ESTUDO DA ESTABILIZAÇÃO DO COQUE METALÚRGICO*

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Resumo

Para uma operação estável do alto-forno, o coque é requerido ser de alta qualidade em relação à sua resistência e preservação de granulometria Este trabalho propõe uma metodologia para avaliar o nível de resistência e estabilização do coque, aqui chamado de *Cracking*. Esta metodologia é única e segue os critérios de processo da Gerdau Ouro Branco. A metodologia de *Cracking* provou ser muito útil e aplicável tecnicamente para se determinar o grau de estabilização do coque. Além disso, o trabalho de amostragem levou a oportunidades de melhoriana rota da matéria-prima ao Alto-forno.

Palavras-chave:Coque metalúrgico; Estabilização Mecânica; Coqueria; Alto-forno.

STUDY OF METALLURGICAL COKE STABILIZATION

Abstract

For a stable performance of the blast furnace, coke is required to be of high quality regarding its strength and particle size preservation.This work purposesa methodology to evaluate the level of resistance and mechanical stabilization of coke, here called to cracking.This methodology is unique and follows the processing criteria of the Gerdau Ouro Branco.The Cracking methodology has proved to be very useful and technically applicable to determine the degree of coke stabilization. Furthermore, the sampling work has led to opportunities for improvement in the route from raw materials to the blast furnace.

Keywords: Metallurgical coke; Mechanical stabilization; Coke Plant; Blast Furnace.

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1 INTRODUCTION

The constant evolution of the productive processes is a differential for the survival and growth of the organizations, mainly in a scenery of great competitiveness between the steelmakers in the production of high quality products and lower production costs. One of the major challenges of steelmaking is increase the performance of reducing iron ore in blast furnaces, using low-cost raw materials. Figure 1 shows innovation, which is a premise to ensure competitiveness in steel industry, especially in the area of iron ore reduction.

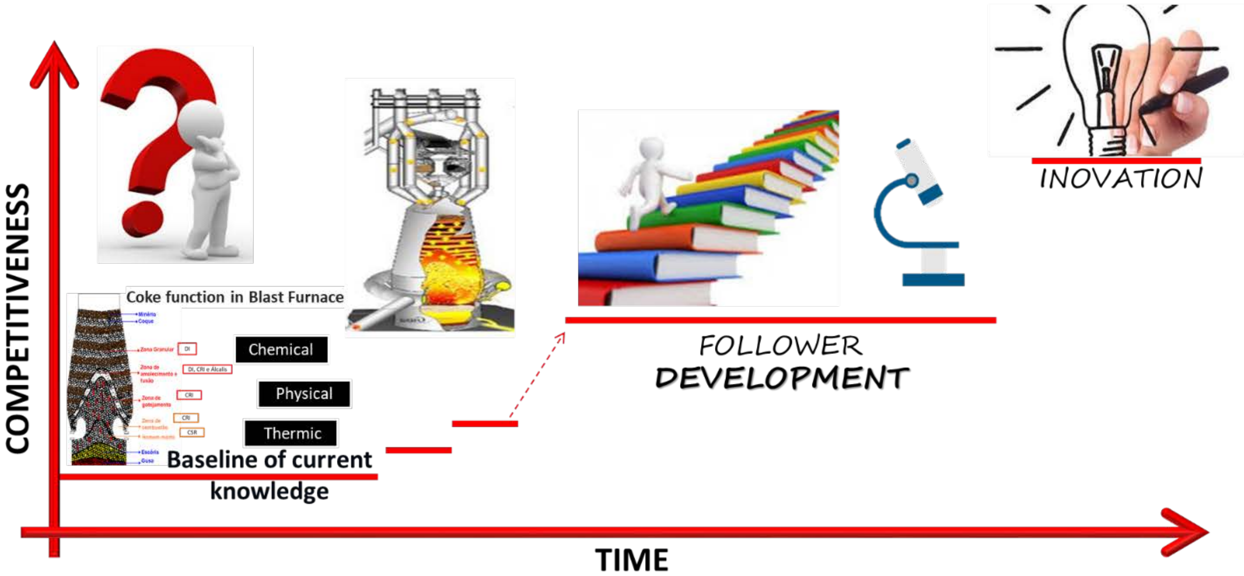

Figure 1. The importance of innovation for the organizations competition.

According to Geerdes (2004) [1], high productivity levels in the blast furnace with low fuel consumption are only possible with an operational stability, which will depend fundamentally on the permeability conditions inside the blast furnace. The permeability of the charge is obtained almost exclusively through raw materials of quality adequate. The granulometry of the charged metallurgical coke is one of the main parameters to guarantee the stability operational.
Sharma et al., (2013) [2] concluded that the mechanical resistance of metallurgical coke interferes directly in the generation of fines resulting from surface fragmentation or volumetric break. Ulhôa (1991) [3] points out that the metallurgical coke tends to degrade due to the handling, transport and several applications. This degradation must be considered before charging it into blast furnace. During quenching and handling, coke is exposed to thermal shocks (wet quenching), mechanical stresses due to the drop (which tends to fragment the coke) and friction between the coke particles and the coke with equipment (in which case the degradation is by abrasion).
The degradation is an important process to the mechanical stabilization of coke, it allows the withdrawn of generated fines before charging the burden into the blast furnace. The mechanical stabilization of metallurgical coke is necessary since this fuel must provide a permeable column that allows the drainage of liquids (hot metal and slag) and, above all, must guarantee the gases rising from the combustion zone to the top of blast furnace, even when subjected to high temperatures.
Accordingly, the focus of this work is the development of a methodology called Cracking. The purpose of this methodology is evaluating the level of resistance and mechanical stabilization of the coke produced at Gerdau Plant in Ouro Branco. This

plant has two Blast Furnaces and has a total productive capacity of about 12 thousand tons of hot metal per day. Gerdau Ouro Branco is located at QuadriláteroFerrífero, in the state of Minas Gerais, and it has a strong operational safety culture implanted. Therefore, this work can be used as a tool to help making decisions regarding the need for increasing coke quality, especially about the mechanical strength, aiming to minimize the generation of fines inside the blast furnace, improving process performance.
Reis et al. (2002)[4] used to construct samples of metallurgical coke. The samples were compared to other materials collected in the industrial circuit from coke oven to blast furnace at another large brazilian steelmaker. In this study it was possible to represent the volumetric degradation of metallurgical coke, using the drop test. Reis constructed comparative graphs between the particle size distribution of the collected sample and the sample obtained from the drop test. The results were very similar and indicate a high degree of representativeness of the test.
Silva (2016) [5], observed that, during transport, screening and charging of coke in the blast furnace, it exists three distinct mechanisms of fragmentation, evidenced in Figure 2.

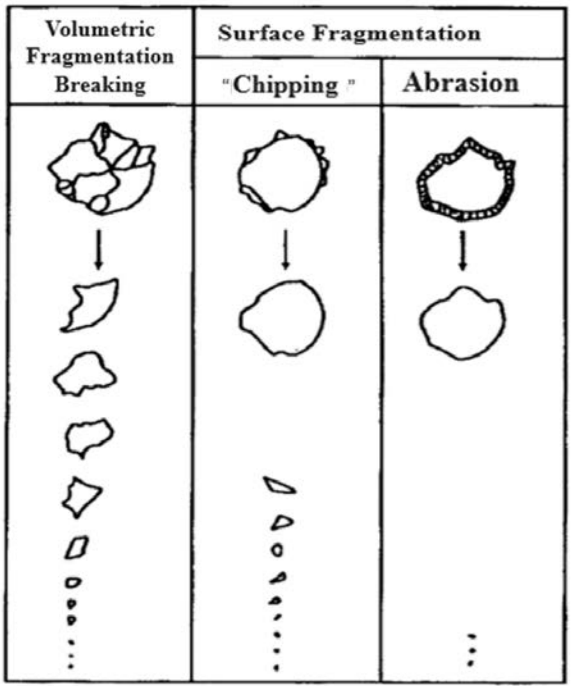

Figure 2. Fragmentation mechanisms. Adapted from Sahoo (2007) [6].

For Silva (2016) [5], even if the drum test does not accurately represent all the efforts that coke is submitted to its consumption in the blast furnace, the test must essentially reproduce the mechanisms of degradation that occurs in such fuel, considering the importance of evaluating the coke resistance to mechanical fragmentation.
According to Silva (2016) [5], initially the surface degradation rate of the coke submitted to the drum is high. This rate is reduced through the progression of the test. According to Ulhôa (2011) [7], the concept of mechanical stabilization is usually applied according to the volumetric fragmentation of coke, however, according to Silva (2016) [5], this concept can also be extended to surface degradation. These conclusions were also observed in this study and they were used as a basis for the analysis of the Cracking application results.

2 MATERIALS AND METHODS

The development of the Cracking methodology was divided into three parts, the first one was the collection of the metallurgical coke at four points of the industrial coke circuit, in the coking plants, until the final consumption, in the Blast Furnace 1 of the company studied.

Therefore, the first sampling point was in coke plants, in the samplers type Cross Belt located in the conveyor belt after wharf, according to the company's sampling standard, based on ASTM D 346. In the coking plants, the coke was sampled for 3 months, generating about 645 kilograms of coke, 430 kilograms of coke 1 and the remaining 215 kilograms of coke 2. This sampling rate is close to that of blast furnace consumption, each coke oven.

The second sampling point of the coke was named PVQ 101, this point is right after the first sieving of the coke produced in the coking plants. In the sieve occurs the separation of three granulometric bands of the coke produced. The metallurgical coke is the one in question, retained in 25 mm, and it was collected on the belt that goes to the blast furnace. The others granulometric bands were not studied in this study. The third sampling point (TCQ 111) is after the two coke drops from a height of about 2 meters each, before the charging the stock-house in the Blast Furnace. The collection of the coke in these two points was also based on the ASTM D346 standard and was made manually on the conveyor belts.

The fourth sampling point (C1BC) is right after the storage silos and the sieving of the coke that occurs in the area of the blast furnace. No further significant drops occur before its charging into the blast furnace. The same sampling method was also used for all sampling point, except for the first one. In total, 10 samples were taken at each point of the circuit during the three months of study. In addition, during the period in question no significant changes were made to the coke oven's coal blend. Figure 3 is an overview of the sampling points.

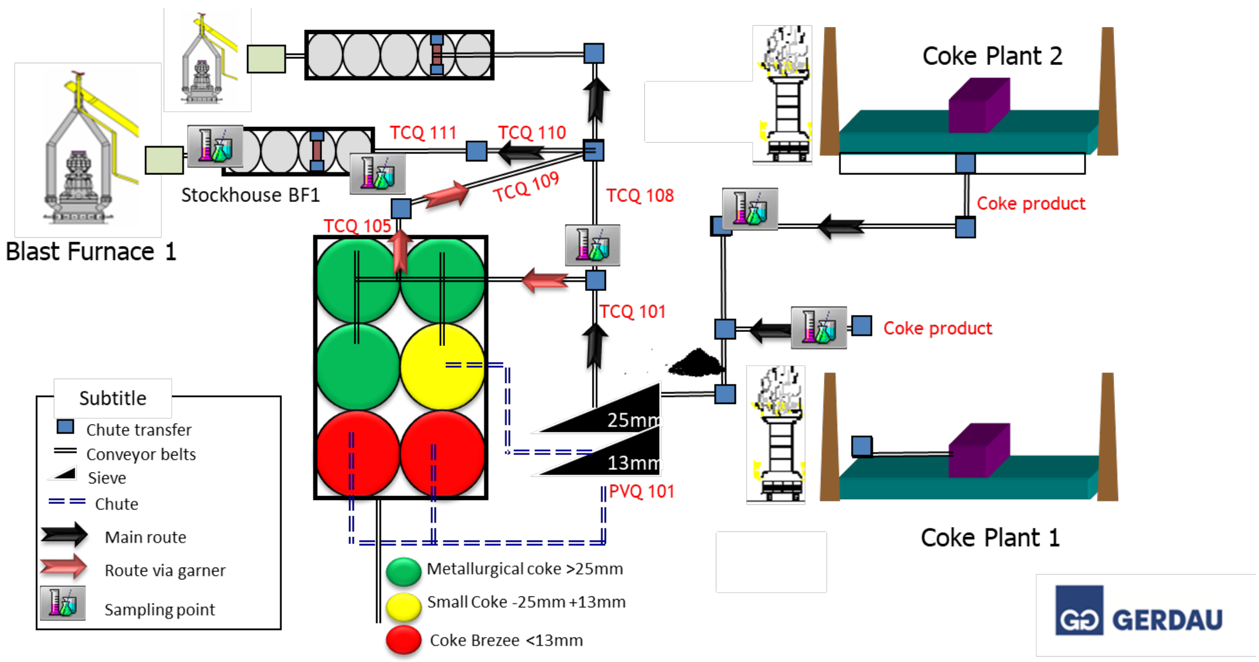

Figure 3. Overview of the coke sampling points along the coke circuit from the coke oven to the blast furnace 1.

The second part of this work was the physical-chemical characterization of the coke sampled in the previous stage. The sieving was done in the following meshes: 75, 50, 31, 25, 13 mm and <13mm. The quality of coke used in this study was tested, it was measured the drum index (DI), Coke strength after reaction (CSR), reactivity (CRI) and average size (AS). The results were compared with those obtained in the samples that would be obtained from the drop test.
The last part was the cracking test, using the base sample of 645 kilograms of coke from coking plants. This part was also divided into 3 steps. The scheme of Figure 4 explains the necessity of these three stages for Cracking execution, in order to represent all the samples collected at each point of the industrial circuit.

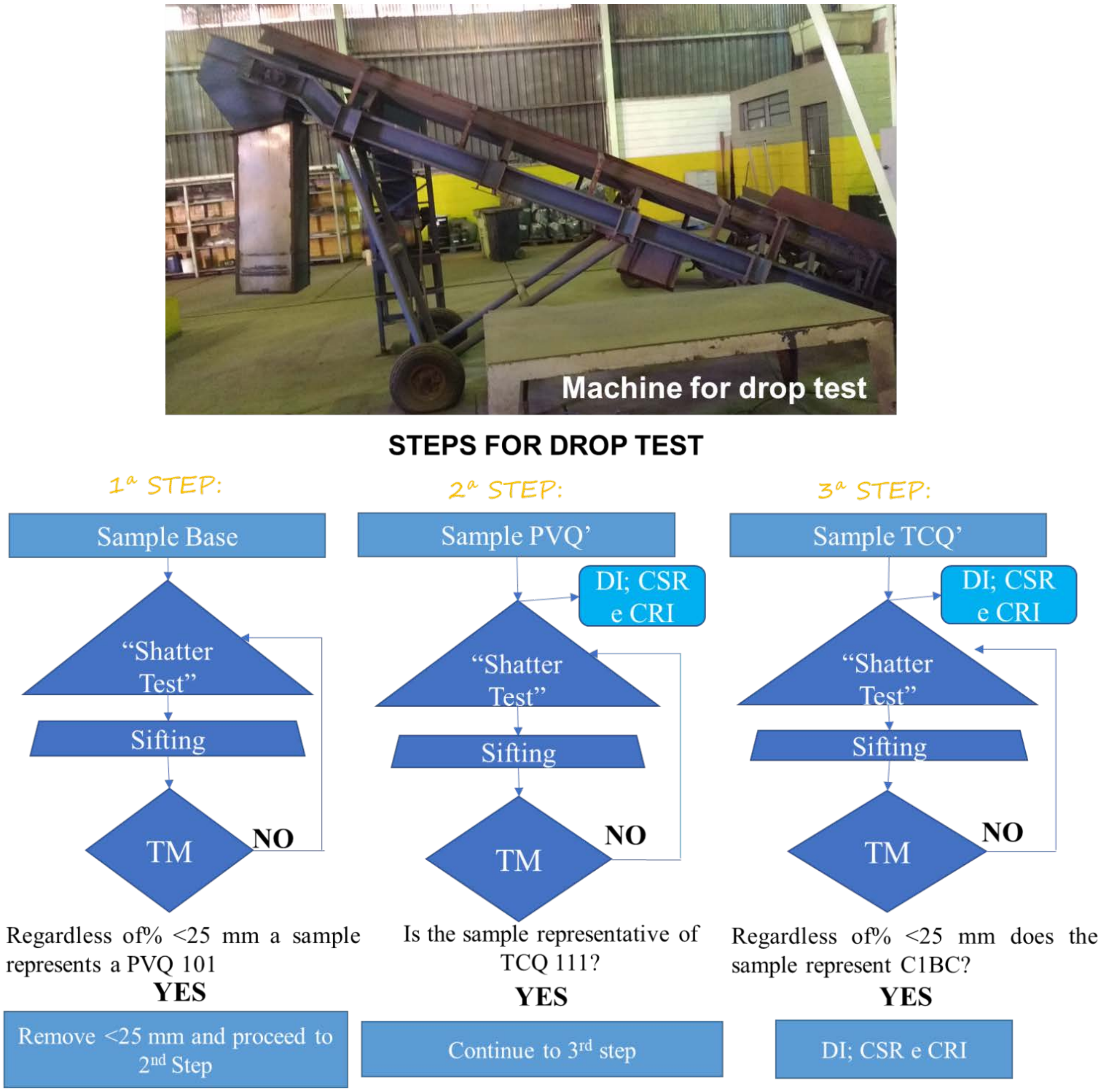

Figure 4. Scheme of the steps for the realization of the Cracking drop test.

3 RESULTS AND DISCUSSION

The first results of this work were the physical-chemical characterization of the sampled coke at the four points of the industrial circuit. It was represented the comparison between the mechanical stabilization of the coke collected in the circuit and those in the Cracking test. The base coke that started the drop test was analyzed as Sample Start Cracking or Coke Base and it showed the following characteristics, in Figure 5.

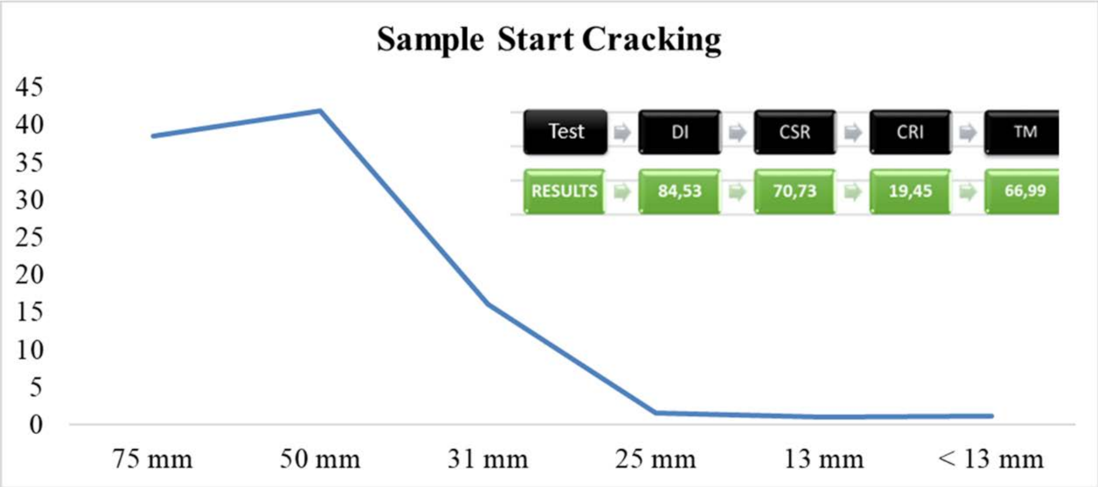

Figure 5. Chemical-physical characterization of Coke Base that started the Cracking.

As the drops were processed, it was possible to evaluate the mechanical stabilization presented in the coke sampled from the coking plants. It was observed that there was a strong similarity between the process of mechanical stabilization that occurs in the industrial circuit and that which occurs using the methodology described as Cracking. Another important fact that led to the characterization of the coke as a single sample, called coke base, was the tendency of stabilization very close between the coke of the two coke plants as the drops began. This point is justified by the fact that the coal blend used for both plants has the same composition.

3.1 Accuracy of the Cracking Methodology

The diagram in Figure 6 shows the drop heights from the coke oven to the blast furnace. Comparing with the height of each drop of the Cracking (~ 2.15 meters), it was estimated that between the 3rd and 4th drop it would be possible to simulate the samples of the PVQ 101 because they would drop for approximately 6 meters. For TCQ 111, the estimate considering the 12 meters of drop was between the 6th and 7th drop and for the C1BC was between the 10th and 11th drop.

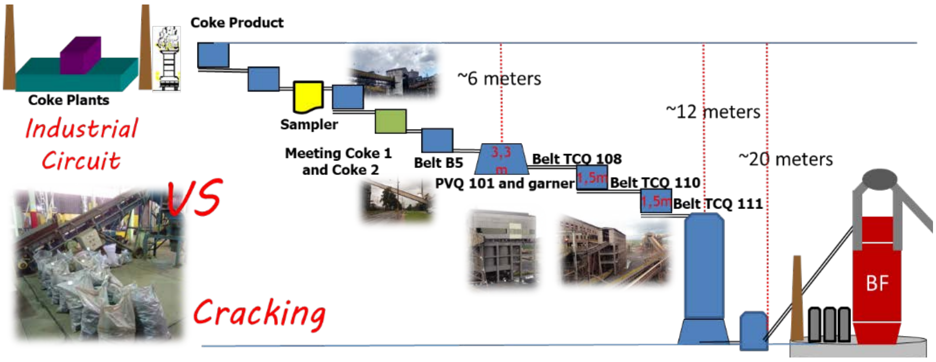

Figure 6: Overview of drop heights between the coke plant and the blast furnace.

The graph of Figure 8 shows that the initial estimate for PVQ 101 and for TCQ 111 was accurate. The results showed that the 4th drop and the 6th drop had the percentages retained in the metallurgical meshes within the range of the samples collected at points PVQ 101 and TCQ 111 respectively. In addition, they were close to the average of each mesh. In figure 7, the points in red are the results of the cracking drops and the points in blue are the average obtained from the circuit samples.

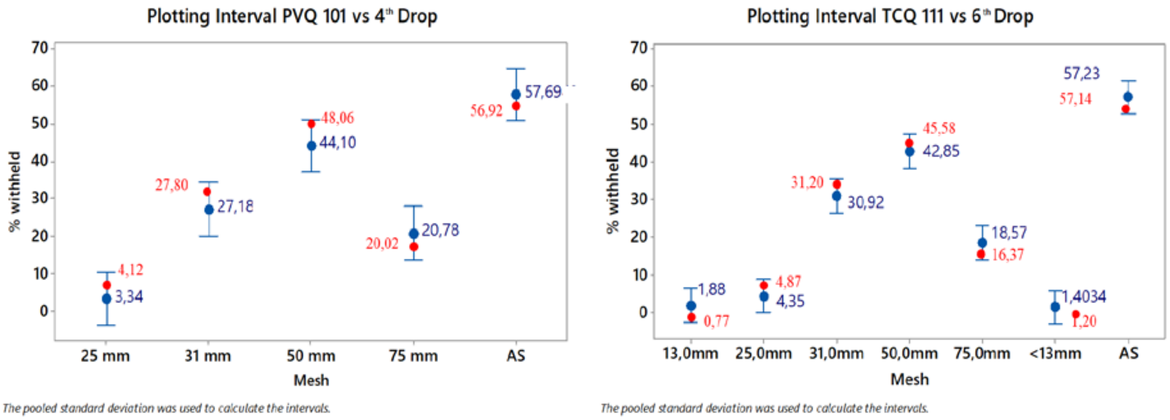

Figure 7. Comparison between the results of the 4th and 6th drop within the range of the particle size distribution of the industrial circuit samples.

As for the last point of the industrial circuit called C1BC, it was not possible to characterize it in granulometric terms until the 12th drop of Cracking. It is believed that, to simulate the efforts the coke is subjected inside the silos, greater amounts of drops are required. Figure 8 shows the plotting interval between the C1BC and the 12th drop.

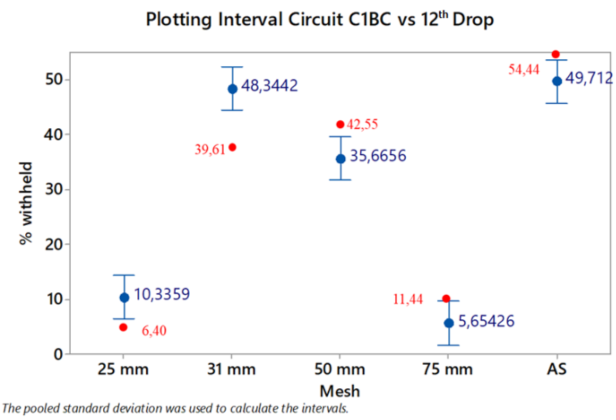

Figure 8. Comparison between the results of the 12th Drop and the C1BC samples.

To verify how close, the mechanical resistance indices were, the results of the circuit representative samples and the Cracking samples were compared. Figure 9 shows a comparative scheme in which AS values are in millimeters and the other parameters are indices.

TEST	DI	CSR	CRI	AS
START	84,53	70,73	19,45	66,99
PVQ	87,6	70,87	20,43	57,69
4th DROP	86	72,05	18,84	56,92
TCQ	87,1	71,31	20,57	57,23
6th DROP	86,9	72,04	20	57,14
C1BC	88,9	73,09	17,15	49,7
12th DROP	88,7	72,16	18,05	54,4

Figure 9: Comparison of results until the 12th drop of Cracking.

The results of Cracking are very similar to the indices of drum Index DI and CSR, as well as for coke reactivity (CRI). There was an increase in the coke DI of more than 4 points, meaning that the coke increased its degree of mechanical stabilization and it is more prepared to guarantee the permeability highlighted by Geerdes (2004) [1] to guarantee high productivity in the blast furnace. The CSR gain was positive, and it is also important in the blast furnace for liquid depletion. The reduction of reactivity, although small, was also very close between the 12th drop and the C1BC and it is still positive for the fuel consumption in the process of the metallic charge reduction.
Regarding the AS, a very similar reduction was observed until the TCQ 111 and the 6th drop. A reduction of about 9.8 mm was observed in the industrial circuit and 9.85 mm in the Cracking. As for C1BC, this point showed a decrease of 4.7 mm more than in the 12th drop. A mathematical modeling was made considering the drops processed in the Cracking to investigate the number of drops necessary to represent the C1BC.

3.2 Cracking Validation

To observe the generation of fines that would occur in the 12th drop along the drops, a graph was constructed considering the "known points" (drops realized). This graph defines an exponential curve that representes the stabilization process that occurred in the Cracking. The points that allowed better adjustment of the exponential curve are plotted on the axis of the graph abscissa on Figure 10.

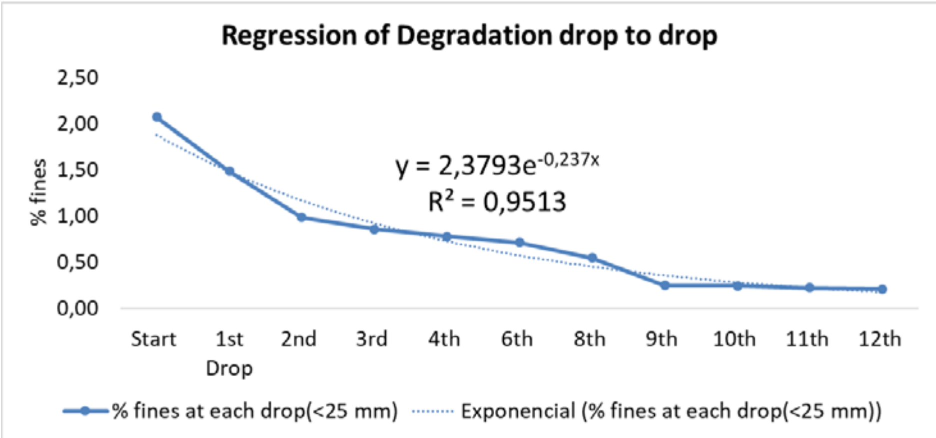

Figure 10. Curve of Mechanical Stabilization of Coke.

Considering the curve obtained, the first point for the validation of Cracking is the definition of the stabilization level that was intended to be achieved in the study. Thus, the criterion adopted in this work considers the smaller percentage of fines possible to be handled on a pilot scale for tests. In this case, the value of 0.05% of particles with an average size of less than 25 mm was established. Therefore, the ratio "df / dq", where "df" is the derivative of the fine function (Y) obtained in the graph of Figure 11 and dq, the number of drops (X), should be less than 0.05%. Based on this calculation the stabilization of metallurgical coke was obtained between the 16th and 17th drops. The stabilization graph can be observed in Figure 11.

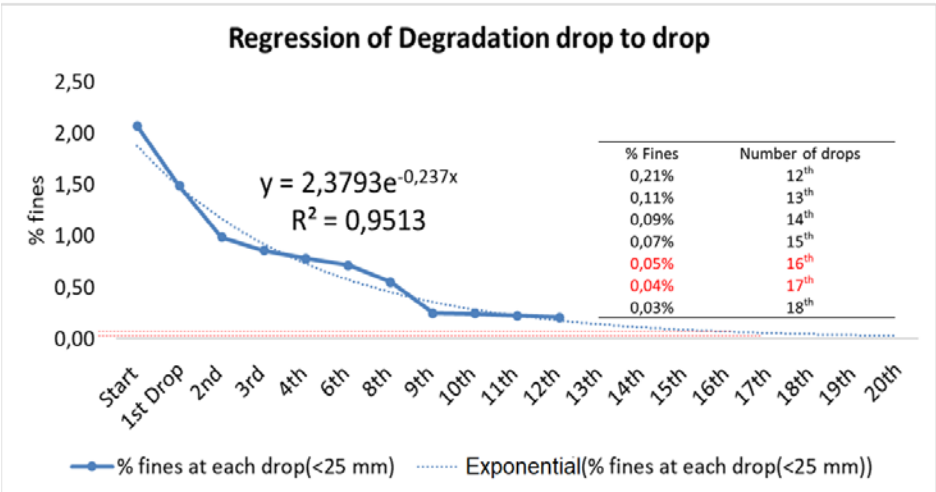

Figure 11. Estimation of mechanical stabilization of coke.

3.3 Application of the Study at Gerdau Ouro Branco

To complete the objective of the work, it was necessary to know in which drop it would be possible to represent the coke sampled in the C1BC, and then to see if the coke was stabilized according to the developed methodology.
Thus, in the graph of Figure 12, the same regression principle was used previously for the validation of the Cracking method but using the average values (mm) of the samples obtained.

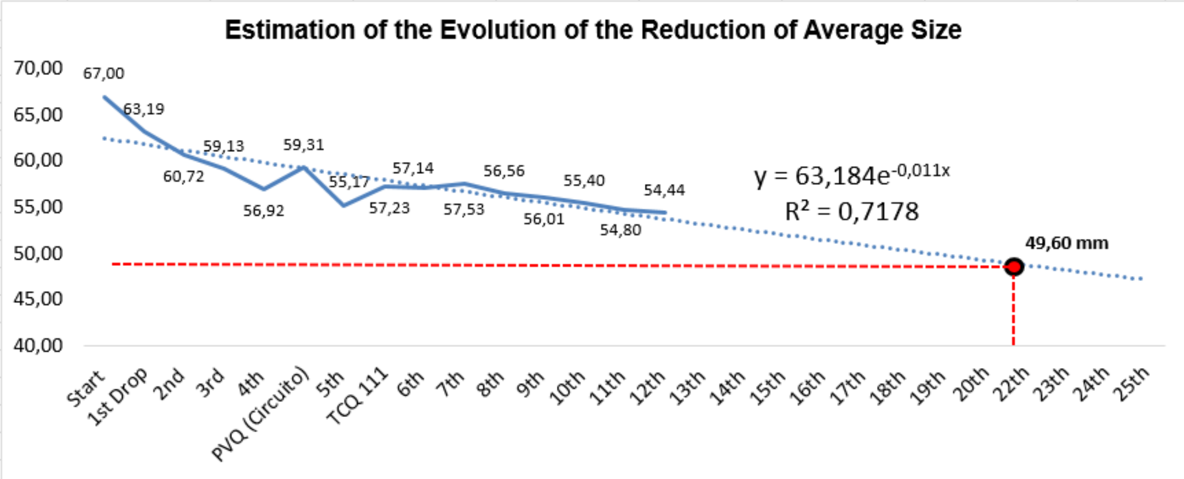

Figure 12. Estimation of the drop that would represent the average size of metallurgical coke charged in the blast furnace.

In the graph of Figure 12, an exponential regression was performed using the data of the reduction of the average size as the drops were processed in the Cracking. Knowing that the average sample size of the C1BC is 49.71 mm, using the Cracking methodology, its mechanical stabilization is expected on the 22th drop.
As already seen, the metallurgical coke is stabilized in the 17th drop. So, the coke has enough resistance to be charged in the blast furnace in the 22th drop. In this way, it is concluded that the metallurgical coke charged in the blast furnace of the company studied is ready to withstand the impact, compression and shear forces that will occur when it is charges into the interior of the blast furnace.

4 CONCLUSION

This methodology is unique and follows the processing criteria of the Gerdau Ouro Branco, so it does not apply directly for other companies without right execution adjustments. For the company, Cracking proved to be very useful and technically applicable to determine the degree of coke stabilization, product of the coking plants in the steelmaker. In addition, the sampling work has led the team to observe opportunities for improvement in the route from raw materials to the blast furnace, such as the installation of more automatic samplers on the route.
Another important point is related to the level of mechanical stabilization adopted for this work, the value considered is less than 0.05%, which requires high mechanical resistance to coke. In this way, the coke of the C1BC, when represented by the 22nd drop, has a level of mechanical stabilization that guarantees the permeabilizing role of the coke in the Blast Furnace.
The mechanical stabilization in the 17th drop can be used as a reference standard to the Blast Furnace 1 of Gerdau Ouro Branco, to continue the tests when a

comparison or verification of the level of mechanical resistance expected for the coke charged in the Blast Furnace is required.

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