# OTIMIZATION OF COMMINUTION PROCESS OF COALS*

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## Resumo

Uma marcha estável do alto-forno (AF) está ligada à consistência das propriedades químicas, físicas e metalúrgicas das suas matérias-primas (MP), especialmente, as do coque. As propriedades do coque são reflexos das propriedades dos carvões que lhe deram origem. Em termos de propriedades ligadas à natureza do carvão, a qualidade do coque é bastante influenciada pelo rank dos carvões, que compuseram sua mistura, ou seja, quantidades de macerais reativos e inertes, bem como suas propriedades coqueificantes, que é, exatamente, a habilidade inerente aos carvões aglutinantes de quando aquecido, amolecer, tornar-se plástico e solidificar em uma massa coerente. Neste contexto, o presente trabalho se propõe a evidenciar as mudanças no modelo de britagem de carvões da Gerdau Ouro Branco, bem como a operacionalização do padrão criado. Após a implantação, verificou-se a elevação de 1.8% em DI.

**Palavras-chave**: Carvão; Caracterização; Faixas granulométricas; Qualidade da mistura; britagem; DI

## OTIMIZATION OF COMMINUTION PROCESS OF COALS AT GERDAU

## Abstract

A steady operation of the blast furnace (AF) is linked to the consistency of the chemical, physical and metallurgical properties of their raw materials (MP), especially the coke. The coke properties are reflections of the properties of the coal from which the coke arose. In terms of properties related to the coal nature, the coke quality is strongly influenced by the rank of coal which composed the mixture, i.e., the quantity of reactive and inert macerals and their coking properties, which is exactly the inherent ability of binders for coal, when heated, to soften, become plastic and solidify into a coherent mass. In this context, this paper intend to highlight the changes of coal crushing model at Gerdau Ouro Branco as well as the operation of the created standard. After the implantation, it was possible to see a increase around 1.8% in DI.

**Keywords:** Coal; Characterization; Particle size distributions; Quality of mixture; Crushing; DI.

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## 1 INTRODUTION

In order to obtain a particle size distribution compatible with the coking process, the crushing of coal is a key operation to the comminution process of the coal in the mixture. However, due to different coal hardness, particle size distribution by the material reception, significant percentage of particles on the particle size required for coal (<2.80 mm) and wear of the crushing surfaces, the operation becomes very complex.

According to Ulhôa[1] "the crushing of a coal to a more suitable particle size distribution and a higher constancy of this distribution have a positive influence on the strength and homogeneity of coke, resulting in gains in terms of coke yield for blast furnace and reduced coke rate". Thus, the particle size of the mixture is critical to obtain cold mechanical coke strength, *Drum Index* 150-15, as shown in Figure 01 below.

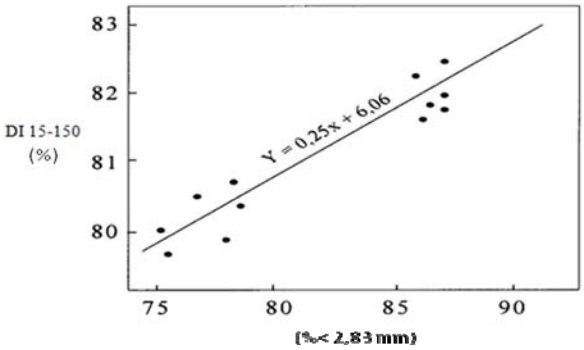


Figure 01: Effect of particle size level on DI (ULHÔA[1])

A side effect of raising the percentage below 2.80 mm is the excessive generation of coal dust (<0.149 mm). This material reduces the charge density and consequently the effectiveness of contact between the filler particles as well as the mechanical coke strength.

These considerations highlight the importance of the mixture particle size distribution to the coke quality and productivity, what justifies this work.

### 1.1 Comminution of coal

The behavior of coal towards the comminution is peculiar, since, as a heterogeneous material, it has petrographic constituents, macerals, each of which with an individualized mechanical behavior. The mineral matter presented as "released" from the carbonaceous material will have its own mechanical behavior. The other one closely associated with carbonaceous matter will change the behavior of the maceral to which it is associated (Chaves[3]).

Furthermore, the coal has a large number of pores, cracks, interfaces and capillaries. Each of these singularities constitutes a weak point. Bond[5] established the principle that the weakest point of a solid determines its mechanical strength. Relative to coal, there are so many discontinuities that they outweigh any other factors and determine the coal resistance to comminution. Because of the number of imperfections and the power of their influence, the coal can be theoretically considered as a pre-fractured solid.

## 1.2 Bond's Law

Bond[5] postulated an empirical law often called the "Third theory of comminution". The energy consumed to reduce the size of a material is inversely proportional to the square root of the size". The size defined was the sieve opening through which 80% of the material passes.

It was suggested the use of an index known as WI (Work Index), which is defined as the work necessary to reduce the weight unit (short ton = 907 kg) of the given material, from a theoretically infinite size (F = ∞) to a particle size 80% passing in 100 mm. Therefore:

$$Wi = E_o\left[\frac{1}{\sqrt{100}} - \frac{1}{\sqrt{\infty}}\right] \qquad E_o = 10\,Wi \qquad (1)$$

CHAVES[4] states that the ratio between WI and HGI (degree of grindability) of each coal is given by:

$$WI = \frac{435}{HGI^{0,91}} \qquad (2)$$

The comminution capacity of coal varies according to the rank, as shown in Figure 02, from Bond.

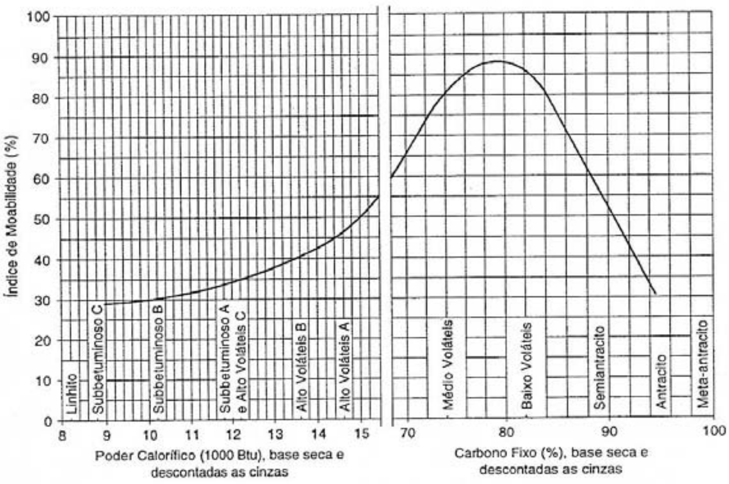


Figure 02: Grindability index in function of rank.

From the petrographic point of view, it is remarkable the concentration inertinites in the uppermost coal particle sizes, indicating that this material has high hardness and resistance to comminution, when compared with the reactive portion which is softer and shows a behavior contrary to that in inertinites.

Kubota e Nomura[6] noted the sharp difference in the concentration of inertinites, mostly in thicker particles, according to Figure 03.

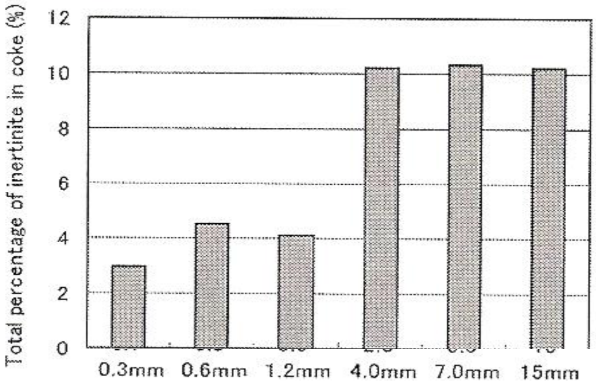


Figure 03: Concentration of inertinites=f(grain size mesh)

The nature isolated in separate groups the more and less coking constituents; however, they can be recombined into a more homogeneous mixture by particle size reduction of the entire load, thereby creating conditions for a better distribution of those.

Ulhôa[2] showed that the coking resistance can be improved by increasing the pulverization without any change in the maceral composition of the coal.

The analysis of microlithotypes (typical maceral association) provides an explanation for this phenomenon. For example, a strongly coking maceral may be present in a load in amounts of up to 10%, but its effect may be limited, depending on its particle size. A pulverization will result in:

- A better distribution of coking maceral and therefore a better effect.
- A size reduction of the organic and inorganic inert macerals, allowing their incorporation in the coke structure and eliminating weak areas responsible for fractures and cracks in the coke.

## 2 MATERIALS AND METHODS

### 2.1 Crushing standard

First of all, we created a crushing model for individual coals part of the mixture.

The model is based on the physical-metallurgical composition of each coal.

**Physical parameters**: HGI, WI, %<2,80mm and %<0,149mm in receiving.

**Metallurgical parameters**: Rheology, represented by fluidity; Petrography, measured by rank, % inertinites and CBI (Composition Balance Index), the latter measures the actual proportion of reactive / inert macerals compared to the optimal one.

The model consists in measuring a crushing constant which represents the need for comminution of each material. To level the impact of each explanatory variable, since the orders of magnitude are very different, it was necessary to normalize the variables around the value 1. For this we used a reference value of each, according to Table I. Thus the parameters fluidity*, inert*, HGI*%, <* 2,80mm were created, which represents the required particle size and% <0,149mm*, representing the fine particle size range.

Table I – Reference values of the model

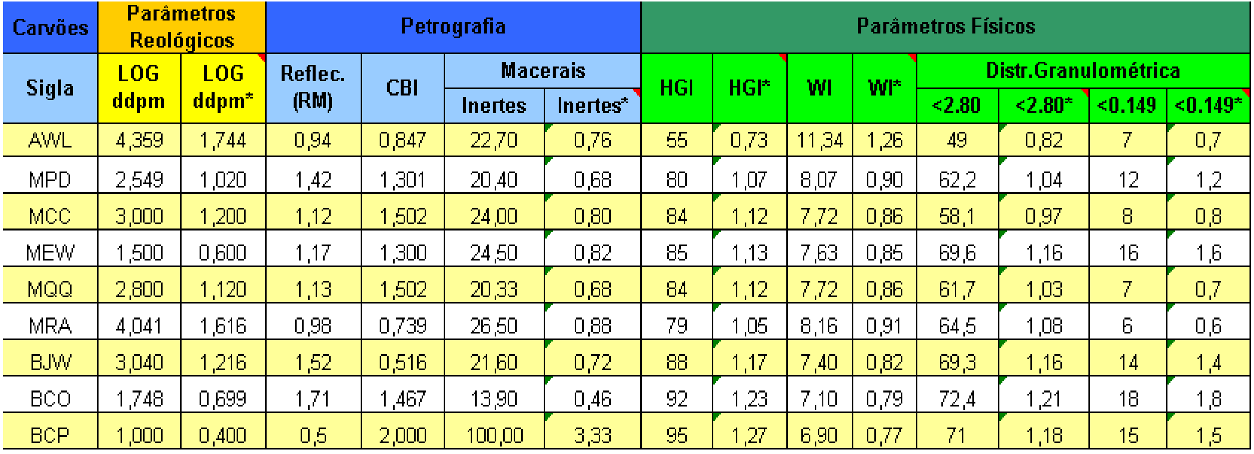
| Parameter | Reference value |
|---|---|
| Fluidity | 2,5 |
| Inert | 30 |
| HGI | 75 |
| %<2,80mm | 60 |
| %<0,149mm | 10 |

Thus, for example, the Fluidity* to be used in the model is given by:

$$\text{Log(ddpm)}^* = \frac{\text{Log(ddpm)}}{2{,}5} \tag{3}$$

The Table II illustrates the variables in the model, as well as their values to some coal blends.

Table - Crushing Model for individual coals part of the mixture.



| Carvões | Parâmetros Reológicos | | Petrografia | | | | Parâmetros Físicos | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sigla | LOG ddpm | LOG ddpm* | Reflec. (RM) | CBI | Macerais | | HGI | HGI* | WI | WI* | Distr.Granulométrica | | | |
| | | | | | Inertes | Inertes* | | | | | <2.80 | <2.80* | <0.149 | <0.149* |
| AWL | 4,359 | 1,744 | 0,94 | 0,847 | 22,70 | 0,76 | 55 | 0,73 | 11,34 | 1,26 | 49 | 0,82 | 7 | 0,7 |
| MPD | 2,549 | 1,020 | 1,42 | 1,301 | 20,40 | 0,68 | 80 | 1,07 | 8,07 | 0,90 | 62,2 | 1,04 | 12 | 1,2 |
| MCC | 3,000 | 1,200 | 1,12 | 1,502 | 24,00 | 0,80 | 84 | 1,12 | 7,72 | 0,86 | 58,1 | 0,97 | 8 | 0,8 |
| MEW | 1,500 | 0,600 | 1,17 | 1,300 | 24,50 | 0,82 | 85 | 1,13 | 7,63 | 0,85 | 69,6 | 1,16 | 16 | 1,6 |
| MQQ | 2,800 | 1,120 | 1,13 | 1,502 | 20,33 | 0,68 | 84 | 1,12 | 7,72 | 0,86 | 61,7 | 1,03 | 7 | 0,7 |
| MRA | 4,041 | 1,616 | 0,98 | 0,739 | 26,50 | 0,88 | 79 | 1,05 | 8,16 | 0,91 | 64,5 | 1,08 | 6 | 0,6 |
| BJW | 3,040 | 1,216 | 1,52 | 0,516 | 21,60 | 0,72 | 88 | 1,17 | 7,40 | 0,82 | 69,3 | 1,16 | 14 | 1,4 |
| BCO | 1,748 | 0,699 | 1,71 | 1,467 | 13,90 | 0,46 | 92 | 1,23 | 7,10 | 0,79 | 72,4 | 1,21 | 18 | 1,8 |
| BCP | 1,000 | 0,400 | 0,5 | 2,000 | 100,00 | 3,33 | 95 | 1,27 | 6,90 | 0,77 | 71 | 1,18 | 15 | 1,5 |

The Crushing Constant for each coal named K is given by:

$$K = \frac{Fluidez* \,.\, WI* \,.\, Inertes * \,.\, CBI}{Reflec \,.\, \%{<}2.80\ mm* \,.\, \%{<}0.149\ mm* \,.\, HGI*} \tag{4}$$

It is interesting to note that the larger the parameter K, the greater the need for comminution of the material, since:

- The higher the fluidity of the material, the higher volatility, thus, the lower the HGI's;
- The higher the content of inertinites, the larger the parameter K;
- The lower the <2,80mm in receiving, the greater the need for crushing and, therefore, the higher the constant K;
- The higher the% of superfines in coal received, the less need for crushing, therefore, the lower the value of K.

When calculating the K of some coals, the following Table III is obtained.

Table III – Calculation of K

| Grade | Abbr. | K |
|---|---|---|
| Petroleum Coke | CVP | 0,919 |
| High volatile | AWL | 0,883 |
| Medium volatile | MNB | 0,687 |
| Soft | SAL | 0,631 |
| High volatile | ARH | 0,618 |
| High volatile | AJF | 0,600 |
| High volatile | AQQ | 0,592 |
| Medium volatile | MRA | 0,550 |
| Medium volatile | MCC | 0,517 |
| Medium volatile | MUT | 0,502 |
| Medium volatile | MQQ | 0,491 |
| Medium volatile | MAF | 0,377 |
| Medium volatile | MPD | 0,342 |
| Medium volatile | MEW | 0,213 |
| Low volatile | BJW | 0,141 |
| Low volatile | BCO | 0,126 |
| Low volatile | BKS | 0,123 |

Thus, the model proposes the creation of 4 coals groups:

- **<u>Group I: K ≥ 0,80</u>**: Group consisting of those materials which should undergo a high degree of grinding, e.g. AV coals with low HGI and petroleum coke, the one with higher K material, since it has 100% inert material in its composition.
- **<u>Group II: 0,60 ≤ K < 0,80</u>**: In this group are the AVs and Softs coals with intermediate HGIs and inert contents.
- **<u>Group III: 0,20 ≤ K < 0,60</u>**: In this group usually are found the MVs from the MCC with higher volatile matter (~ 27%) to the coals Benchmarking CSR. (MPD / MEW).
- **<u>Group IV: K < 0,20</u>**: It is represented by BVs with high rank, low CBI and high %<0,149mm in receiving. These coals should be minimally crushed in order to refrain from increasing the content of superfines and therefore not destroy existing noble macerals in them.

The Figure 04 segregates the coals in the groups mentioned above.

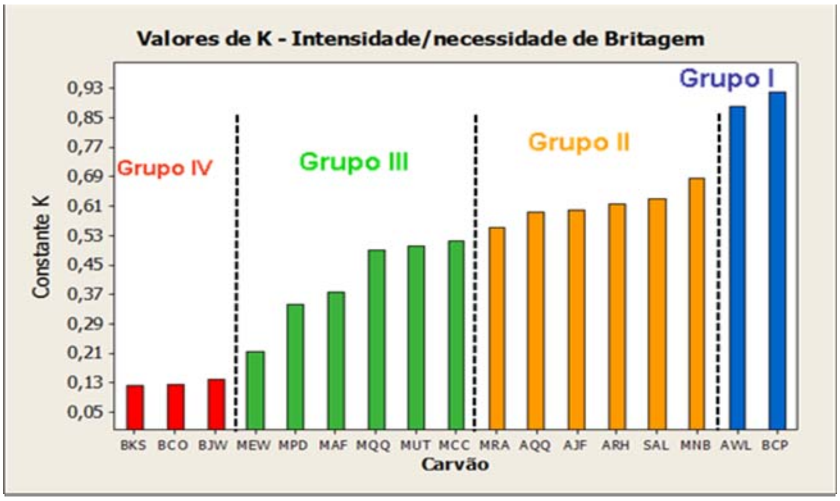


Figure 04: Crushing groups of coals

## 2.2 Design of Experiments – (DOE) in Crushing Process

In order to make operational the Crushing model created, it was performed a Full Factorial Experiment with 4 factors in two levels, as described below:

- Crusher rotation: 450 e 650rpm.
- Feed flow: 250 e 400t/h.
- %< 2,80 mm in receiving: 50 and 70%.
- HGI: 63 and 87.

To conduct the experiments, typical coals from each group were chosen as per Table IV.

Table IV - Coals chosen for DOE.

| HGI | %<2.83mm REC | Coal |
|---|---|---|
| High | High | BCO |
| High | Low | MQQ |
| Low | High | MRA |
| Low | Low | AWL |

The response variables were:

- %< 2,80mm.
- %< 0,149mm.

## 3 RESULTS AND DISCUSSION

In Figure 05, there are the effects of each variable in the two levels considered.
It can be observed the relevance of all factors, both coal-intrinsic as operational (crusher rotation and feed flow) factors.

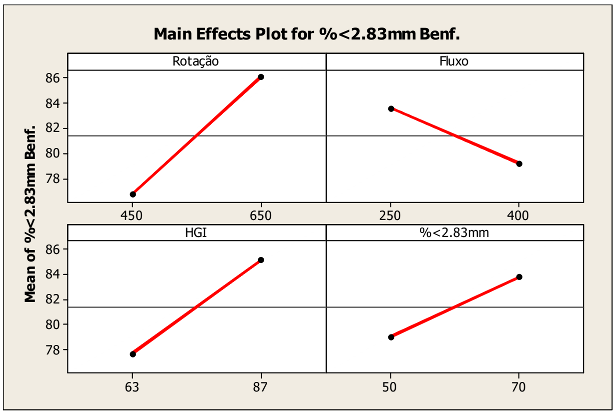


Figure 05: Effects of each variable

Another interesting analysis is the geometric interpretation of the four variables. The Figure 06 shows the results expected for each combination of the DOE variables.

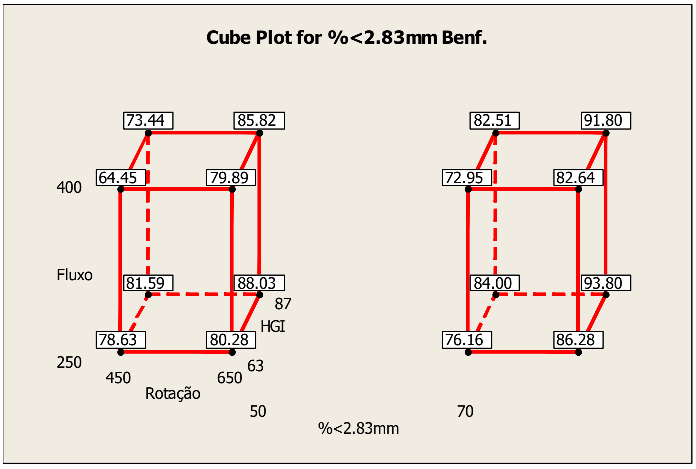


Figure 06: Prediction cube of % < 2,83 mm

Observe the following extreme situations:

- Rotation 450rpm, HGI=63, %<2.80mm=50 and flow of 400t/h results in %<2.80mm =72,95%
- Rotation 650rpm, HGI=87, %<2.80mm=70 and flow of 250t/h results in %<2.80mm =93.80%

The Figure 07 shows the operating abacus for AWL. In this case, in order to obtain % over 80% < 2,80 mm, it should be worked on the area indicated below.

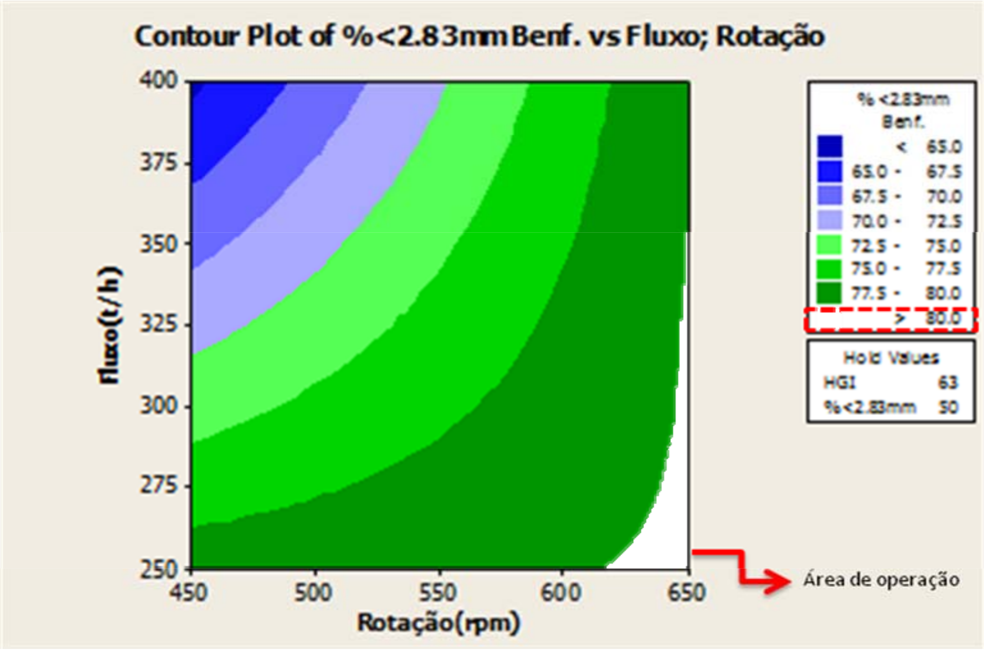


Figure 07: Operating abacus for AV - AWL

### 3.1 Behavior changes in particle size of the mixture and coke quality

After the implementation of the crushing standard, it was performed an evaluation of the effects on the particle size fractions of the mixture and coke quality, especially DI. The Figure 08 shows the control cards in each particle size range of the mixture.

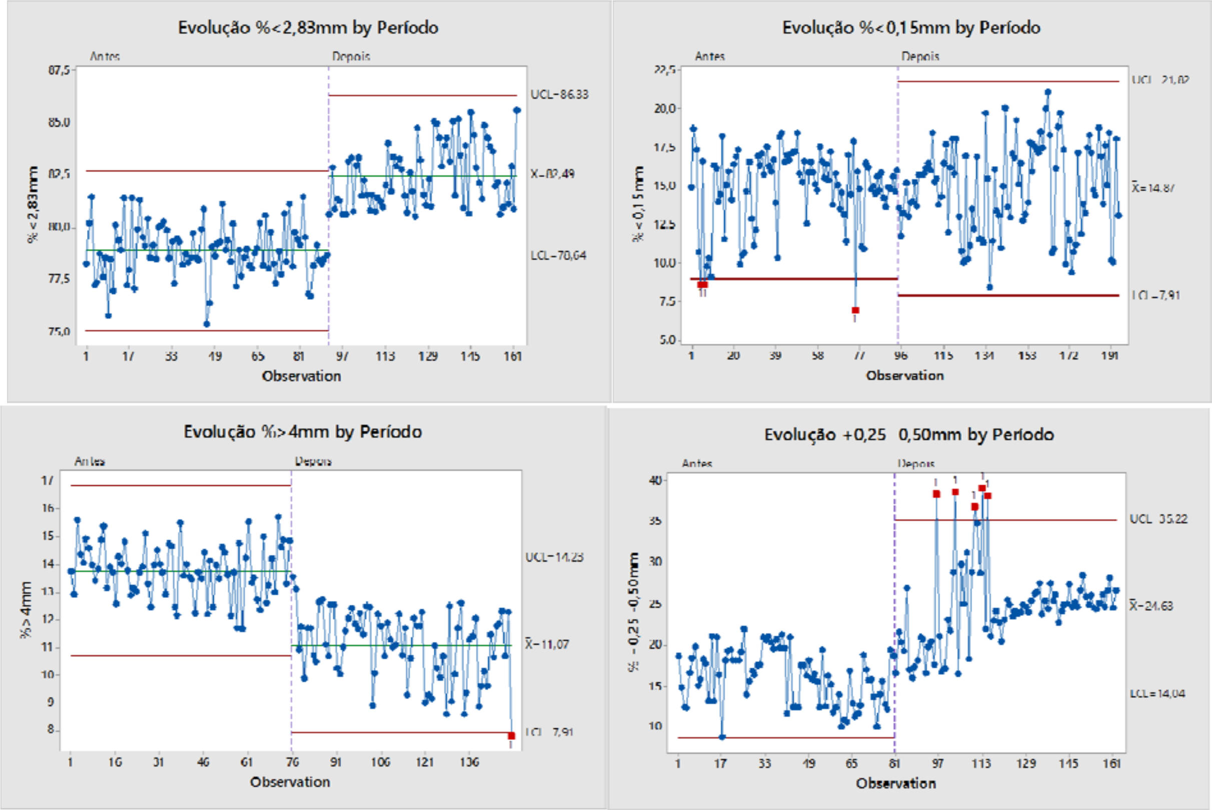
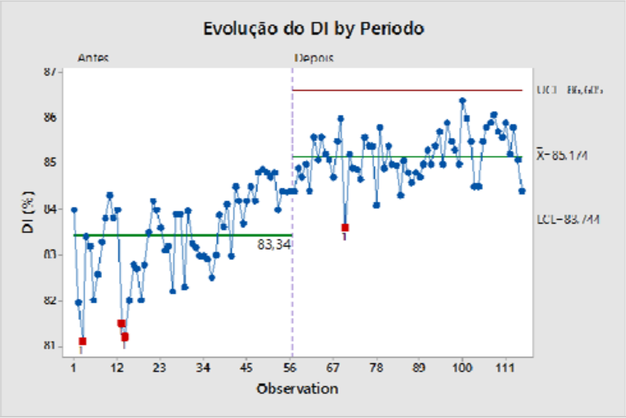


Figure 09: (a)% > 4 mm in the mixture; (b) % +0.15mm to -0.5mm in the mixture.

The Figure 09 shows the impact of particle size changes on the mechanical coke strength.



Δ - 1.8%

Figure 10: = DI evolution

The Figure 10 shows a gain of 1.8% in DI of Coke, i.e., this gain of DI based on the efficient mechanical treatment of coal allows the impoverishment of the mixture due to the entry of coal without coking power and / or lower rank, such as petroleum coke.

It is noticed the strong negative correlation between DI and the coarse fraction (% retained in 4mm); however, a high positive correlation is observed in relation to % <2.80mm and% (> 0:25 - 0.5mm).

## 4 CONCLUSIONS

From the tests conducted under the operating conditions reported in this study, it can be concluded: the materials of different particle sizes are significantly different, especially regarding the concentration of reactive material in the finer fractions and decreased inertinites in these ranges; the Crushing model created changed the comminution approach at Gerdau, aiming the optimal particle sizes for each type of coal, whose impact was evident on the particle size distribution of the mixture and especially on the mechanical coke strength, with an increase of 1.8% in DI.

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