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STAINLESS STEEL AS ANTIWEAR SOLUTION TO SUGAR PLANT [1]

Wilian da Silva Labiapari [2]
José Antônio N. Carvalho [2]
Jose Daniel Biasoli de Mello [3]
José Roberto de Andrade [4]
Cláudio Moreira Alcântara [5]
Paulo Sergio de S Balsamo [6]

Abstract
The aim was to study the wear mechanism at sugarcane preparing in sugar and alcohol industrial plant, understanding the real possibility to use stainless steel on this application, improving the industrial performance. On this way, lab tests were performed, comparing stainless steel and carbon steel like A36 used at sugar plant. The equipment Calowear was used at UFU, showing good results with stainless steel. After this, some samples was used at sugar plant industrial area, showing the same results as the lab ones. As industrial results was seemed the increase of equipment industrial life, reducing the maintenance costs. As technical results were possible to see that stainless steel can be used when the system has corrosion and abrasive agents. On this way, reducing the corrosion system is possible to reduce the abrasive one, improving the sugar plant performance.
Key words: Abrasion; Stainless steel; Sugar and alcohol plant.

AÇO INOXIDÁVEL COMO SOLUÇÃO ANTIDESGASTE PARA USINAS SUCOALCOOLEIRAS

Resumo
O foco do trabalho foi o estudo do mecanismo de desgaste em usinas de açúcar e álcool, principalmente no setor de preparação da cana de açúcar. Esta compreensão responderia a real possibilidade de utilização de aço inoxidável neste setor, melhorando o desempenho industrial. Neste sentido foram realizados ensaios de desgaste em laboratório na UFU - Universidade Federal de Uberlândia, comparando aço inoxidável e aço carbono, como A36, utilizado em larga escala nas usinas. Um dos equipamentos utilizado, micro abrasômetro Calowear, mostrou bons resultados apontado para uma superioridade do aço inoxidável, principalmente em ambiente úmido. Posteriormente, algumas amostras foram colocadas em usinas de açúcar, apresentando resultados condizentes com os de laboratório. Como resultados para a indústria, houve um aumento na vida útil dos equipamentos, reduzindo a necessidade de manutenção preventiva e corretiva. Como resultado técnico, foi possível ver que o aço inoxidável pode ser usado quando o sistema de corrosão e abrasão atuam simultaneamente. Desta forma, ao reduzir a componente de corrosão do sistema, consegue-se reduzir o desgaste, melhorando o desempenho da fábrica.
Palavras-chave: Abrasão; Aço inoxidável; Indústria de açúcar e álcool.

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2 *Master of Science – ArcelorMittal Inox Brasil Research Center*
3 *Ph.D. Teacher. – Universidade Federal de Uberlândia*
4 *Technical Support – ArcelorMittal Inox Brasil*
5 *Quality Technologist – ArcelorMittal Inox Brasil Research Center*
6 *Ph.D – ArcelorMittal Inox Brasil Research Center*

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1 INTRODUCTION

The replacement of austenitic stainless steel by ferritics one is the strategy of ArcelorMittal Inox Brasil due to the absence or low nickel content in its chemical composition, minimizing the cost fluctuations made by market.
Actually, the sugar and alcohol sector increases its importance, mainly by the ethanol, since it is ranked by USA as advanced energy sources, compared to corn matrix.(1)
In the '80s was produced 2500 L of ethanol per hectare. Nowadays is nearby 6500 and is expected up to year 2020 reach 13000 L of ethanol per hectare, supported by new technologies like cellulose hydrolysis from pulp.(1)
This sector was born with familiar administration model, but has changed by a model very professional, i.e. working to have higher efficiency with lower cost. On this way, the work with stainless steel starts in 2001, with initial tests on equipments from sugarcane preparing, regarding to be a new emerging market for the use of stainless steels.
It was proposed the DIN 1.4006, henceforth P410D, because it has the lower chromium content permissible for a stainless steel, 11%, getting a cost reduced. It was originally developed for structural applications, but, as reported by some papers, it has conditioned for antiwear applications too.(2)
An important step in this work was made by University of Uberlândia – UFU that worked at lab to compare the P410D with its main competitors. Beside this, several samples were applied at sugarcane plants in order to see the real results of wear resistance of this material in the field, always in a comparative way.

2 OBJECTIVE

The objective was to measure the P410D performance at sugarcane and alcohol industry, for applications where the moderate wear resistance is a decisive point.

3 DEVELOPMENT

As characteristic of stainless steels, wear resistance studies began at ArcelorMittal Inox Brasil in 2001. The work was focused on sugarcane plant, maily on the preparation stage, i.e., on the reception and work with sugarcane, whose wear is high and usually has high humidity.

3.1 Wear Mechanisms

The main mechanisms of mechanical wear are described in DIN 50.320,(3) as shown in Figure 1.

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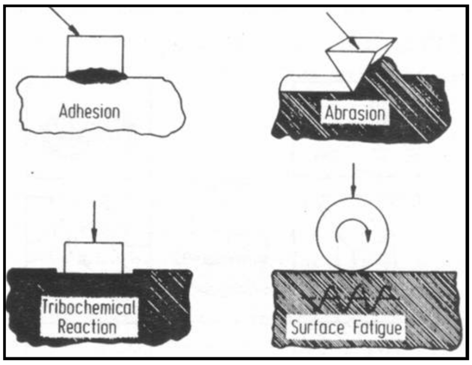

Figure 1 – Wear mechanism.

From these mechanisms, abrasive wear, sliding and rolling of particles as shown in Figure 2, seems to be capable to occur at the industrial system.

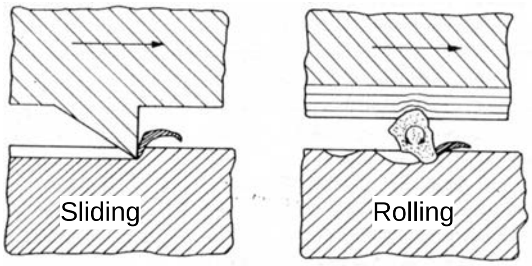

Figure 2 - Mechanisms capable to occur in industrial sugarcane plants.

3.1.1 Lab test: rolling wear particles

The first studies were performed on UFU lab equipment called LTM, that is able to reproduce rolling and sliding wear particles mechanism. The tests were made on wet and dry way. The goal was to compare the P410D stainless steel, its similar stainless competitor with 12% Cr, henceforth called SS12%Cr, and a low carbon steel, ASTM A36, which is widely used mainly by its low cost. The samples were analyzed by SEM (Figure 3), showing that the mechanism of rolling particle was reproduced.

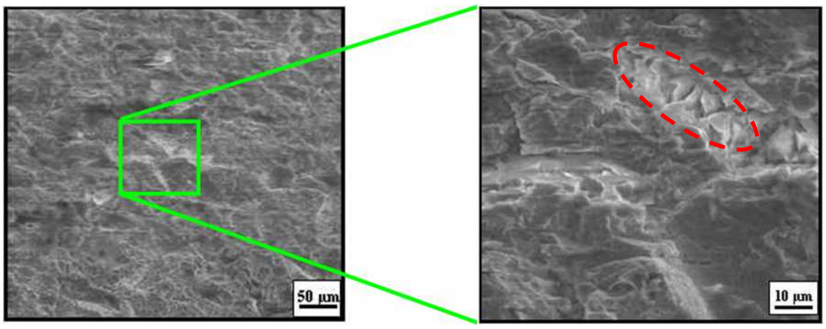

Figure 3 – Rolling wear mechanism analyzed by SEM.

At Figure 4 is possible to see the first results. It was seemed that at dry environment, the P410D and SS12%Cr are equivalent and both, superior to carbon steel. Another interesting point was that on wet environment, when the difference from carbon steel increases.

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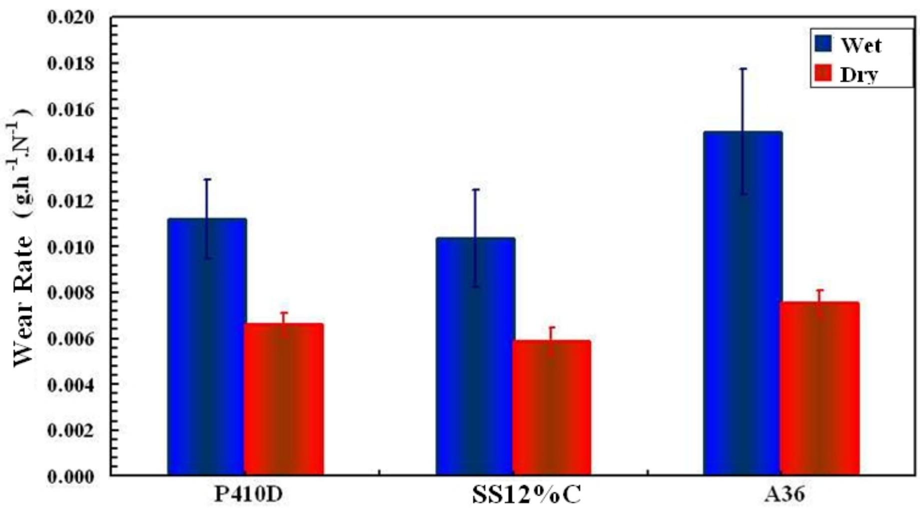

Figure 4 – Wear Rates on dry and wet environments.

The wear increased on wet environment can be associated with a corrosion component, but, on the other hand, can also be associated with another kinetic work of abrasive between the bodies. The water can change the surface energy between the body and the abrasive particle.

3.1.2 Wear characterization at industrial plants

After three years, some samples were caught, together with some others from carbon steel to evaluate the wear mechanism. The main mechanism found at industrial plants was the sliding particles.

Typically, the sliding particles promote greater wear on body surface. Further, it was observed for stainless steel, the surface appeared polished and the carbon steel much more damaged. It was observed too, some corrosion points on surface, increasing the roughness, as can be seen in Figure 5, by results of three-dimensional interferometer.

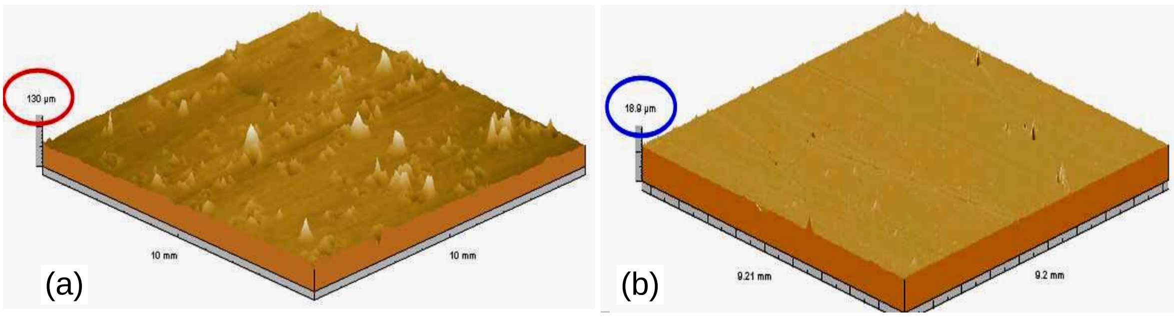

Figure 5 – Three-dimensional analyze by interferometer (a) Roughness increased by corrosion points. (b) Smooth surface of P410D steel.

From this analysis is possible to see that roughness of carbon steel is almost ten times higher than one for P410D stainless steel. Like lab results, it was found in industrial plants that increasing the humid environment, the performance of P410D is better when compared with carbon steel.

But, as can be seem at Figure 6, the mainly mechanism observed on this samples was sliding wear particles. So, another bath test were necessary.

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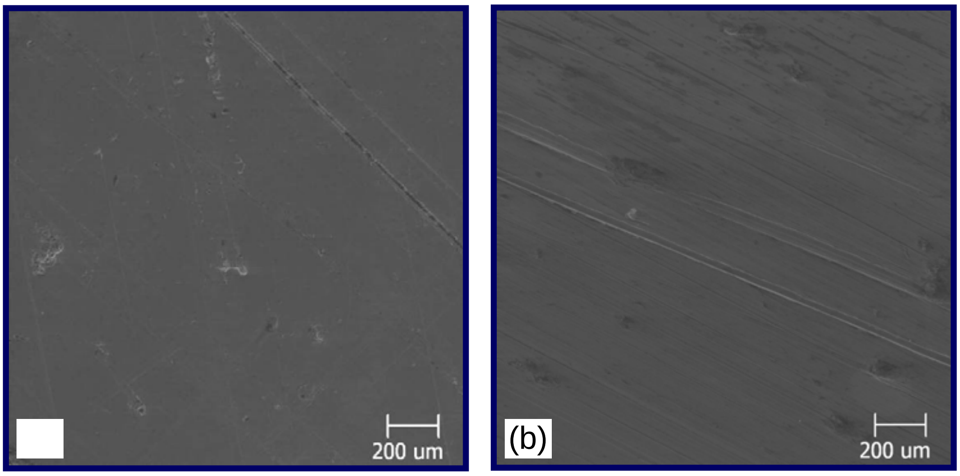

Figure 6 – Scratches on surface causing the wear on sample from (a) P410D and (b) carbon steel for samples caught at industrial sugarcane plant.

3.1.3 Lab test: sliding wear particles

As the main wear mechanism identified was due sliding abrasive particles, a new bath test was conducted, in humid way, evaluating five different steels listed at Table 1. In this case, the equipment used was Calowear, as described at Figure 7.

Table 1 – Chemical composition

	C	Mn	Si	Cr	Ni
Steel C	0,18 máx	1,40 máx	1,50 máx	0,60 máx	-
P410D	0,03 máx	1,50 máx	1,0 máx	10,5~12,0%	0,3~1,0%
SS 12% Cr	0,03 máx	1,50 máx	1,0 máx	10,5~12,0%	0,3~1,0%
304	0,08 máx	2,00 máx	0,75 máx	18,0~20,0%	8,0~10,5%
A36	0,26 máx	-	0,40 máx	-	-

At the Figure 8 is possible to see the comparative results between each material and some interesting points can be observed:

1. The P410D is better than its competitor SS12%Cr on this new test.
2. The austenitic stainless steel AISI 304, that is more expensive and knew than P410D, doesn't have better result.
3. The carbon steel A36 was the worst.
4. A interesting point is that the “Steel C”, that has 400MPa as yield point, against 290MPa for P410D, had better result. But, at industrial sugarcane plant, the P410D has good results. To understand that, a new bath test was made, using a “waiting time”, to allow the corrosion component to be started. The Figure 9a shows that at “Steel C”, a oxidation process starts during Calowear test.

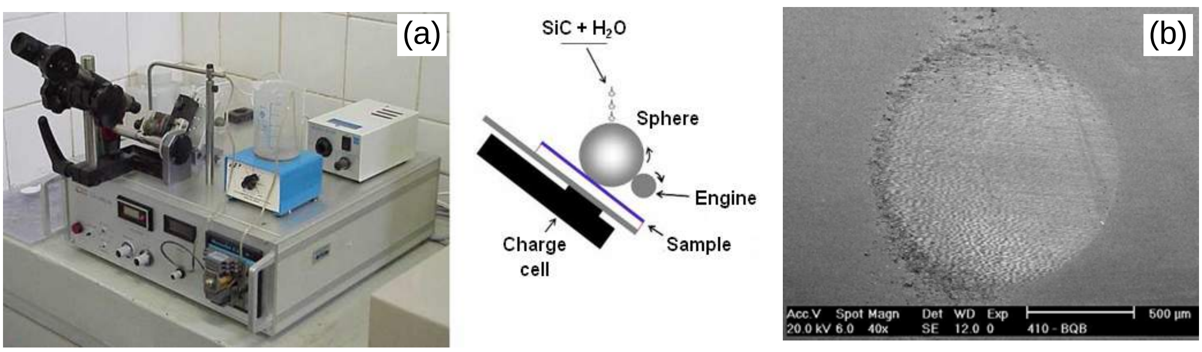

Figure 7 – (a) Calowear from UFU and a (b) sample after test analyzed by SEM.

ISSN 2179-3956

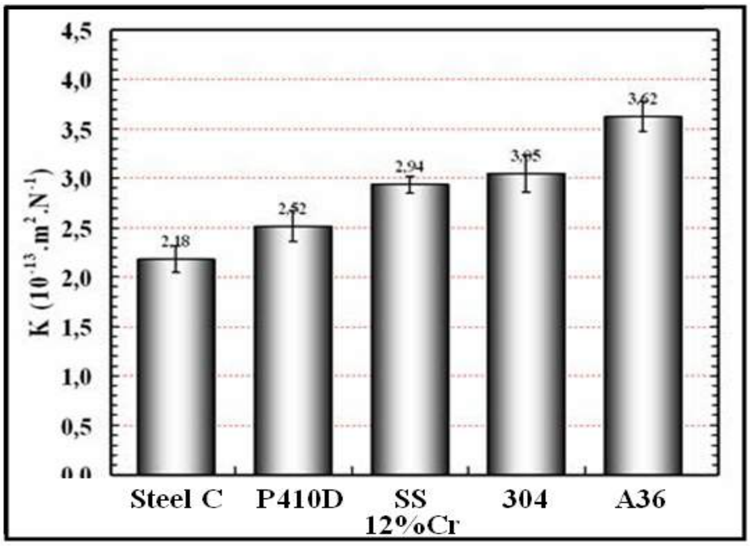

Figure 8 – Results made by Calowear from UFU for different steels.

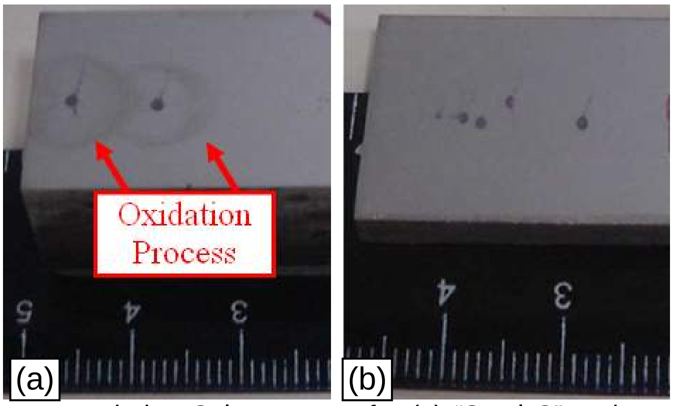

Figure 9 – Oxidation process during Calowear test for (a) “Steel C” and no oxidation for the 410D steel grade.

With the “waiting time” on Calowear test was possible to see the influence of corrosion process on “Steel C”. When the “waiting time” is zero minute, as it doesn’t have time enough to the corrosion process works, the “Steel C” is better. But when is sixty minutes between each step from this test, the P410D steel grade is much better, as shown at Figure 10. This result is comparable with the industrial plant, mainly when it has humid environment, because the corrosion component exist and emphasize the wear mechanism to the carbon steel. To the stainless steel, the corrosion component is minimized, and reduces the wear phenomena.

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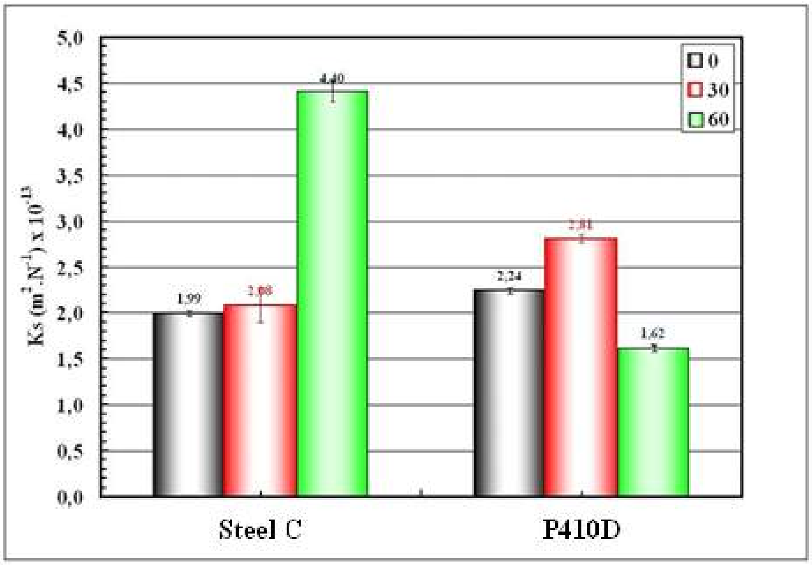

Figure 10 – Results made by Calowear from UFU, with "waiting time".

The synergism that associates abrasion and corrosion has been strongly discussed.(4-6) By some autors it increase the cession mechanism.(5)
A interesting result can be observed on BELLO results,(7) when the eletrochemical activity increases with the abrasion processes to the stainless steel. On this way, is possible to understand that for the stainless steel, when the waiting time increase to 60 minutes, the passive layer can restore, reducing the electrochemical activity.

3.2 Industrial Experiments and Results

With the lab results aligned with the initial industrial ones, some different sugarcane industry started to use the P410D as antiwear product for its system. Regarding the results at one of them, at the same equipment were used A36, 9mm thicker, and P410D, 6mm thicker. The place is just where the sugarcane arrives to start to be processed. The thickness was pointed along the length, like shoed at Figure 11.

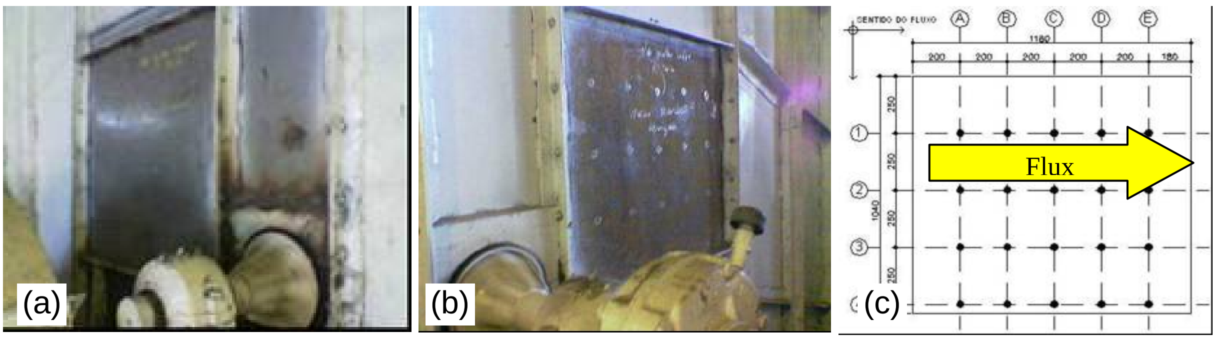

Figure 11 – Place where were used (a) A36 and (b) P410D steel grade. (c) Map to measure the wear along thickness.

The wear result at industrial plant were measured and plotted at Figure 12. The pointed line at represents the wear on each point at the column A on the Figure 11c, to the carbon steel. The full line represents the same area, but, to the P410D. As is possible to see, the carbon steel has bad result compared with the stainless steel.

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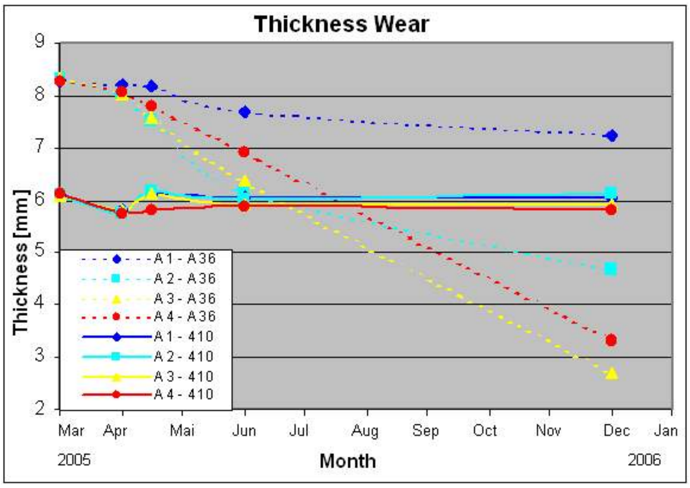

Figure 12 – The thickness wear measured along a year comparing between the P410D and the carbon steel.

At the Figure 13 is possible to see the corrosion process at an equipment that doesn't worked during three month, when the sugar cane isn't able to be process. As can be seemed, the corrosion process occurs during this time to the carbon steel, increasing the wear mechanism when it starts to work. When used stainless steel, this problem doesn't exist at the same intensity.

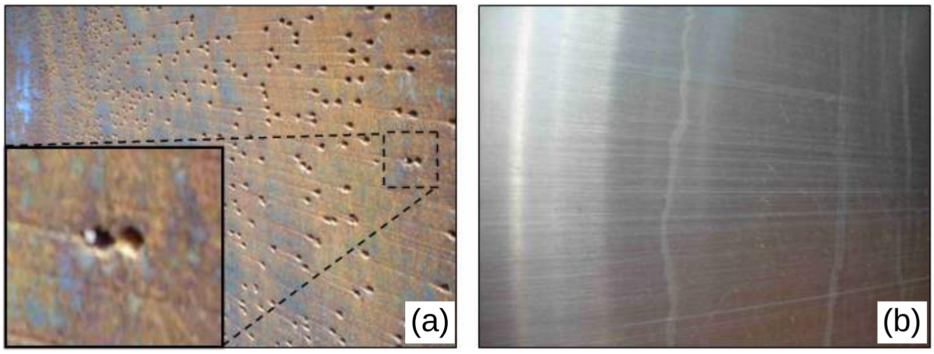

Figure 13 – (a) Corrosion and wear process working together to the carbon steel, A36, compared against (b) P410D, stainless steel, no corrosion.

At a place where the sugarcane started to be cut, to initiate the juice extraction, is possible to see the difference between the two materials, like showed at Figure 14.

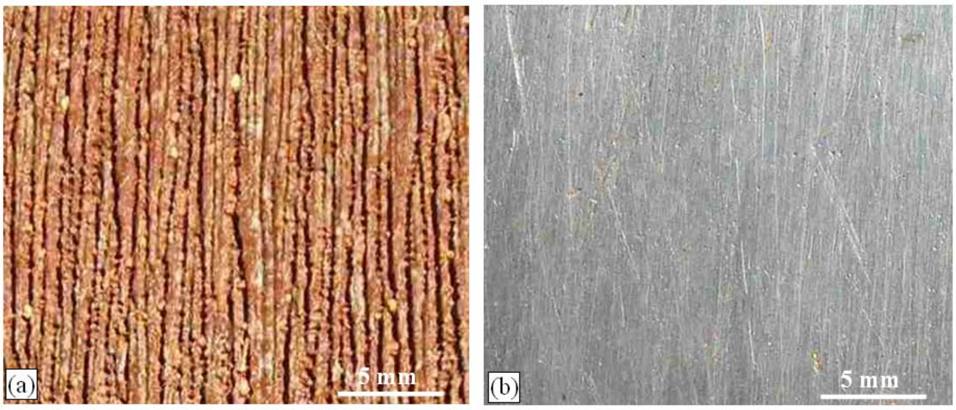

Figure 14 – Surface for (a) carbon steel and (b) stainless steel at a place where the sugarcane started to be cut, initiating the sugar extraction.

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As final measurement, to quantify the sugar quality, the producer measures the weight of magnetic particles at final product, sugar, due the wear along the plant. This is a kind of quality control for sugar. As can be seemed at Figure 15, before 2002, a good quality sugar could be produced after some weeks started the plant work. Using stainless steel, increasing up to 2007, a good quality sugar could be produced during the first week.

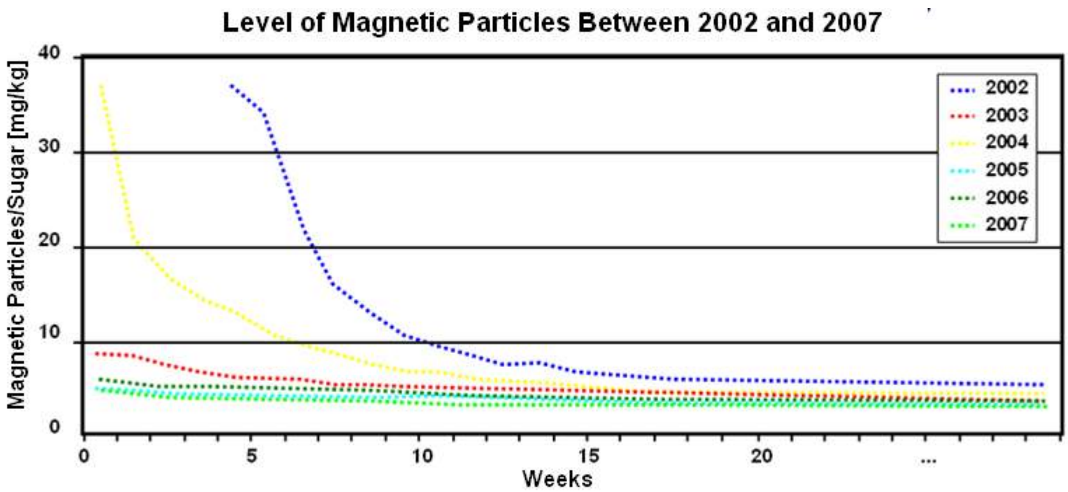

Figure 15 – Measurement of quantity of magnetic particles at sugar plant between 2002 and 2007.

To exemplify the results to sugarcane industry, at the Figure 16 can be seemed the difference between the wear thickness for carbon steel and P410D, applied at the same equipment and working beside each other along two years.

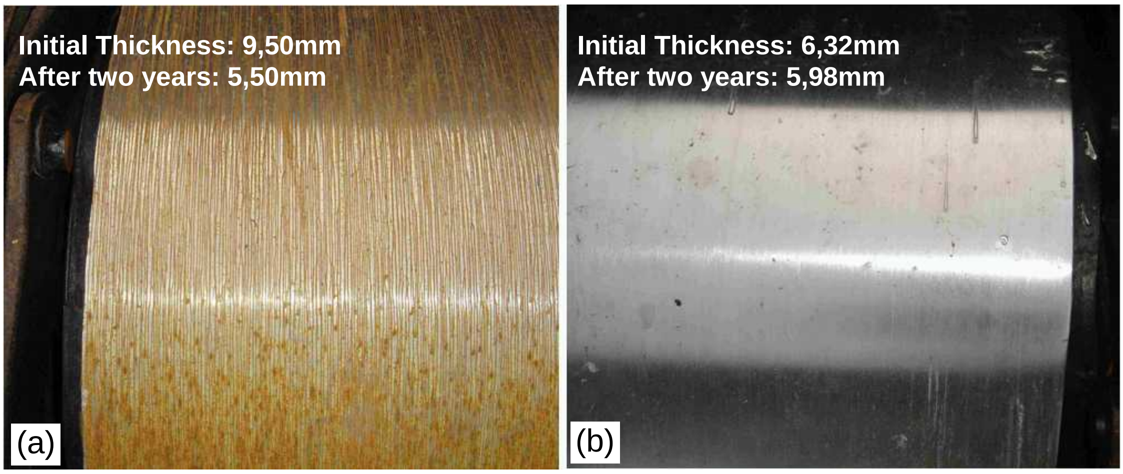

Figure 16 – Equipment surface from initial process, working as conductor of sugarcane, made of (a) A36 and (b) P410B.

As result to ArcelorMittal Inox Brasil, in 2001 was produced 70t from P410D to the sugar and alcohol industry. In 2007, it was produced 4000t.

4 CONCLUSIONS

The emphasis of this work remained in the laboratory reproduction of wear mechanisms found in the study of sugarcane industry. As a result, there was a concordance of industrial and laboratory results, which might be translated into technical arguments for the commercial sector of ArcelorMittal Inox Brasil.

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It was finding the superiority of P410D in environments where abrasive wear is moderate, but combined with a corrosive component. Under this point, the plant with the concept of high efficiency has improved its results using P410D.
At a condition of pure abrasive wear, usually in dry environment, the P410D has not proved so effective. Its some times works better than the carbon steel, but not enough to overcome the “Steel C”, which is prepared specifically for abrasive wear system.

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