19.0 mm sieve cum	%	97.0	98.5	96.9	96.6	98.8
12.5 mm sieve cum	%	97.6	98.9	97.7	97.4	98.9
Passing 12.5 mm	%	2.4	1.1	2.3	2.6	1.1
75mm+25mm	%	59.7	92.7	63.2	76.2	91.6
ASTM Stability	%	61.5	63.2	58.8	57.7	61.3
ASTM Hardness	%	70.2	68.9	70.5	69.8	69.2
M ₄₀ (20mm)	%	72.5	71.7	65.8	62.8	67.9
M ₁₀ (20mm)	%	8.2	6.3	8.4	8.1	6.6
Micum Slope		0.0073	0.0070	0.0074	0.0078	0.0076
IRSID I ₄₀ (20mm)	%	49.7	50.5	43.1	39.5	44.7
IRSID I ₂₀ (20mm)	%	75.7	79.0	75.3	75.3	78.4
IRSID I ₁₀ (20mm)	%	22.0	19.3	21.7	21.5	19.7
IRSID Fissure Free Size	mm	52.7	52.6	47.0	45.1	50.1
IRSID Stabilization	%	72.4	90.9	67.3	70.4	85.8

South Stabilizers:

For the south stabilization unit, we do not have a similar base case as all the preliminary work was performed at the north end. However, we can compare to the north end results, comment on the level of stabilization achieved and the net result on coke physical quality.

The level of coke stabilization achieved at Blast Furnace No. 2 (south end) is 91%. This is significantly higher than the base value measured at 82%. The wharf level of stabilization at 67% to 72% for both Coke Plants No. 2 and 3 are similar to the level reported in their base cases (67% to 70%). With stabilization, there is a shift to a lower mean coke size and tighter size distribution as shown in Figure 3. 93% of the blast furnace coke is between 25mm and 75mm from a base level of 85%. Fissure free size is 53mm. ASTM stability values have increased from 61.5% at the wharf to 63.2% at the blast furnace. I_{40} values remain constant with an improvement in the I_{10} to 19%.

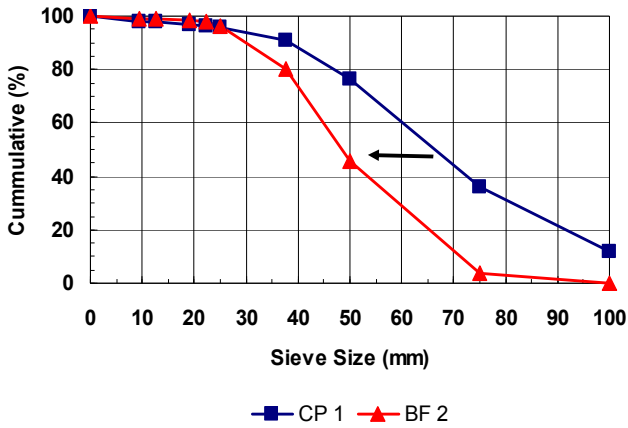


Figure 3: Size Distribution at the South End

North Stabilizers:

The level of coke stabilization achieved at the Blast Furnace No. 4 (north end) is 86%. This is higher than the base case of 82%. The wharf values at 67% (CP2) and 70% (CP3) are similar to the levels reported in the base case (67% and 70% respectively). With stabilization, there is a shift to a lower mean coke size and more consistency in size distribution at the blast furnace as shown in Figure 4. 92% of the blast furnace coke is between 25mm and 75mm compared to a base level of 85%. Fissure free size is \approx 45 to 50mm which is slightly lower than at the south end.

It should be noted (Table 3) that at the wharf, the mean coke size at Coke Plant No. 2 is similar to the base situation, but the mean coke size at Coke Plant No. 3 is smaller. This effect is seen in the reduction in mean coke size at Blast Furnace No. 4 coke samples. This is due to the faster coking rate at Coke Plant No. 3 since the base sampling took place.

Table 3 Mean Coke Size – North End Values

Sample Location		CP#2 Wharf	CP#3 Wharf	BF #4
Pre Stabilization Mean Coke Size (square screen)	mm	67.5	67.7	56.3
Post Stabilization Mean Coke Size (square screen)	mm	65.9	57.5	51.1
Pre Stabilization %plus 50mm	%	73.0	71.6	55.4
Post Stabilization %plus 50mm	%	72.0	58.2	44.4

However, it should be noted that mean coke size and coke size distribution at both blast furnaces is quite similar with the stabilization units in place. (Figure 5)

I_{40} values are lower especially at Coke Plant No. 3 due to the smaller coke size being produced during the sampling period. I_{10} values have remained the same as in the base period and are improved over the wharf values.

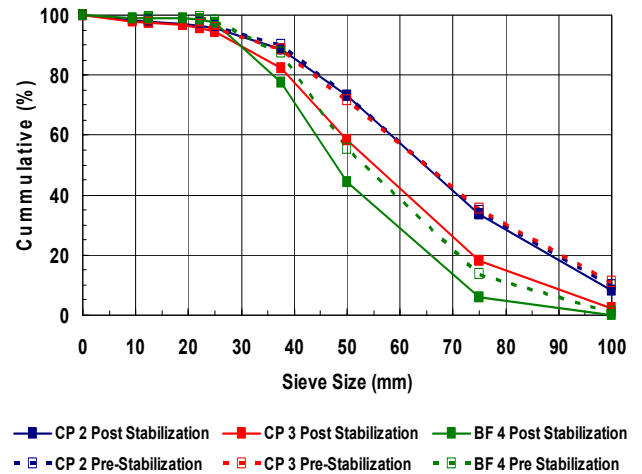


Figure 4: Pre versus Post Stabilization at the North End

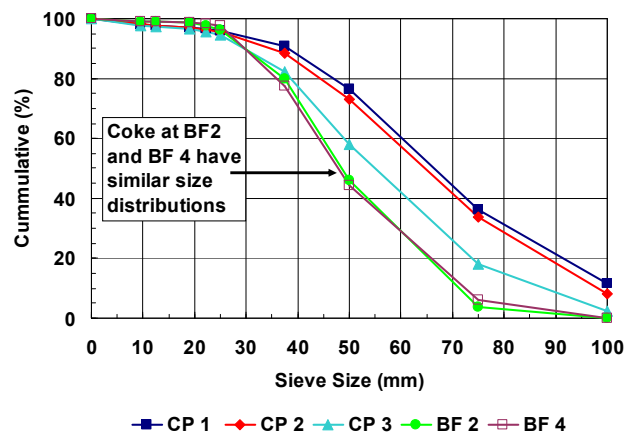


Figure 5: Post Stabilization Size Distribution Summary

Data Trends:

With the implementation of coke stabilization, Figures 6 and 7 are used to show a summary of all the data from this project. This includes all the samples that were taken during the various stages along with plant samples that were stabilized in the laboratory and movable wall oven cokes that were produced and dropped numerous times. This data can be used to better understand the stabilization phenomena.

From Figure 6, the following can be concluded:

- Increasing the level of stabilization by 1% increases ASTM coke stability by 0.19%. This increase is seen in the coke samples for both blast furnaces. (Table 2)
- A lower level of coke stabilization leads to a greater variability in ASTM coke stability.
- Wharf coke shows a greater variability in both the level of stabilization and ASTM coke stability.

From Figure 7, the following can be concluded:

- Increasing the level of stabilization by 1% decreases the %plus50mm coke size fraction by 1.1%. This effect was seen at both blast furnaces. (Table 2)
- A lower level of coke stabilization leads to a greater variance in the %plus 50mm size fraction.
- Wharf coke shows a greater variability in both level of stabilization and %plus50mm coke size.

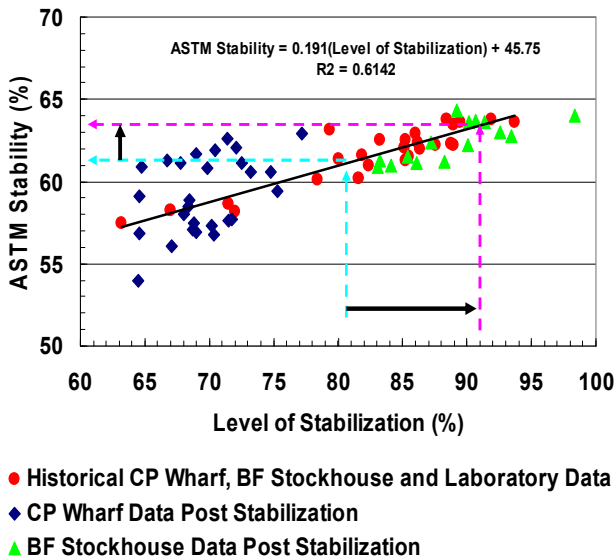


Figure 6: ASTM Stability versus Level of Stabilization

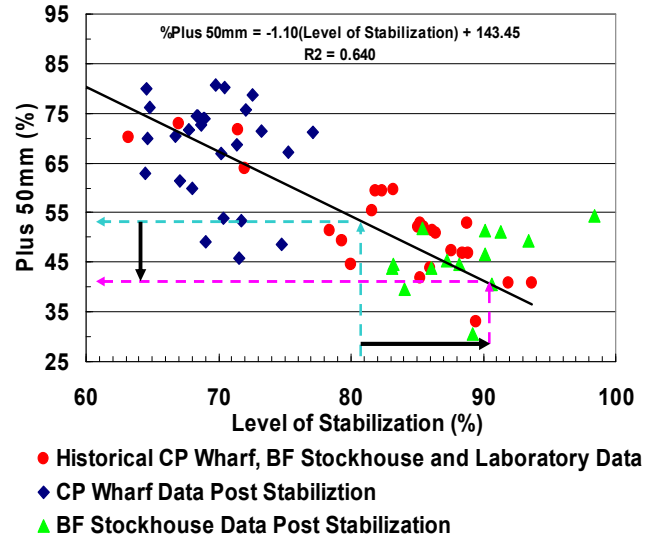


Figure 7. %Plus 50mm versus Level of Stabilization

As the level of stabilization increases, there will be a decrease in mean coke size as seen in Figure 8, but this will result in a tighter size distribution as measured by the %-75mm+25mm coke size fraction (Figure 9). This effect provides uniformity in both coke size, shape and coke bed permeability which will favorably affect blast furnace aerodynamics. The coke size distribution will remain more consistent when charged into the blast furnace after stabilization because the coke has been already been “broken” along the major natural occurring fissures. Without stabilization, this coke breakage would occur on handling and charging into the blast furnace which would result in an inconsistent coke size and strength inside the blast furnace.

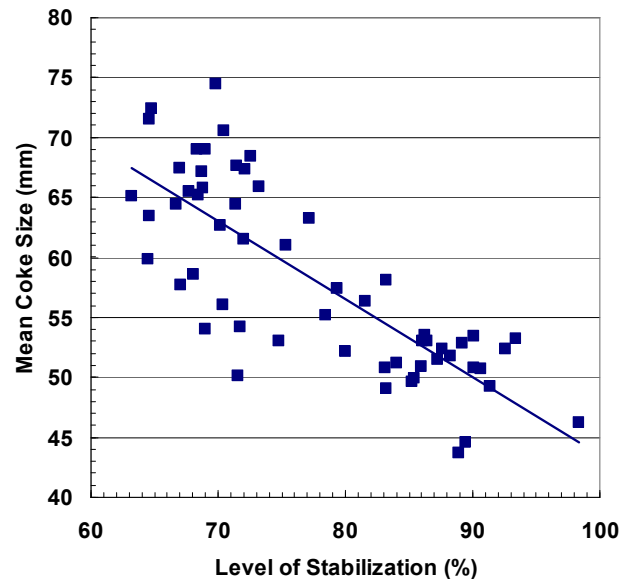


Figure 8: Mean Coke Size versus Level of Stabilization

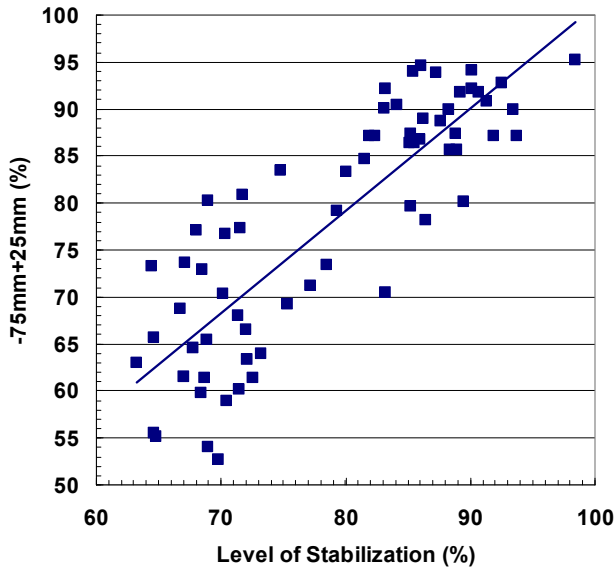


Figure 9: %-75mm+25mm Size Fraction versus Level of Stabilization

It is important to note that the mean coke size itself is independent of the fissure free size as seen in Figure 10.

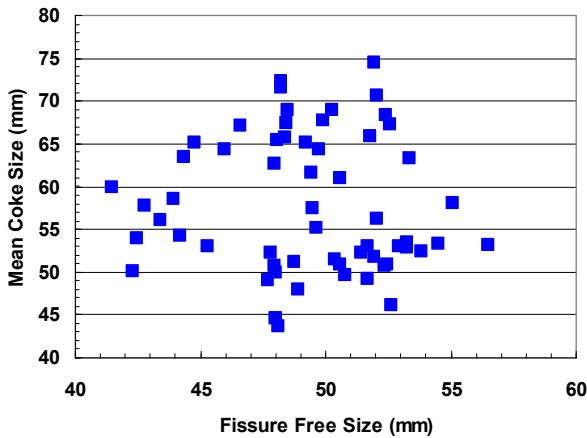


Figure 10: Mean Coke Size versus Fissure Free Size

The effect of fissure free size on coke strength is shown in Figure 11. The ASTM stability values are less affected than the IRSID I_{40} or Micum M_{40} values. What this figure shows is that a larger fissure free size is important to establishing high cold coke strength. A fissure free size of ≈ 50 mm to 53 mm will establish an ASTM stability value $>60\%$, an IRSID I_{40} value $>50\%$ and an $M_{40} >70\%$.

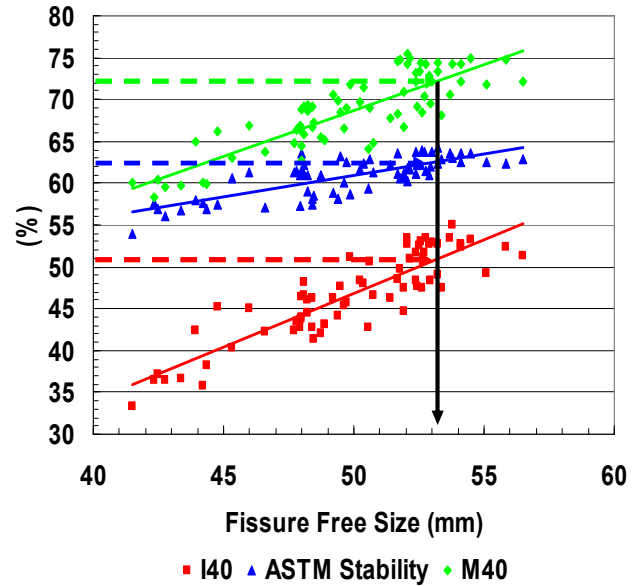


Figure 11: Coke Strength Parameters versus Fissure Free Size

Just having larger mean sized coke is not sufficient enough. The larger the coke, the lower the level of stabilization will be as seen in Figure 12. The larger sized coke will have many natural fissures which will cause the coke to break on handling which will in turn cause the coke size distribution to be variable and inconsistent depending on the degree of handling. Stabilization after the wharf prior to the blast furnace is most desired.

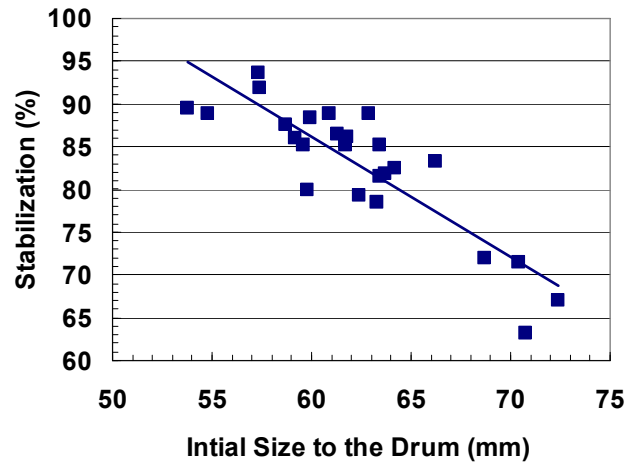


Figure 12: Stabilization versus Initial Size to the Drum

A series of movable wall oven tests were also run during this project to establish the coal and cokemaking parameters which influence both fissure free size and coke stabilization.

It was found that fissure free size increased with increased coal rank, increased coal melting range and a lower flue temperature. Fissure free size did not depend on coal bulk density.

It was also found that coke stabilization increased with increased coal rank, increased melting range but did not depend on either flue temperature or coal bulk density.

In order to further improve the level of coke stabilization, the key is to improve fissure free size. A series of experiments are being set up to investigate the fissuration mechanisms associated with the coal to coke transformation. This work is scheduled to begin once a high temperature dilatometer is purchased at CanmetENERGY this spring.

Blast Furnace:

The benefits of coke stabilization are realized by recognizing the improvement in blast furnace operational stability. There will be savings due to lower coke rate, flux and oxygen. During the duration of this project, the blast furnaces went through many changes: acid and fluxed burdens, all coke operation, start-up and implementation of PCI. This had made it difficult to do more than a theoretical savings calculation at this time. However, we do have significant data showing operational stability based on the frequency of cut tuyeres as seen in Figure 13.

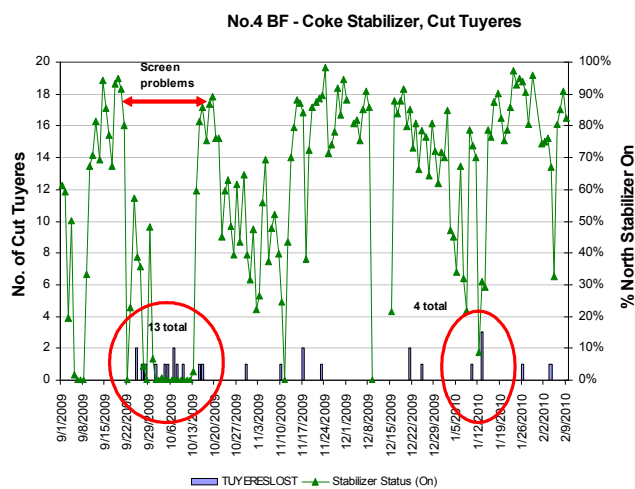


Figure 13: No. 4 BF

With the coke stabilization units in place, Blast Furnace No. 2 has produced 83% more hot metal before a tuyere change out is required due to cut tuyeres. Blast Furnace No. 4 has produced 44% more hot metal before a tuyere change out is required due to cut tuyeres.

In addition, our coke delivery system has also been streamlined with the coke stabilizers in place. We have removed external coke screening and trucking which has resulted in significant savings.

CONCLUSIONS

The installation and operation of the coke stabilizer units have proven to be very important to coke quality improvement in both actual level of quality and variation. Stabilization after the wharf prior to the blast furnace is most desired. The use of coke stabilizers at ArcelorMittal Dofasco has resulted in:

- An increased level of stabilization at the blast furnace from 82% in the base period to the current level of 91% at BF No. 2 and 86% at BF No. 4.
- An increase in ASTM coke stability from 60.2% (BF No. 4) to 63.2% at BF No. 2 and 61.3% BF No. 4.
- A tighter coke size distribution at the blast furnace as measured by the %-75mm+25mm size fraction. (≈92%-93%, up from 85%)
- A similar size distribution at both BF No.2 and BF No. 4.
- An improvement in coke delivery to the blast furnace.
- An improvement in blast furnace operation as measured by the frequency of tuyere change outs.

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Coke Stabilizers at AM Dofasco

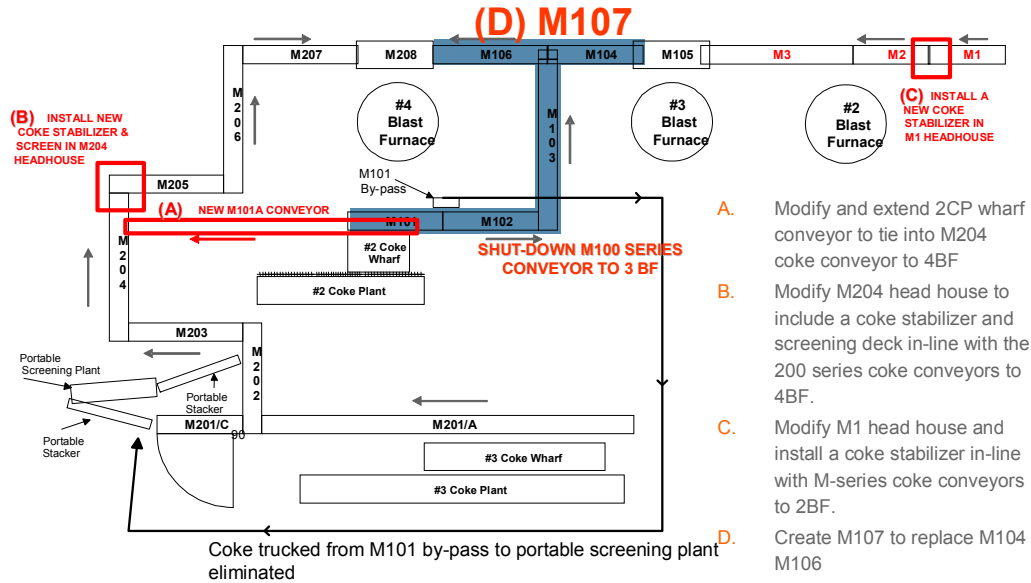


Figure 1: Reconfiguration of the Coke Delivery System with Coke Stabilizers Installed

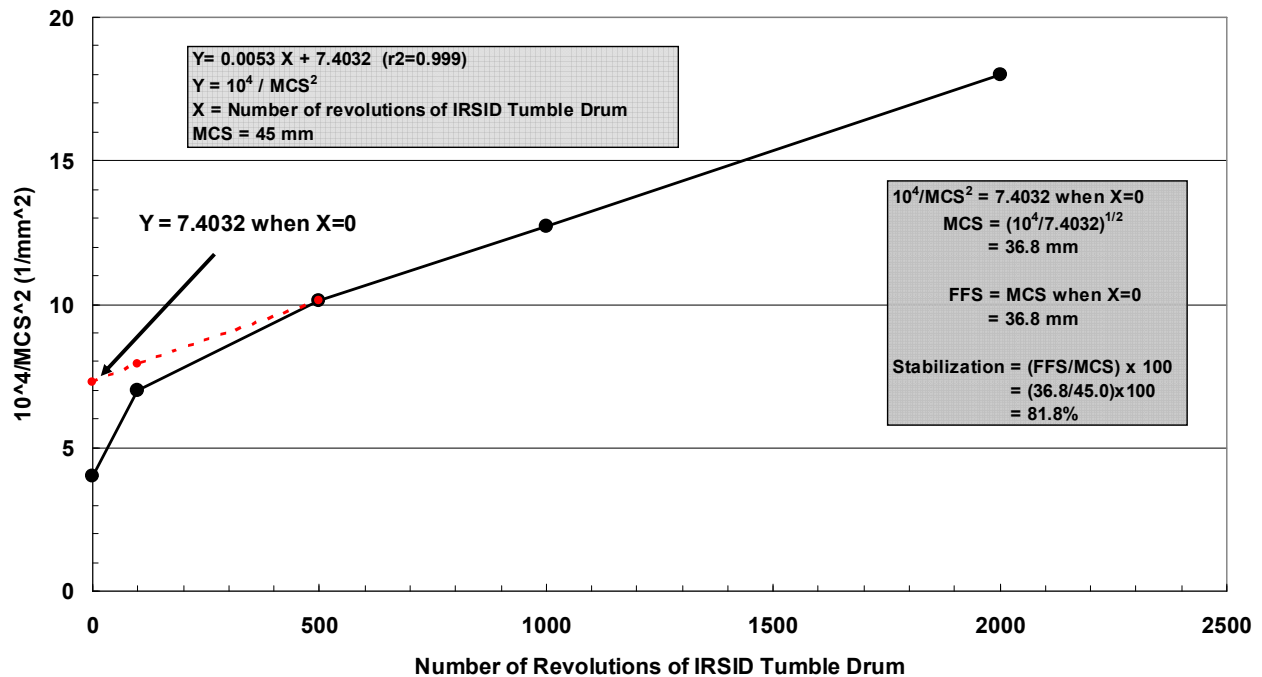


Figure 2: Coke Stabilization Calculation Method